Introduction to 3D Ophthalmic Brachytherapy

Quick review of eye plaque radionuclides and physics
3D printing plaque prototypes
2D Mapping the inner surface of the eye
3D Modeling the eye and tumor
Calculating plaque suture eyelet coordinates
Benefits of 3D Planning

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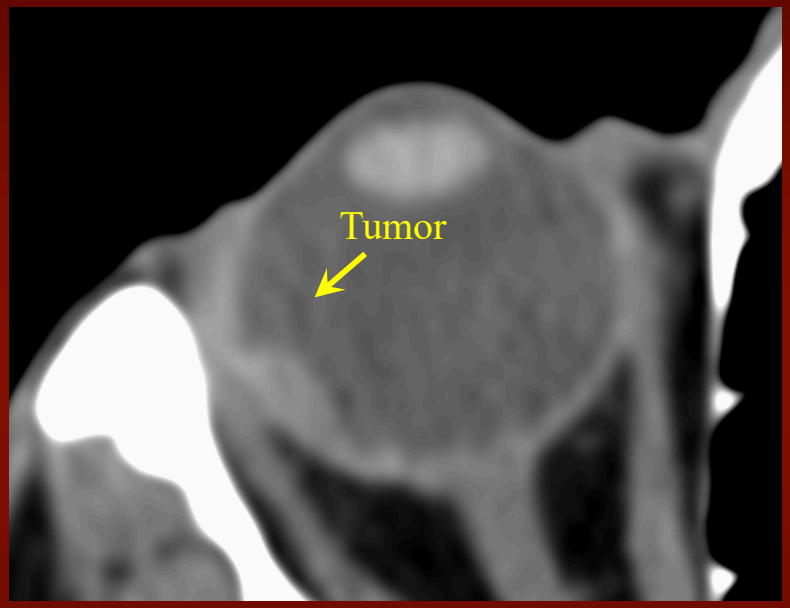
Episcleral plaques are used to treat tumors located inside the eye



Fundamentally, the plaque is just a positioning device for radioactive sources. It is surgically sutured to the outer surface of the sclera covering the base of the tumor for a few days. Radiation from the sources in the plaque damages cellular DNA molecules which can be lethal to rapidly dividing cancer cells.

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Quick review of I-125 physics as it applies to eye plaque treatment planning

A very fast method of calculating dose:

The instantaneous dose rate from an individual radionuclide source at a point (r,ϕ) can be expressed according to the AAPM TG43 formalism as:

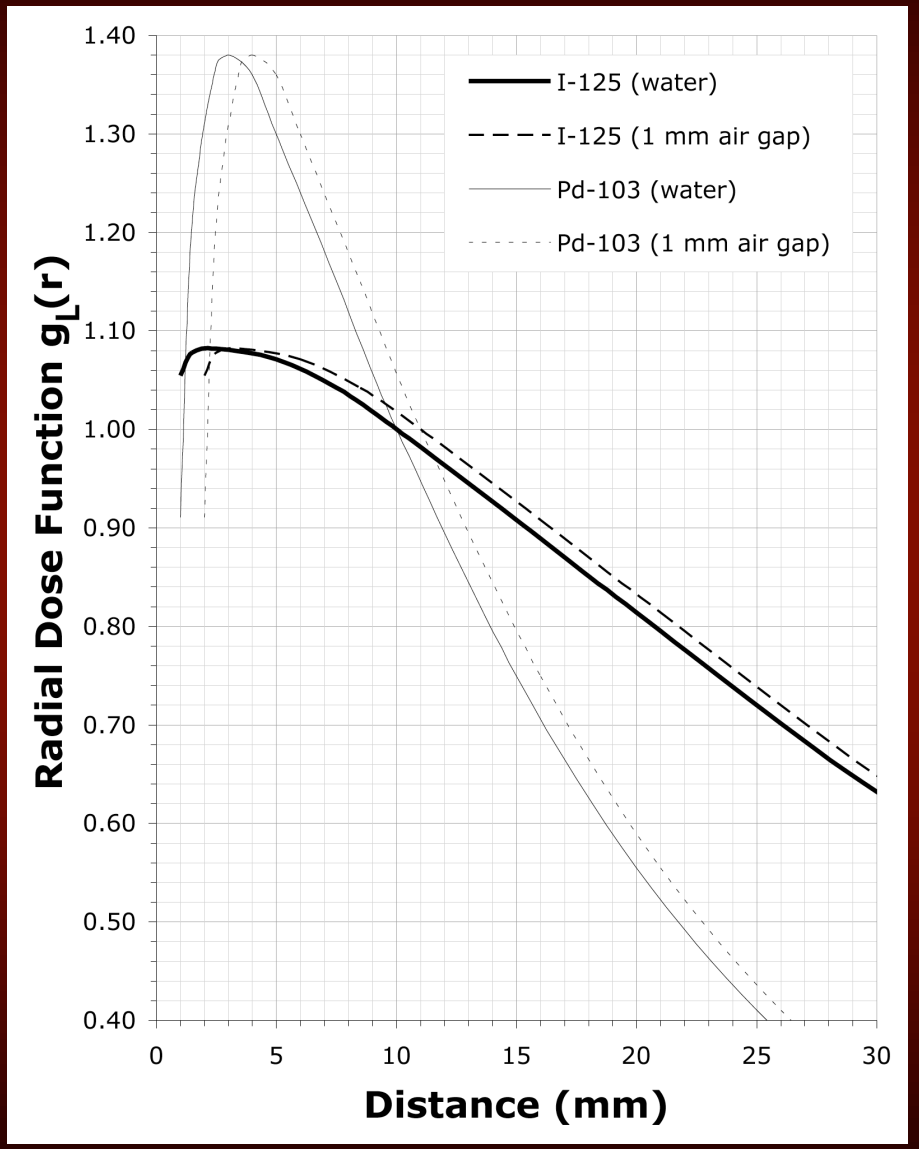
$$D(r,\phi)_{TG43} = S_k * \Lambda * g_L(r) * [G(r,\phi) / G(r_0,\phi_0)] * F(r,\phi)$$

where

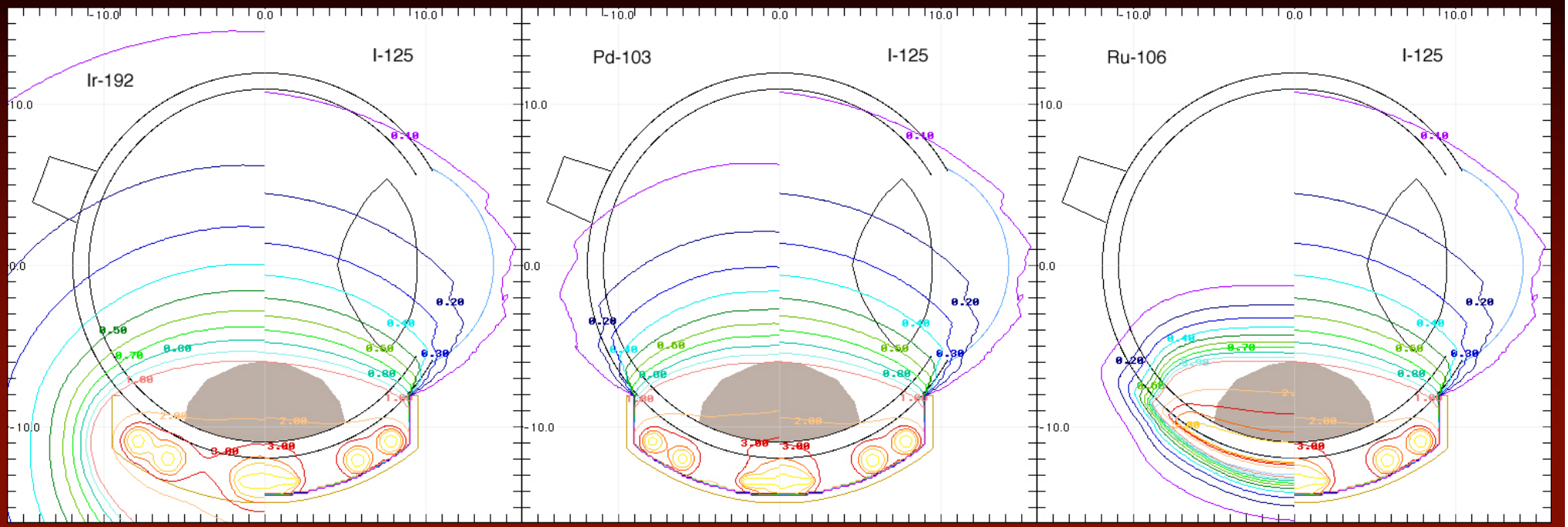
r	= distance between point p and the seed center.
ϕ	= the angle from the seed axis.
S_k	= air kerma strength of source in U (1 U = 1 cGy cm^2 h^{-1}).
Λ	= dose rate constant at 1 cm in cGy $h^{-1}U^{-1}$
$g_L(r)$	= the radial dose function (scatter & attenuation).
$G(r,\phi)$	= the geometry factor.
$F(r,\phi)$	= the anisotropy function.

The TG43 radial dose function is for infinite homogeneous water

Additional factors are needed to account for Silastic attenuation, L flourescent X-rays, finite scattering (e.g. air boundry at the cornea), collimation by the plaque shell and so on…



Choosing a radionuclide for eye plaque brachytherapy:



Radionuclide	Half-Life	Energy	HVL(mm Pb)
^{60}Co	5.26 yr	1.17 & 1.33 MeV	11.0
^{192}Ir	73.8 days	0.136 to 1.06 MeV	2.5
^{125}I	59.4 days	≈28 keV	0.025
^{131}Cs	9.7 days	≈30 keV	0.025
^{103}Pd	17.0 days	≈21 keV	0.008
^{106}Ru	368.0 days	≈1.4 MeV	12

Ru-106/Rh-106 is an example of secular equilibrium. The Ru-106 parent (halflife 368 days) disintegrates via β^- decay with a peak beta particle energy of 39 KeV to radioactive daughter Rh-106. The primary contributor to therapeutic dose is the continuous spectrum of beta particles emitted in the decay of Rh-106 (halflife 30 s). Rh-106 disintegrates by β^- decay with a mean beta energy of about 1.4 MeV and a maximum of 3.54 MeV to the stable element Pd-106. The 90-percentile distance for Rh-106 beta particles in water is 7.92 mm.

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Elementary!

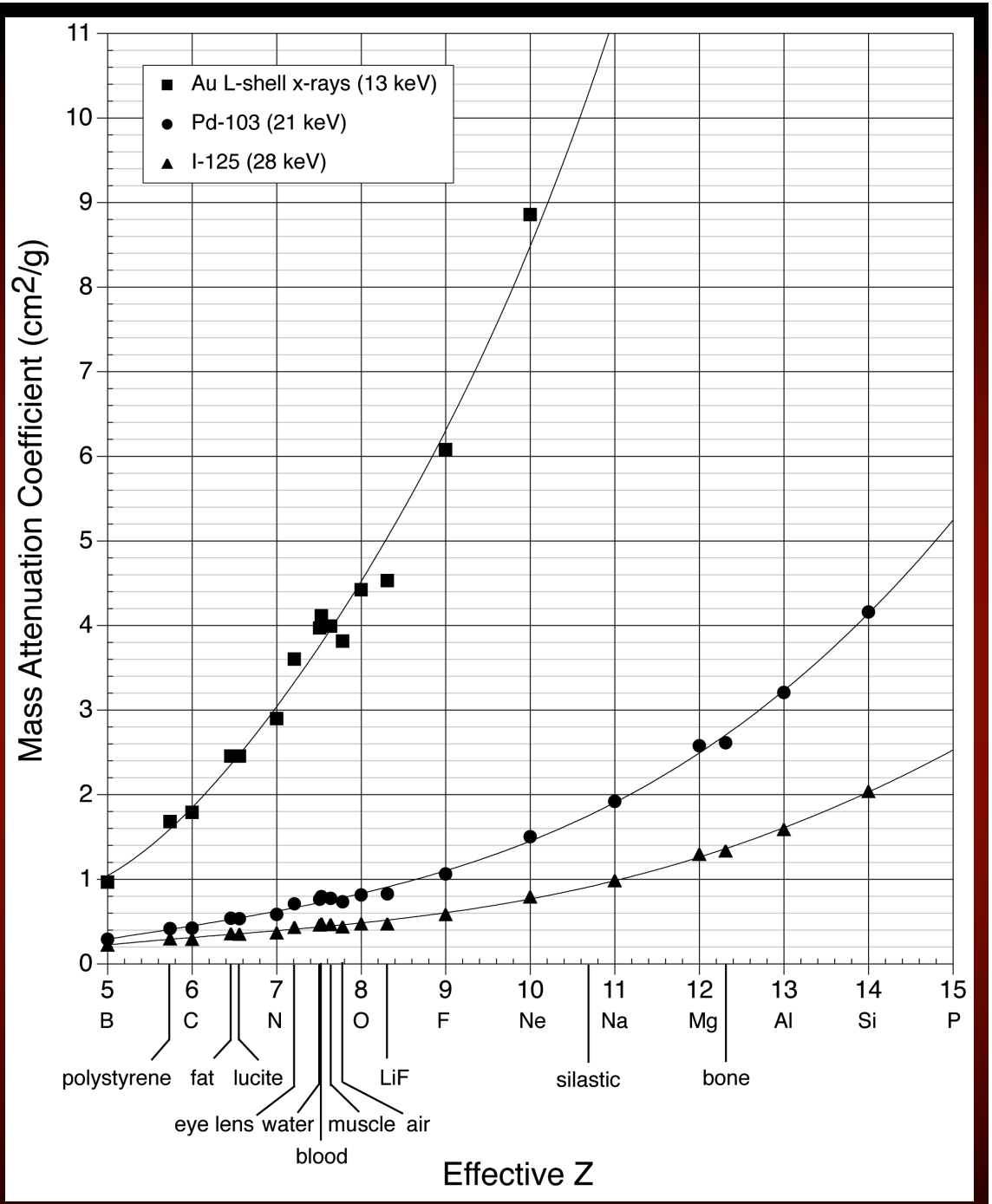
My Dear Watson…

Fraction by weight elemental composition, density and calculated Z_{eff} of some materials

Element	Z	Water	Eye Lens	Blood	Silastic
H	1	0.1119	0.096	0.102	0.063
C	6		.0195	0.110	0.249
N	7		0.057	0.033	
O	8	0.8881	0.646	0.745	0.289
Na	11		0.001	0.001	
Si	14				0.399
P	15		0.001	0.001	
S	16		0.003	0.002	
Cl	17		0.001	0.003	
K	19			0.002	
Fe	26			0.001	
Pt	78				0.00005
ρ		1.0	1.07	1.06	1.12
Z_{eff}		7.4	7.2	7.5	10.7

$$Z_{eff} = (a_1 Z_1^{2.94} + a_2 Z_2^{2.94} + a_3 Z_3^{2.94} + \ldots + a_n Z_n^{2.94})^{1/2.94}$$

where a_1, a_2, a_3, … a_n are the fractional contributions of each element to the total number of electrons in the mixture.



Total mass attenuation coefficient (μ/ρ) expressed in cm^2/g for monoenergetic photons corresponding to the average energies (E_{avg}) of ^{125}I, ^{103}Pd and gold L shell flourescent (characteristic) x-rays.

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Photoelectric absorption occurs when an x-ray or gamma photon interacts with an inner shell electron in an atom. The photon is completely absorbed and its energy is transferred to an electron that is ejected from the electron cloud.

The probability of photoelectric absorption is maximum when the energy of the incident photon is equal to or just greater than the binding energy of the electron and the electron is tightly bound (as in K shell).

The electron that is removed is called a photoelectron and the incident photon is completely absorbed in the process.

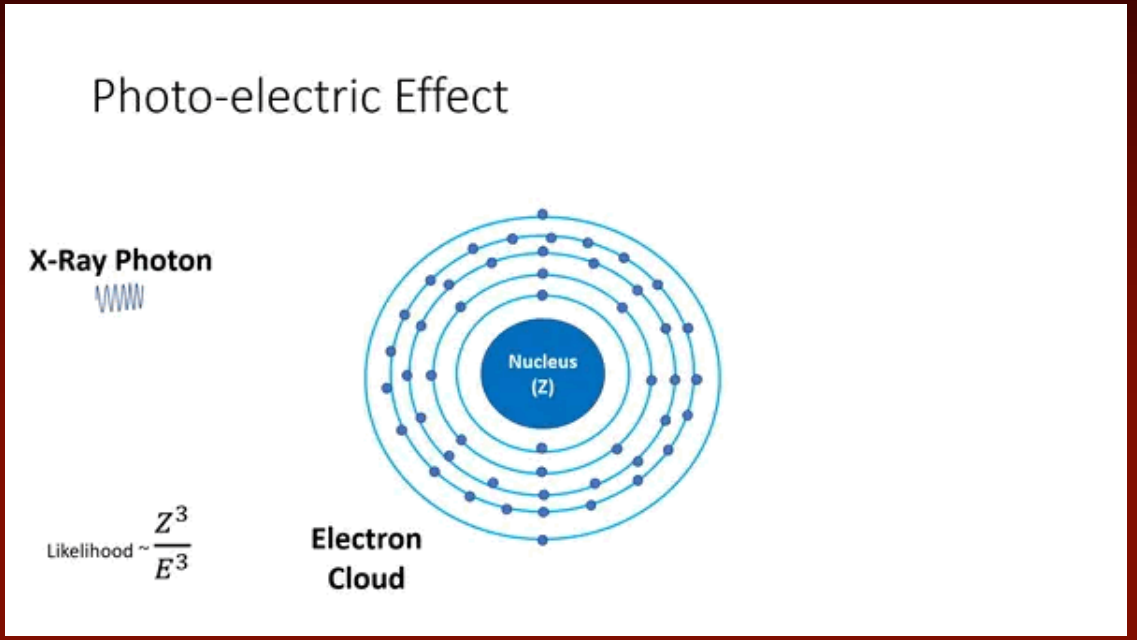
To stabilize the atom an outer shell electron fills the vacancy in the inner shell. The energy which is lost by this electron as it drops to the inner shell is emitted as characteristic radiation (an x-ray photon) or as an Auger electron. These secondary events are of very low enery and are absorbed locally.

The probability of photoelectric absorption is proportional to the cube of atomic number of the attenuating material (Z), inversely proportional to the cube of the energy of the incident photon (E), and proportional to the density of the attenuating material (p).

The overall probability of photoelectric absorption can be summarized as ~ $p \cdot (Z^3/E^3)$

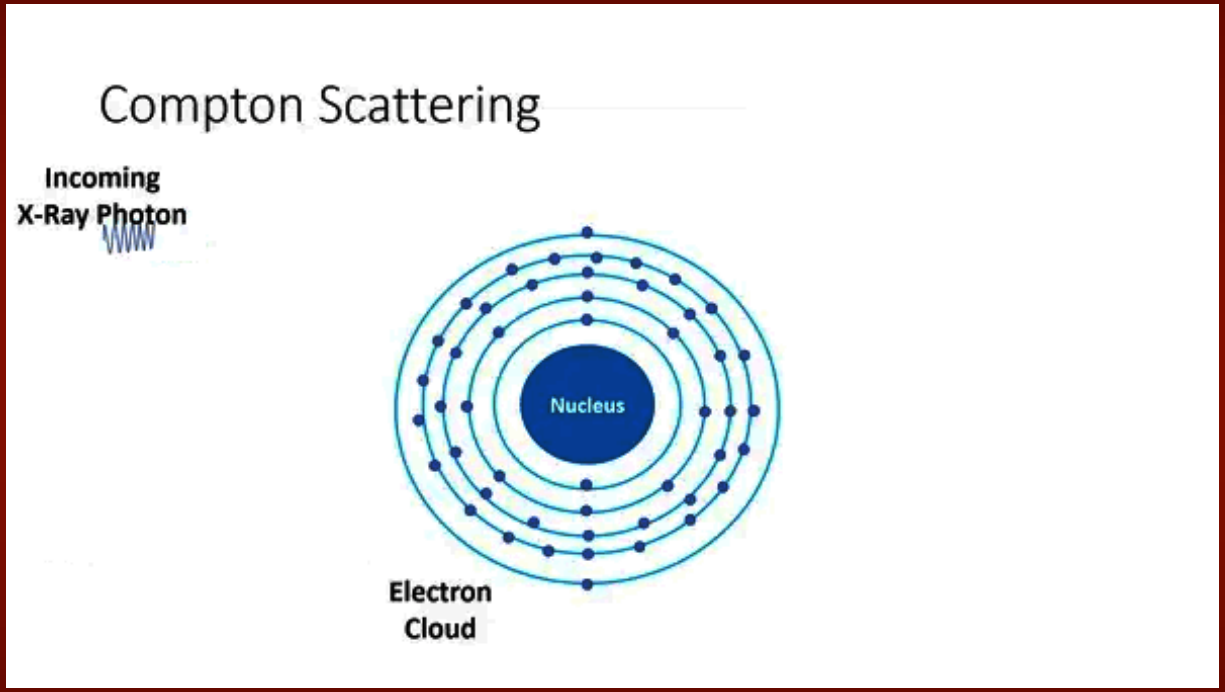
Small changes in Z and E can therefore significantly affect photoelectric absorption.

The dependence of **photoelectric absorption** on Z and E means that it **is the major contributor to attenuation up to approximately 30 keV** (^{125}I radiation $E_{avg} \approx 28$ keV) when human tissues (Z = 7.4) are irradiated. At greater energies Compton scattering predominates.

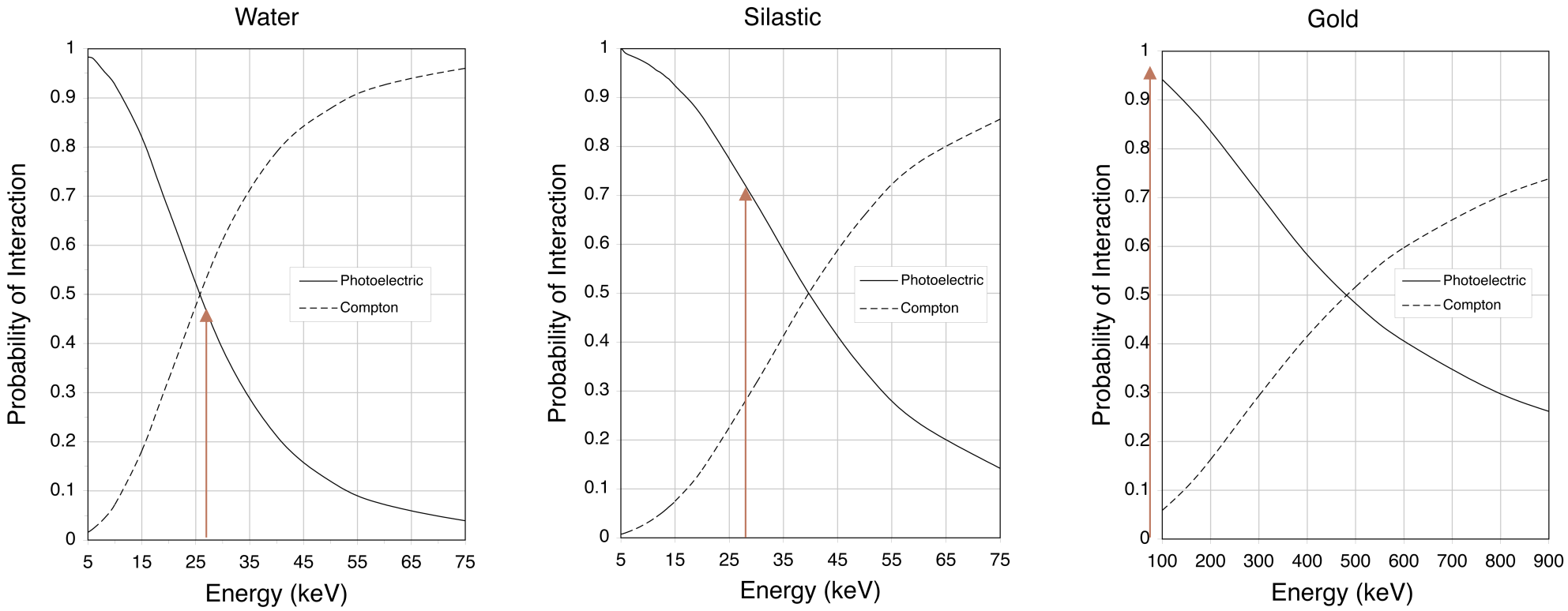


Animation adapted from howradiologyworks.com

With Compton scattering an x-ray photon interacts with a free or loosely bound electron located in the outer shell of an atom. The colliding photon transfers some of its energy and momentum to the electron, which in turn recoils. As a result of the collision, a new photon of reduced energy and momentum is produced that scatters at an angle dependent upon the amount of energy that was transfered to the recoiling electron. The likelihood of Compton Scattering does not depend on Z.

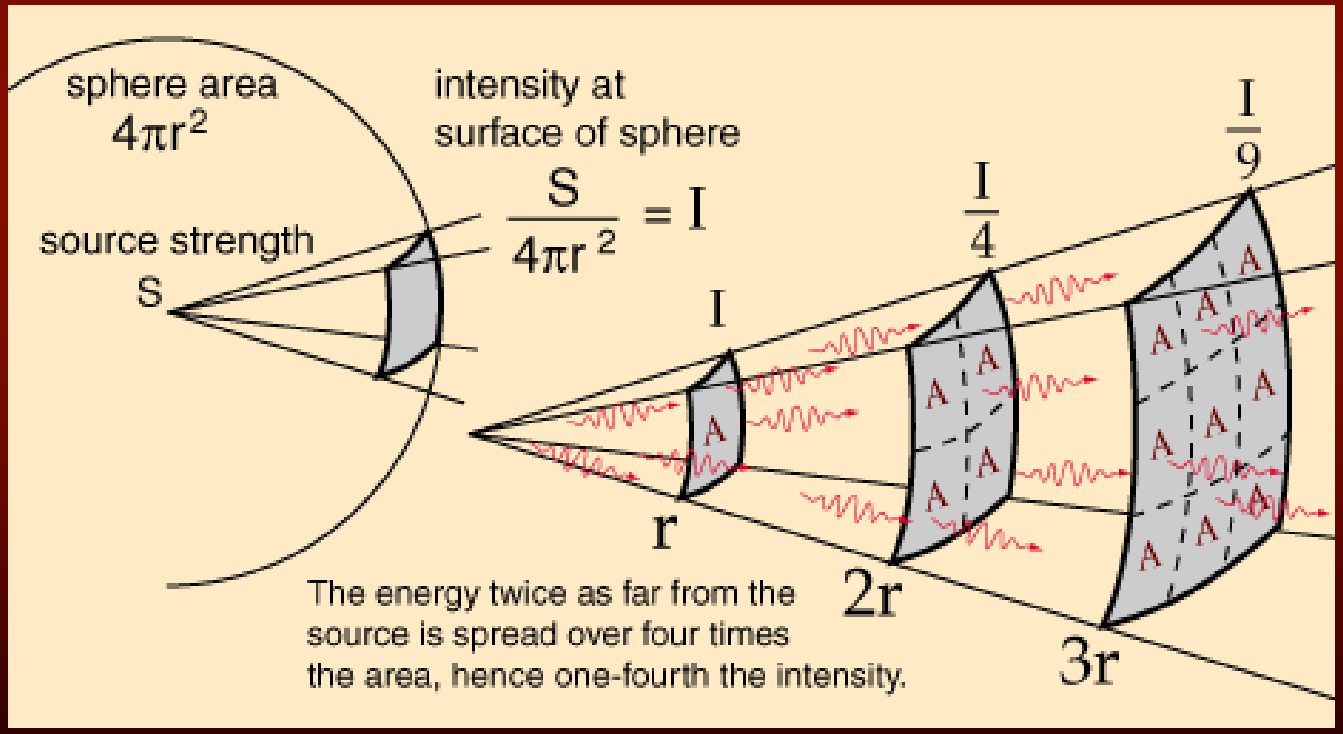


Animation adapted from howradiologyworks.com

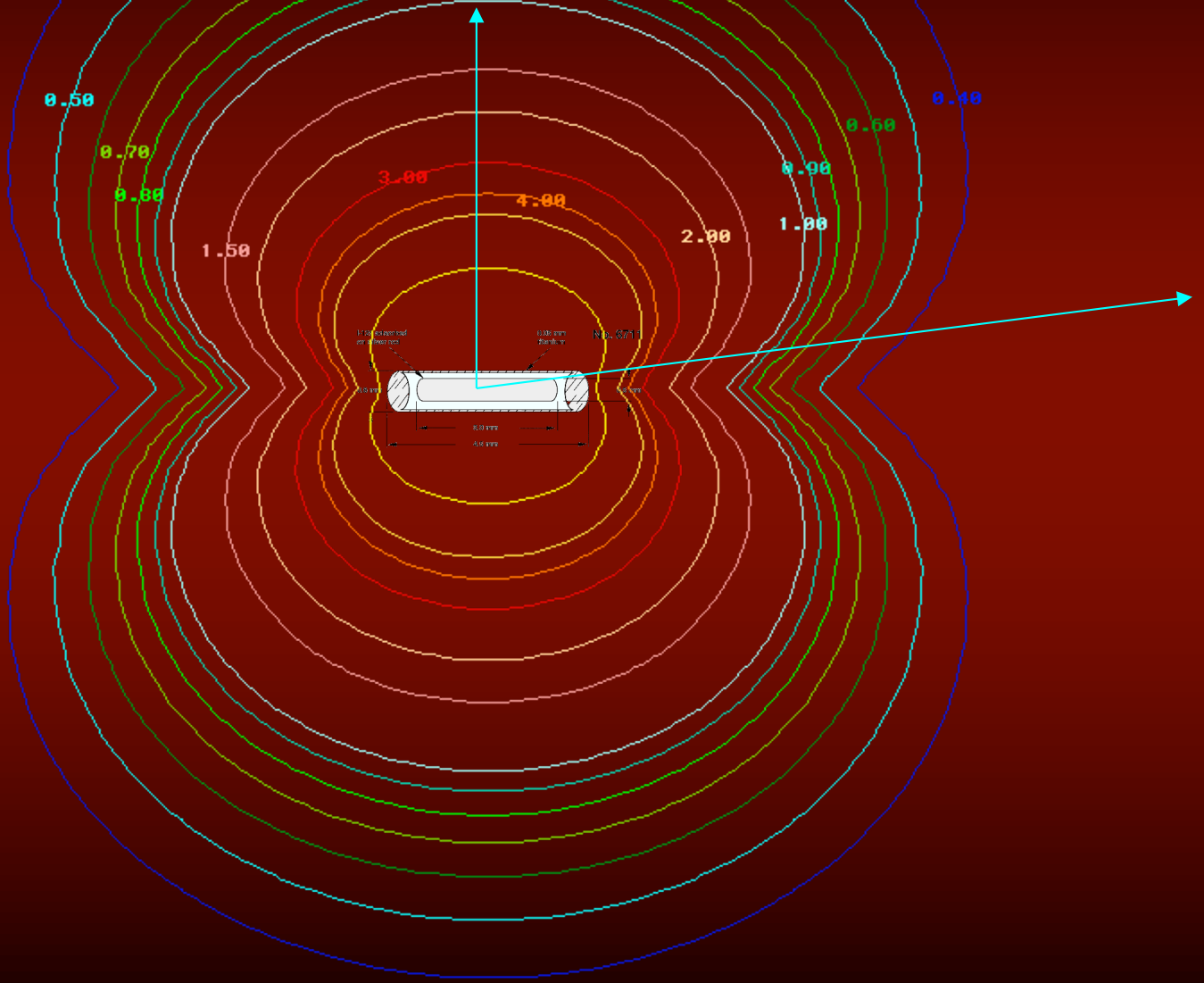


Relative probabilty of photoelectric and Compton interactions as a function of photon energy for (a) water, (b) silastic, and (c) gold. For ^{125}I radiation ($E_{avg} \approx 28$ keV) the chances of photoelectric and Compton interactions are nearly equal in water. Photoelectric absorption dominates in silastic and is responsible for virtually all interactions in gold.

Inverse square law: Any point source which spreads its influence equally in all directions without a limit to its range will obey the inverse square law. This comes from strictly geometrical considerations. The intensity of the influence at any given radius r is the source strength divided by the area of the sphere. Being strictly geometric in its origin, the inverse square law applies to diverse phenomena. Point sources of gravitational force, electric field, light, sound or radiation obey the inverse square law.



Source anisotropy: the dose surrounding an I-125 seed is reduced near the source axis because in this direction primary radiation must pass through a greater thickness of both the radionuclide itself and the titanium shell.



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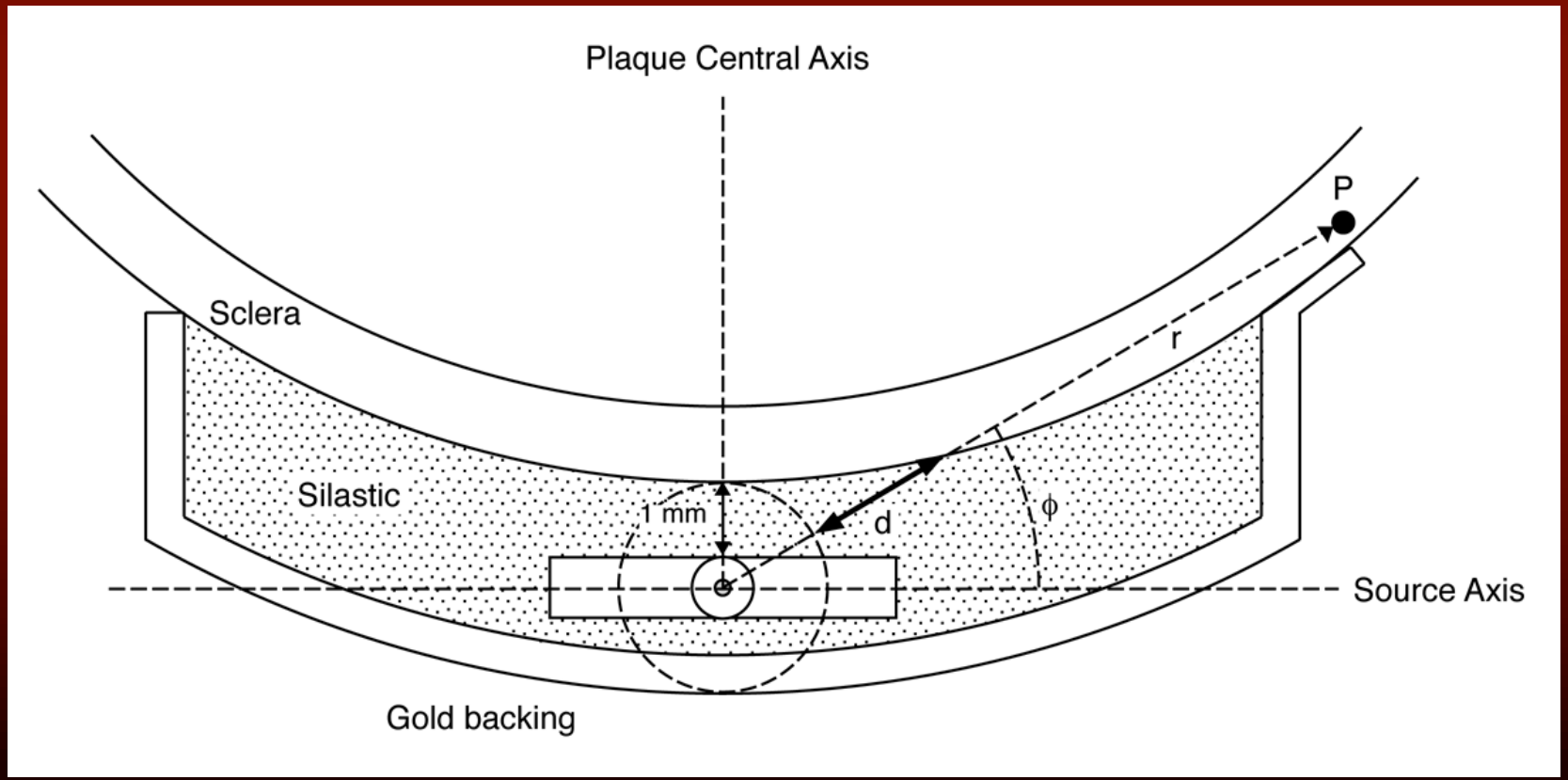
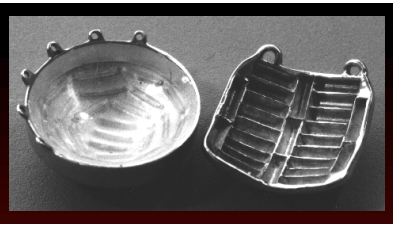
The COMS plaques were designed in the 1980s. They are 2.8 mm thick at their center and range from 3 to 4.2 mm tall at their rims. They displace the seeds by 1 mm from the scleral surface. This offset was intended to reduce the severity of the geometrical "inverse square" difference between the apex of the tumor and the underlying sclera and adjacent retina.

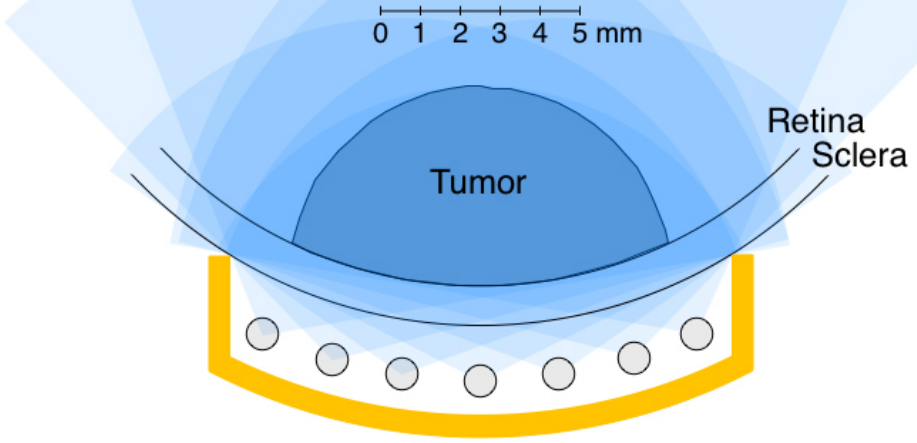


COMS Plaque 1985



USC Slotted Plaque 1995

COMS plaques use geometric displacement to reduce the severity of inverse square effects but that approach results in a thick plaque and also increases dose to the distal side of the eye because dose is prescribed near the tumor apex. It is a good approach for a plaque containing a single seed.



I-125 seeds in COMS plaque

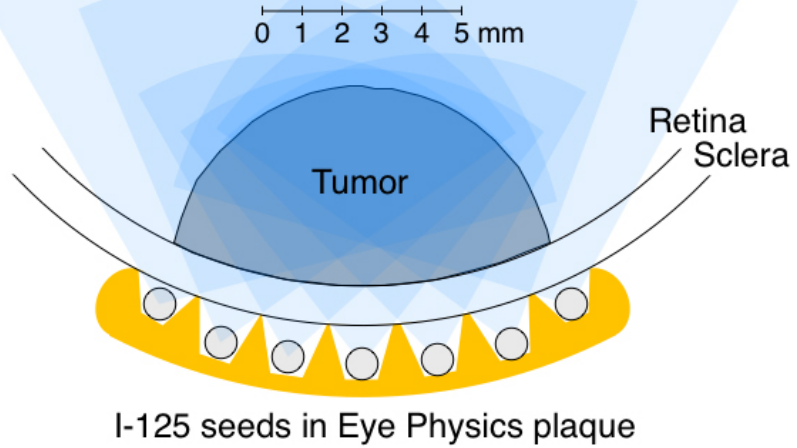
Every seed in a COMS plaque irradiates the retina and sclera under the tumor and adjacent to the plaque.

Dose to inner sclera at the base of the tumor can be up to 10X the dose prescribed to the apex of tall tumors.

COMS plaque dosimetry is complicated by the effective atomic number (Z) of the COMS silicone seed carrier.

COMS plaques are thick at the edges and are designed to fit a spherical eye.

Eye Physics plaques are extensions of the USC slotted design. They are generally thinner and their radiation sources positioned physically closer to the tumor than equivalent diameter COMS plaques. This reduces dose to the distal eye by increasing the severity of inverse square effects (!) WITHOUT increasing dose to the adjacent sclera. How is this possible?



I-125 seeds in Eye Physics plaque

Eye Physics plaques assume there are MANY sources. Each source is collimated to emit an intensity modulated fan-beam. Collimation removes laterally directed primary radiation that would otherwise overlap as it passes through the sclera between the plaque and tumor base, or through sclera and retina adjacent to the plaque, without contributing to the tumor dose. This approach is not good for a single seed but works well when dose is delivered from many overlapping “beams”.

Dose to inner sclera at the base of the tumor is often less than 4X the dose prescribed to the apex of tall tumors.

Eye Physics plaques are designed using the Plaque Simulator software, are prototyped using 3D printing technology, range from 1.5 to 2.1 mm thick and are available in many shapes, sizes and oblate curvatures to better fit aspherical eyes.

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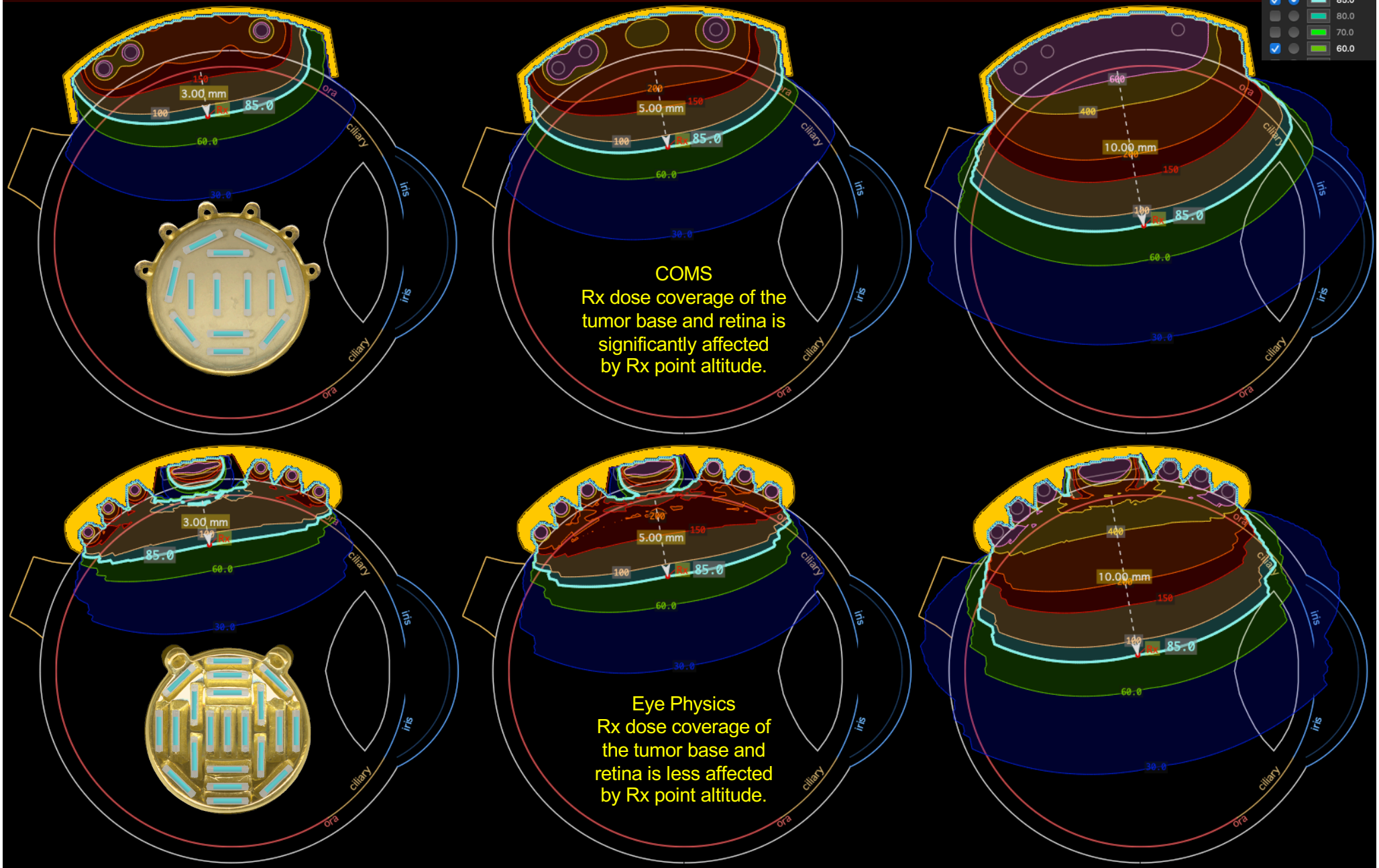
COMS 16mm vs EP1821 (16.17 mm) Uniform seed strength

The problem with selecting a plaque based on physical size rather than dosimetric coverage.



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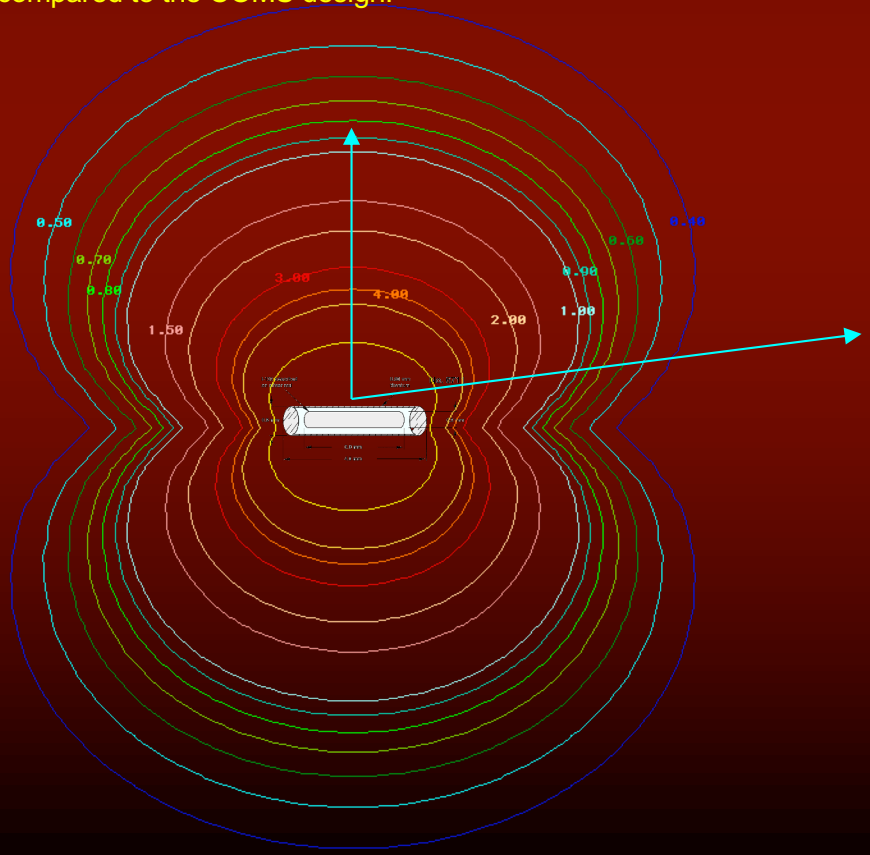
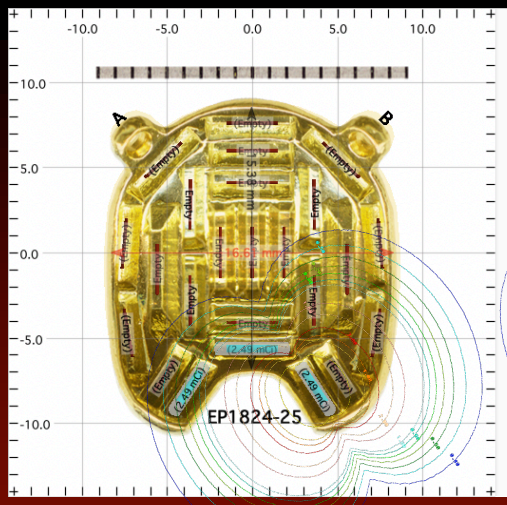
COMS Plaques are poorly designed for peripapillary tumors

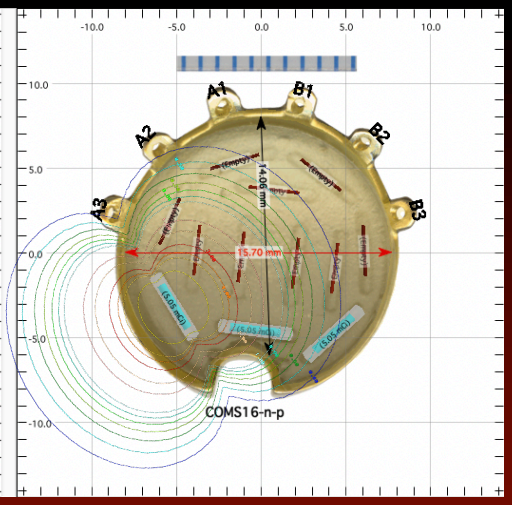
In order to treat peripapillary tumors, eye plaques usually incorporate a “notch” which fits around the optic nerve sheath.

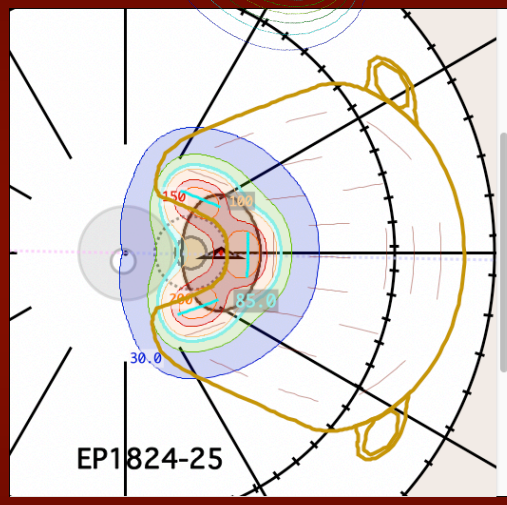
In a COMS plaque, only one of the three closest seeds to a notch is oriented with its axis tangent to the curve of the notch. The other two seeds are located far away and are oriented with their axes pointing towards the notch. Source anisotropy results in underdosing tumor growing around and/or over the disc.

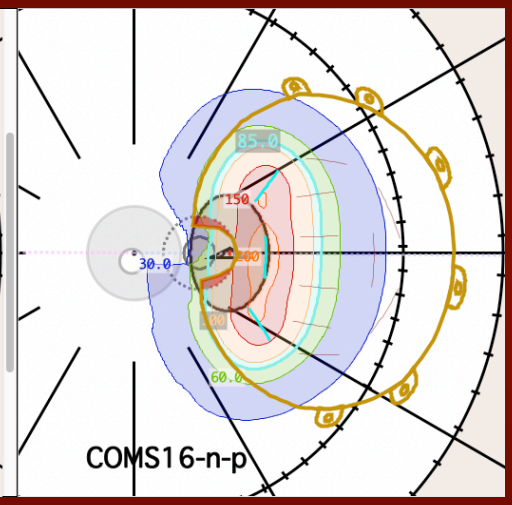
Eye Physics plaques orient all, or at least most of the sources closest to a notch tangent to the curve of the notch resulting in significantly better wrapping of Rx dosimetric coverage around and/or over the disc compared to the COMS design.

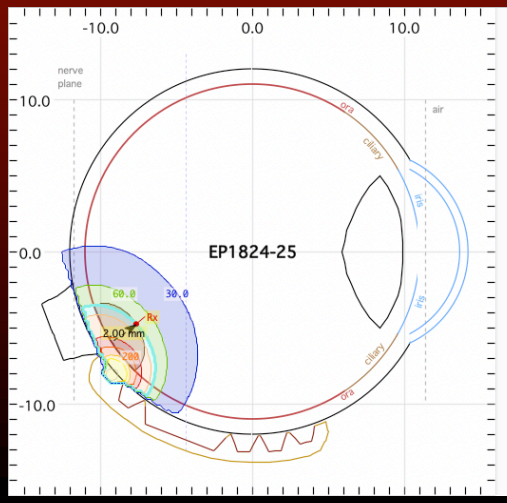


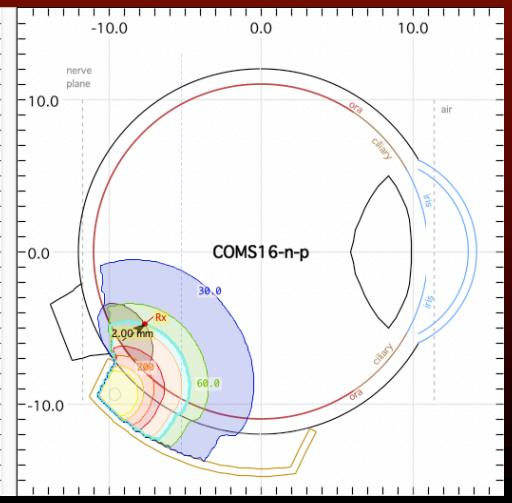












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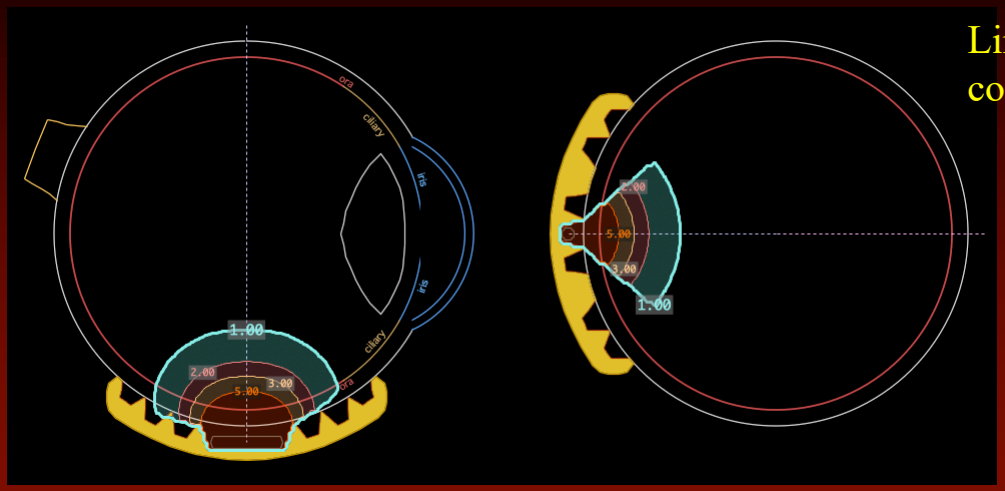
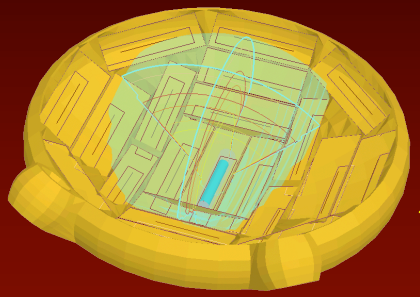
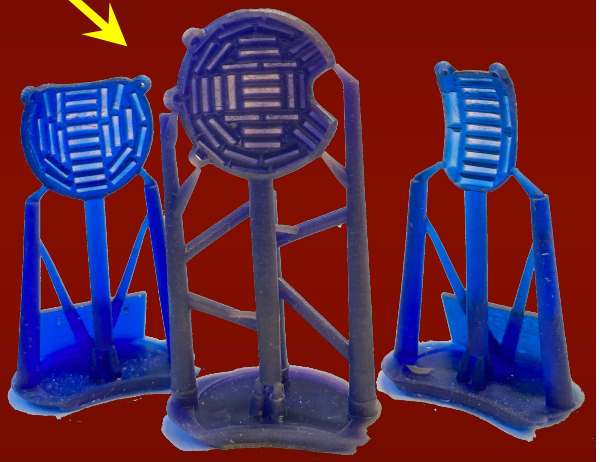
3D printed plaques enable conformal treatments within the eye

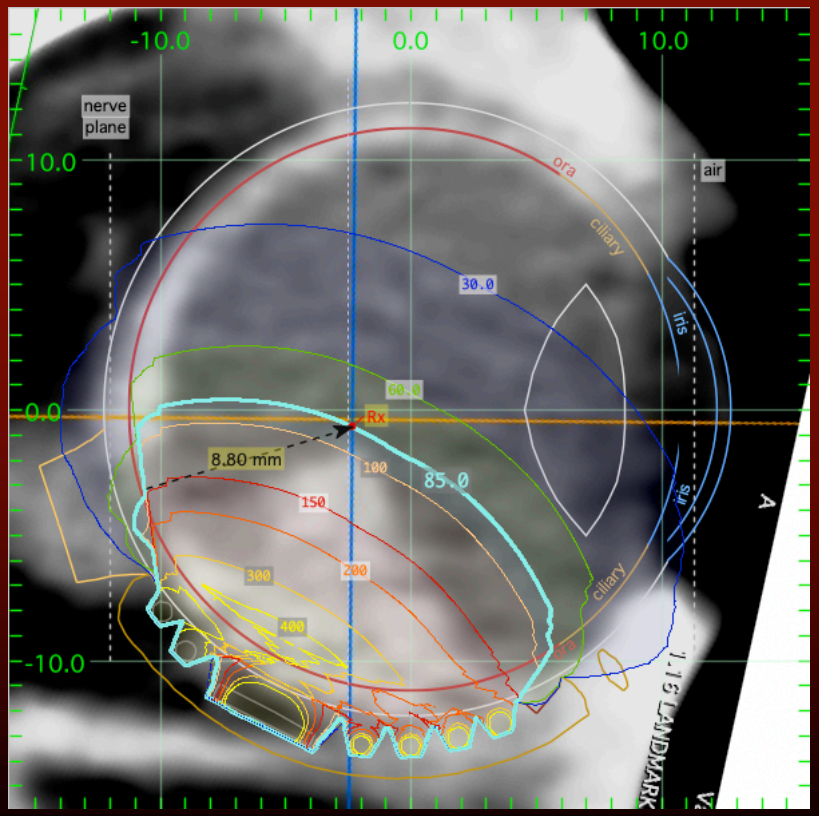


Linear sources in an Eye Physics plaque are individually collimated to create intensity modulated fan beams



The plaques are prototyped by 3D printing using a castable resin





The result is a plaque that can deliver 3D conformal treatment of ocular tumors such as this case of a large tumor that overhangs the optic disc

The protoypes are cast in 18K gold

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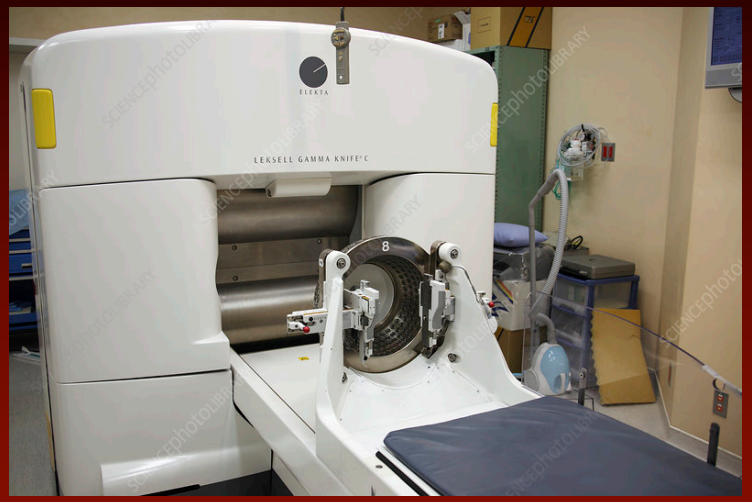
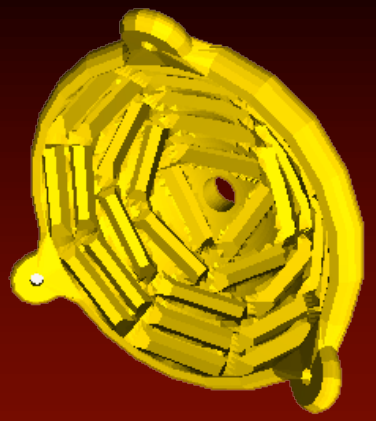
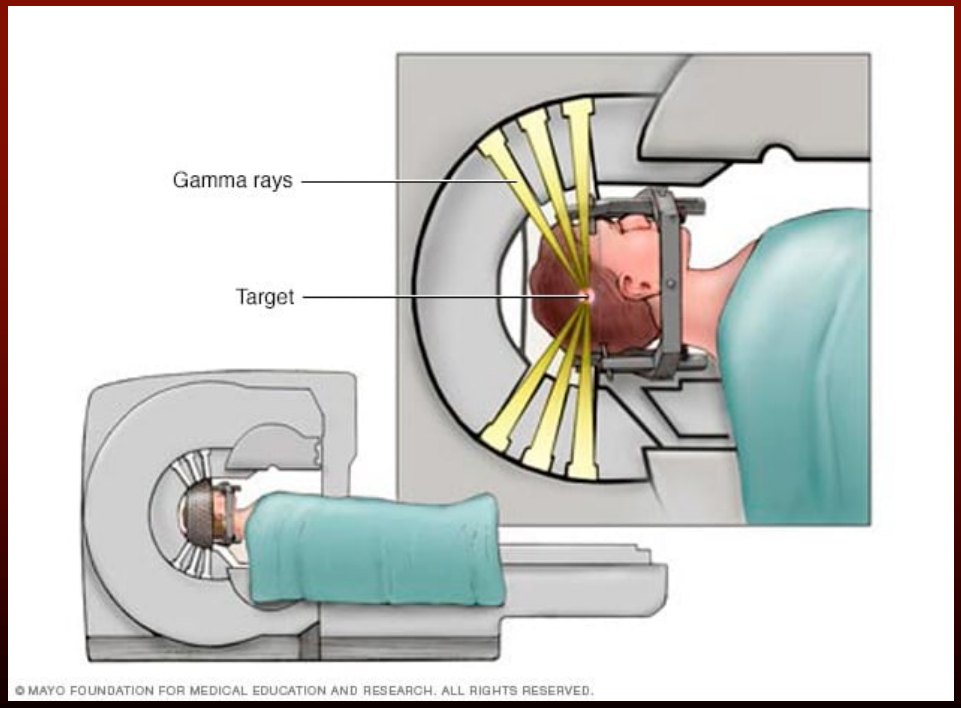
Some Eye Physics plaques were inspired by the Gamma Knife in the 1980s

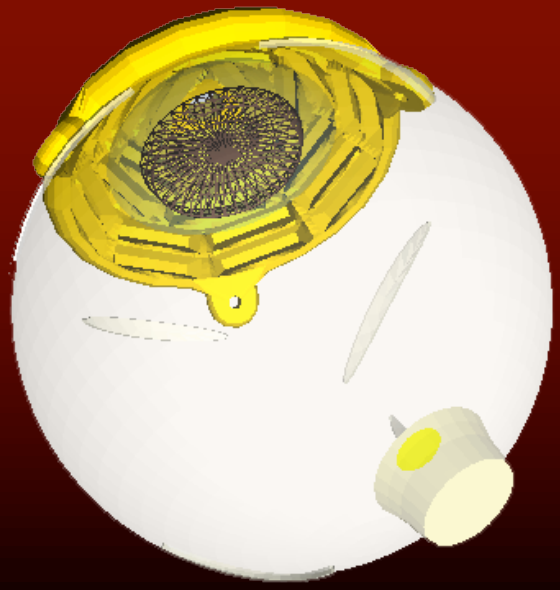




A dome shaped Eye Physics plaque for iris tumors

WOW! converging cone beams with no exit beam ??





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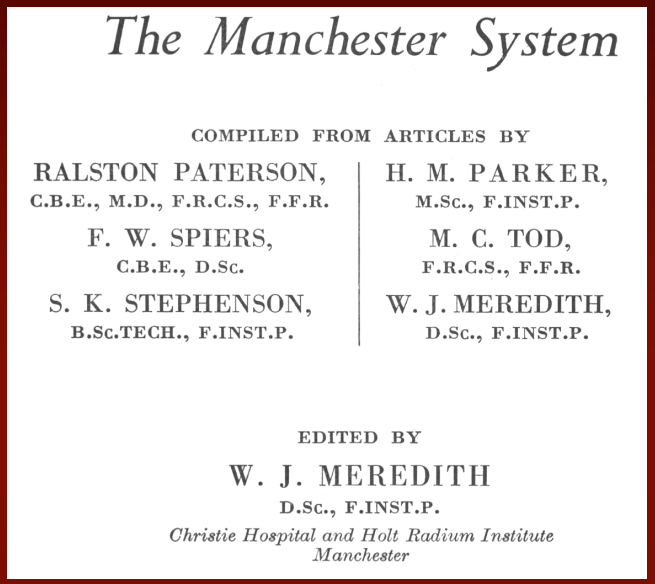
Brachytherapy Source Intensity Modulation

In 1932 James R. Paterson and Herbert M. Parker developed the Paterson-Parker method, or Manchester System, for brachytherapy.

Ralston Paterson
(1897-1981)



The Manchester System

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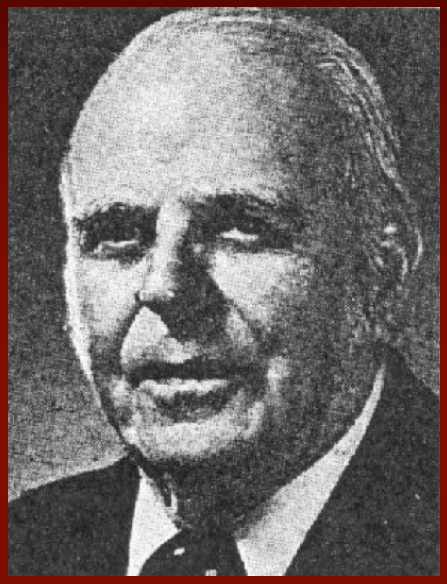

Herbert Parker
(1920-1984)

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Manchester System for Mould Treatments 1932

For COMS14 plaque
(homogeneous @ tumor base)
D = 14 mm
h ≈ 2.4 mm (1.4 + 1)
D/h ≈ 5.8

CHAPTER II

MOULD TREATMENTS

MOULD treatments may be divided into three main classes :—

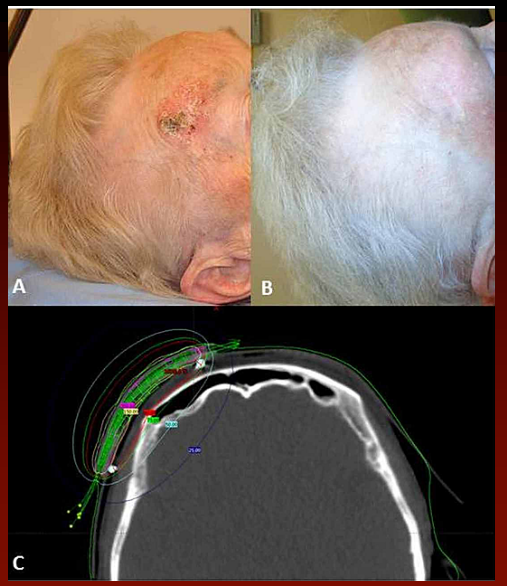
(1) *Planar*, by which is implied that the radium is mounted on one or more " planes " whose curvature is less than that corresponding to a hemisphere or semi-cylinder. The " Area " tables are used for this type. (See Appendix II, Table A.)

RULES FOR PLANAR MOULD TREATMENTS

In this type of treatment, as in all the others, the amount of radium to be used is first determined from the dosage tables (in this case the " Area " tables) for the particular treating distance being used, and then that amount of radium is arranged upon the applicator in one of the following ways, all of which ensure homogeneous irradiation of the treated surface. In all cases the radium-bearing surface should be parallel to the treated surface.

Circles.—The distribution of radium depends on D/h, the ratio of the diameter (D) of the mould to the treating distance (h).

6



(1) For D/h less than 3, a single circle is sufficient. The circle whose diameter is 2·83 times the " distance " (strictly where D/h = $2\sqrt{2}$) is sometimes called the " ideal circle " since the central and peripheral doses are equal, and the dose variation across the circle is minimal.

(2) For D/h equal to, or greater than 3 but less than 6, 5 per cent. of the radium should be placed at the centre, as a " centre spot " and the rest round the periphery.

(3) For larger values of D/h two concentric circles and a " centre spot " should be used as follows :

(*a*) Put 3 per cent. of the total radium at the centre.

(*b*) Use percentages of radium for the outer circle as indicated in this table :

Diameter divided by " distance " . .	6	7½	10
Per cent. radium outer circle . . .	80%	75%	70%

(*c*) Distribute the remainder round a circle of half diameter.

(4) For circles at small " distances " the last arrangement may not be practicable and the following can be substituted but is less accurate : Use a single circle and " centre spot ".

Diameter 6–7 times " distance " = 10 per cent. of total radium at centre.
Diameter 7–9 times " distance " = 20 per cent. of total radium at centre.

The radium, in each case is to be distributed as uniformly as possible around the prescribed circles using as many radioactive foci as possible. However, a circular arrangement may be considered as obtaining if, with a minimum of *six* containers, a space not exceeding the " distance " exists between the active ends of adjacent tubes or needles.

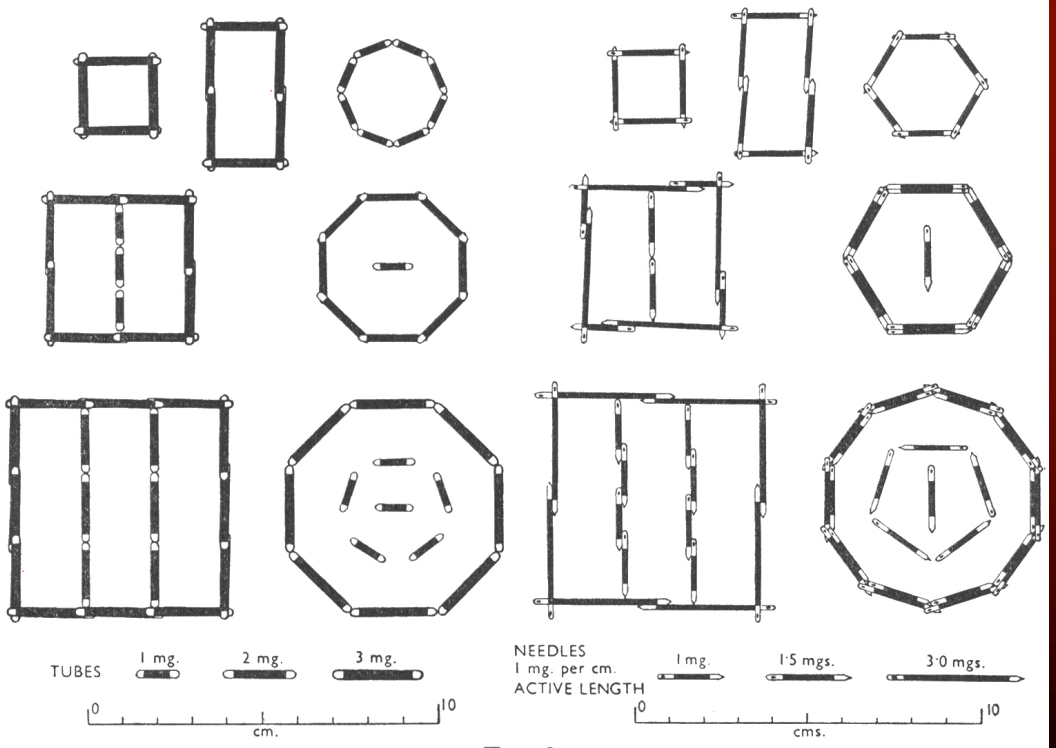


FIG. 2

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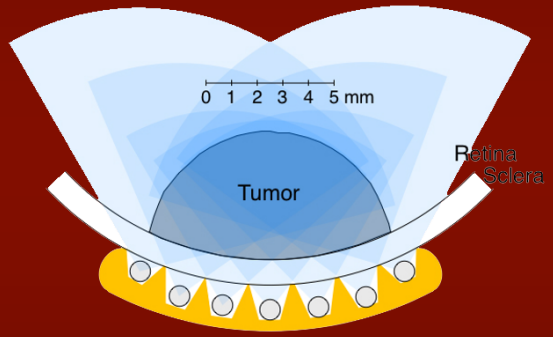
Source intensity modulation in Eye Physics plaques results from:

- Providing for a larger number of sources compared to similar diameter COMS plaques so that sources of lower individual intensity can be used.

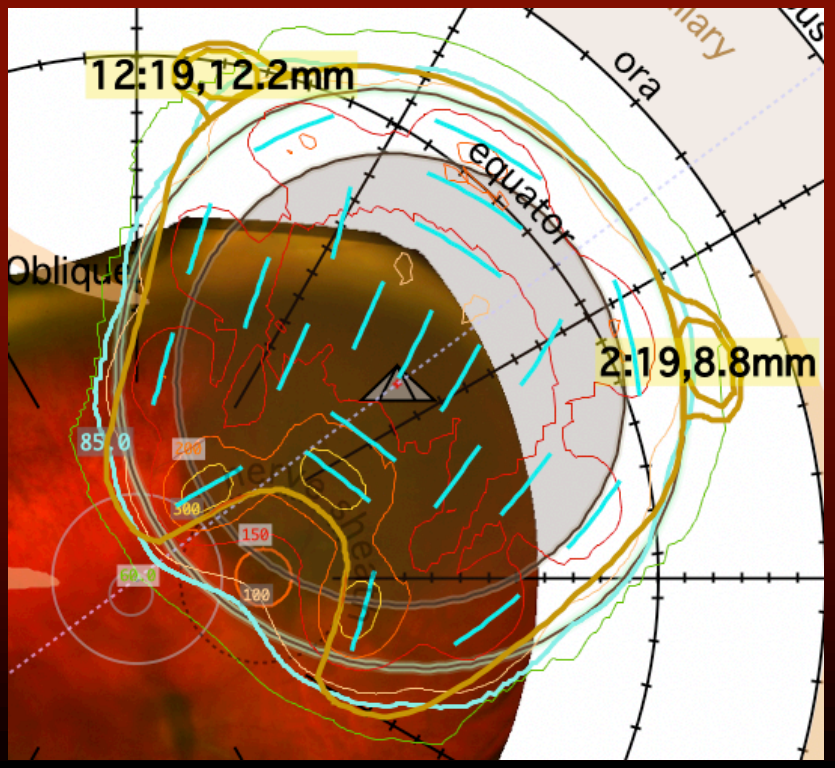
13 sources

21 sources

- Varying the solid angle of irradiation and offsetting sources at different distances from the sclera to leverage inverse square even when using sources of the same physical calibration strength (virtual intensity modulation).



- Using sources of different calibration strengths.



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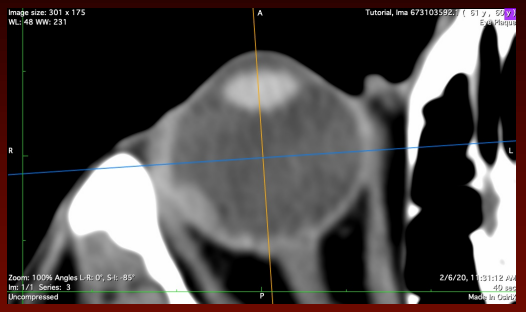
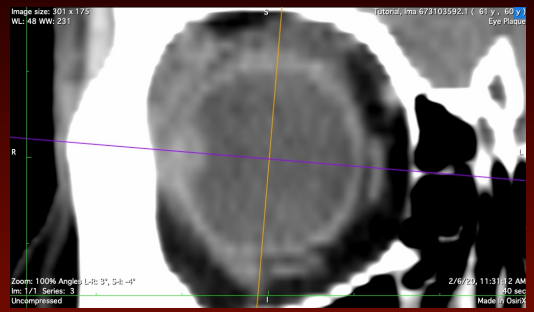
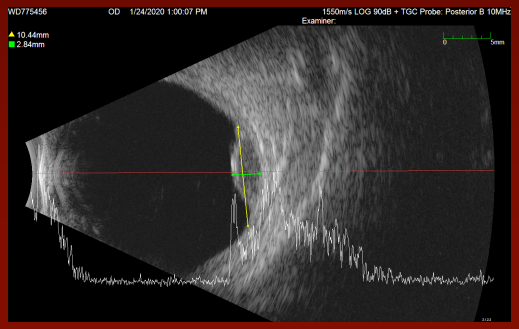
Delivering conformal treatment requires precise plaque placement. Image based 3D modeling shows us where to position the plaque!



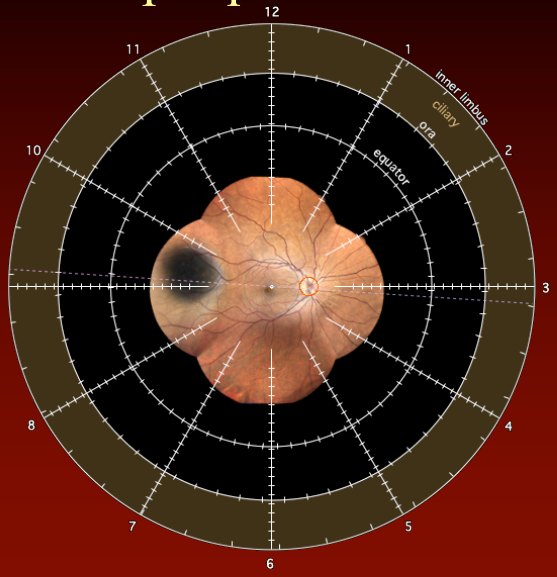


CT

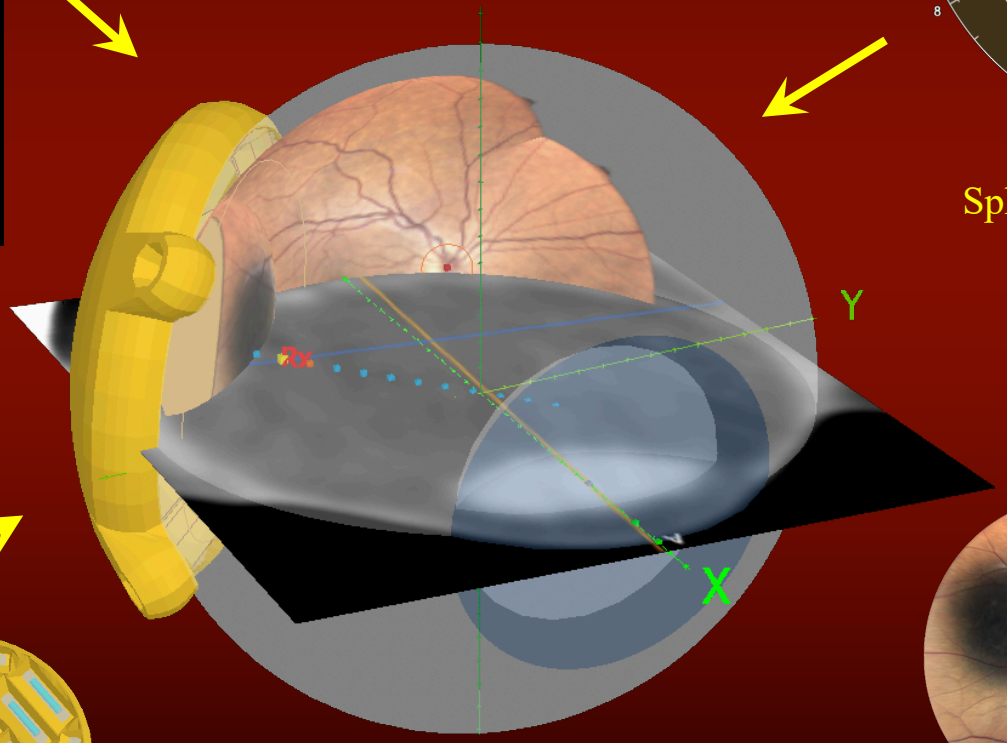


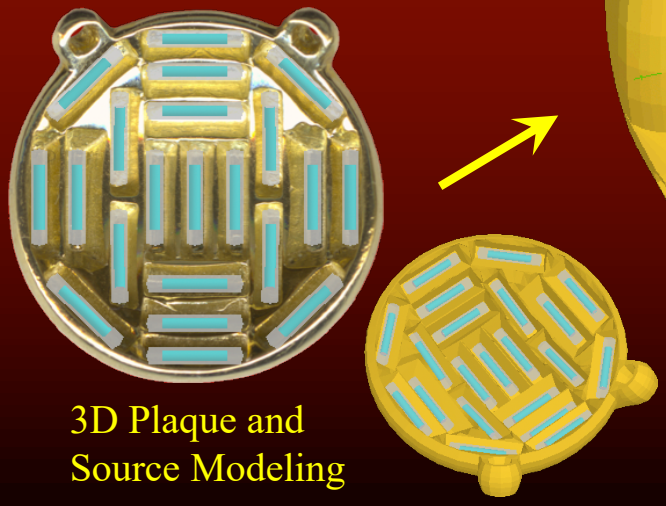
Ultrasound

Z

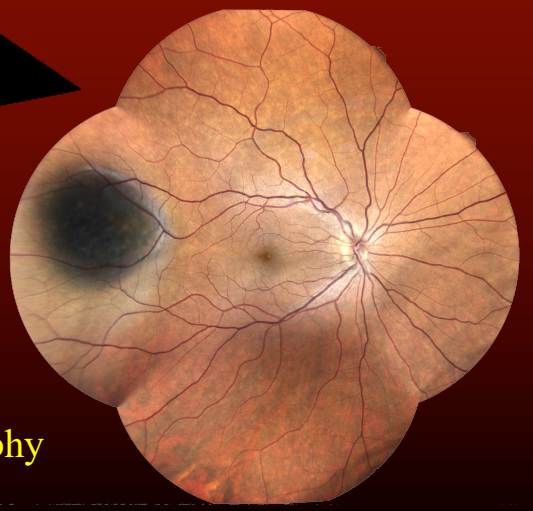


Spheroidal Shell Mapping





3D Plaque and Source Modeling



Fundus Photography

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USC

Build a 3D model of the eye using CT (or MRI) reconstructions and ultrasound imaging

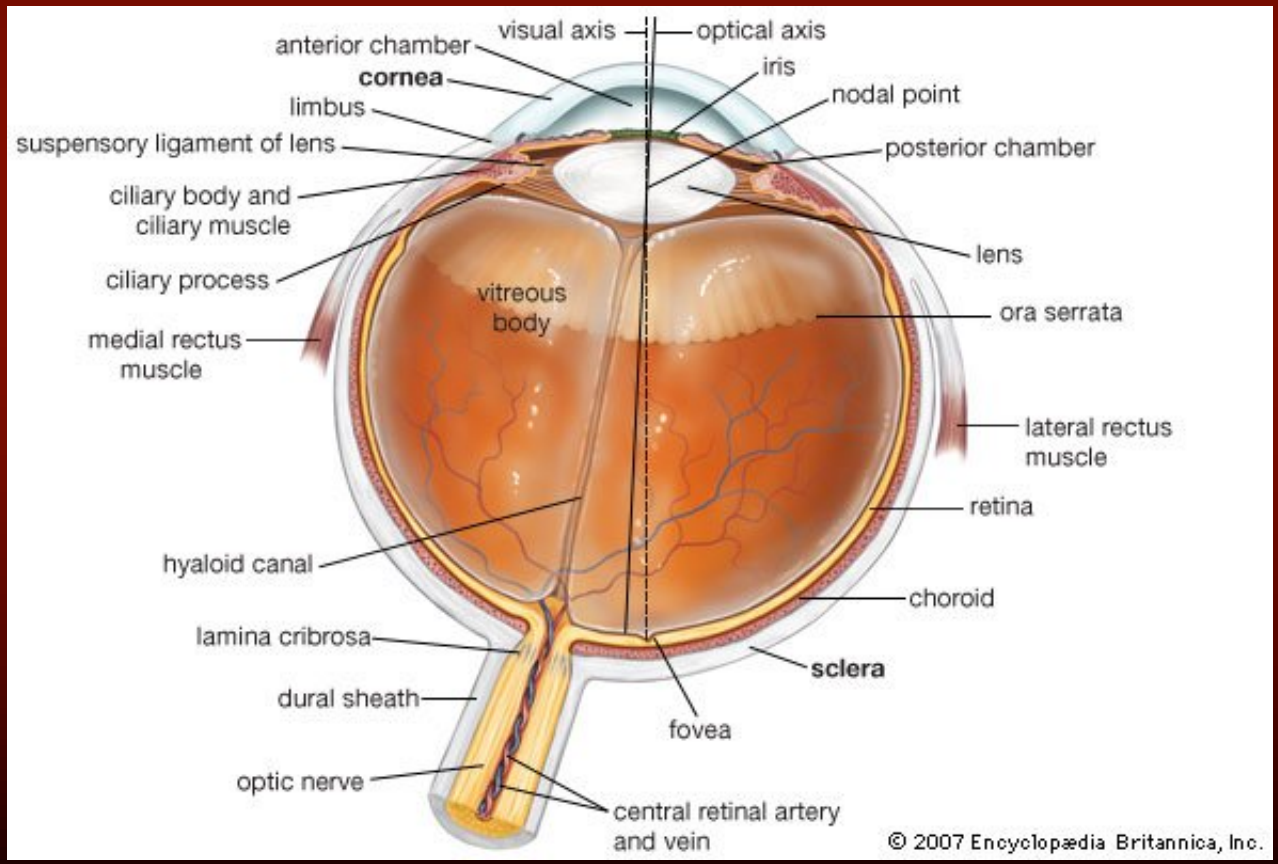
Locate the tumor base using fundus photography and spheroidal shell mapping

Choose a plaque and calculate suture coordinates on the eye

The shape of the eye is approximately spheroidal.

Most ocular sites of radiobiological interest are situated within thin layers that line the inner surface of the eye's scleral shell.

To precisely plan a plaque treatment we need to model the ocular anatomy.
3D models are great, but a 2D map of the inner surface of the shell is easier to work with.

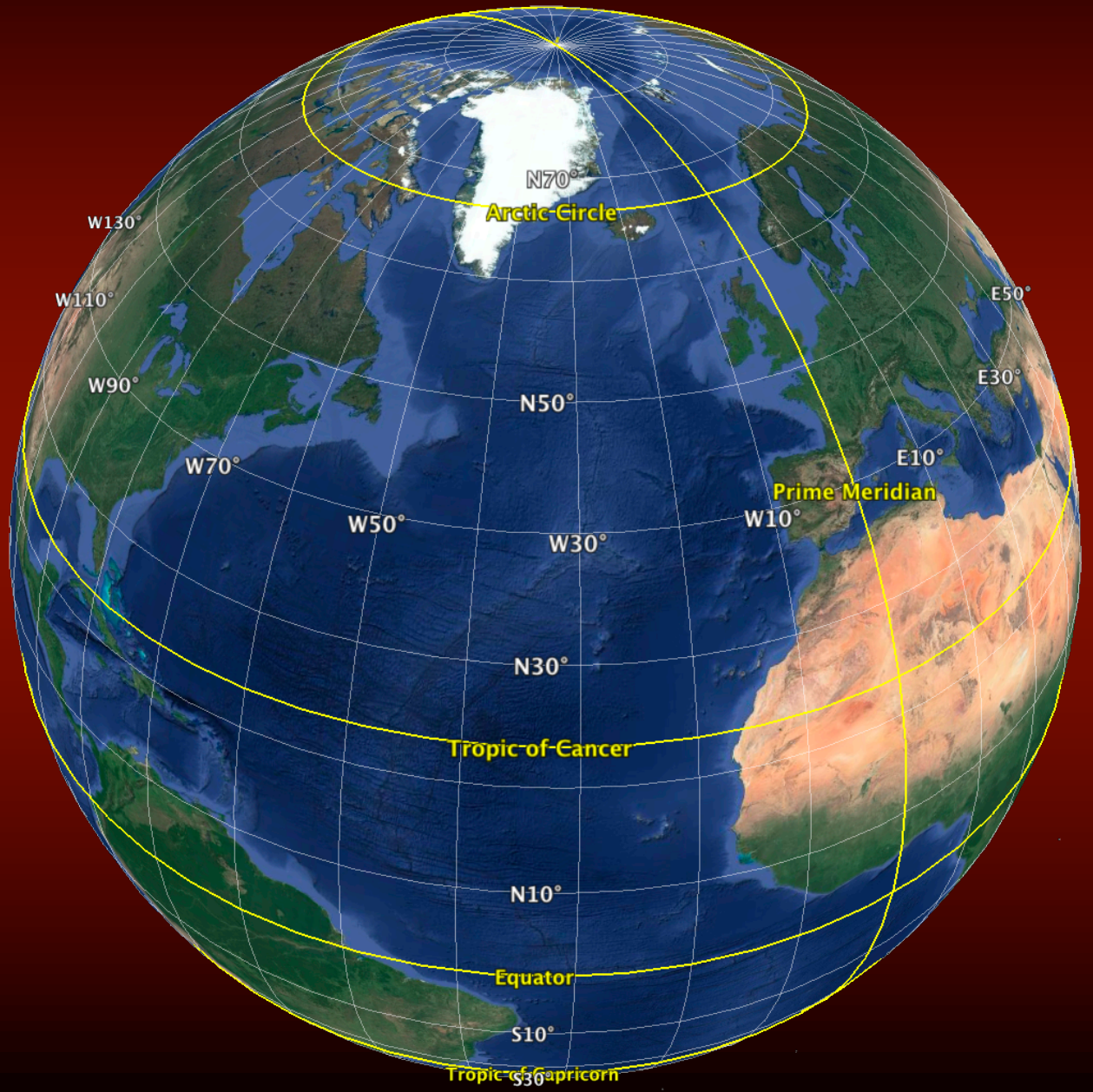


USC

A familiar spheroidal object that we map is the earth.

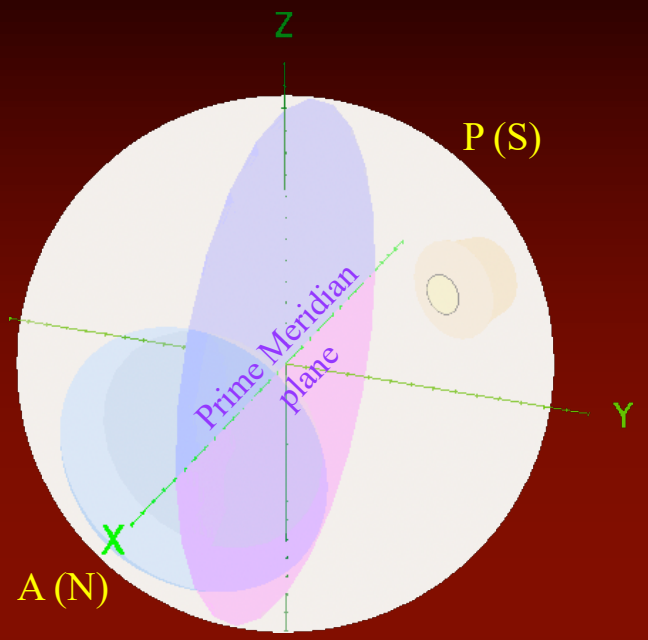
North pole

Anterior pole

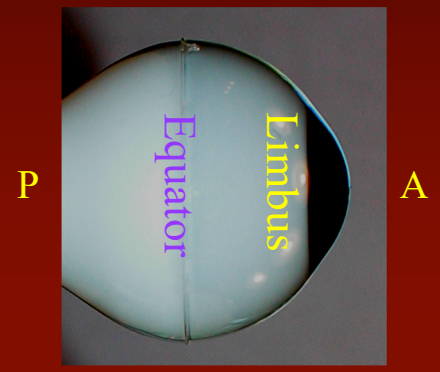


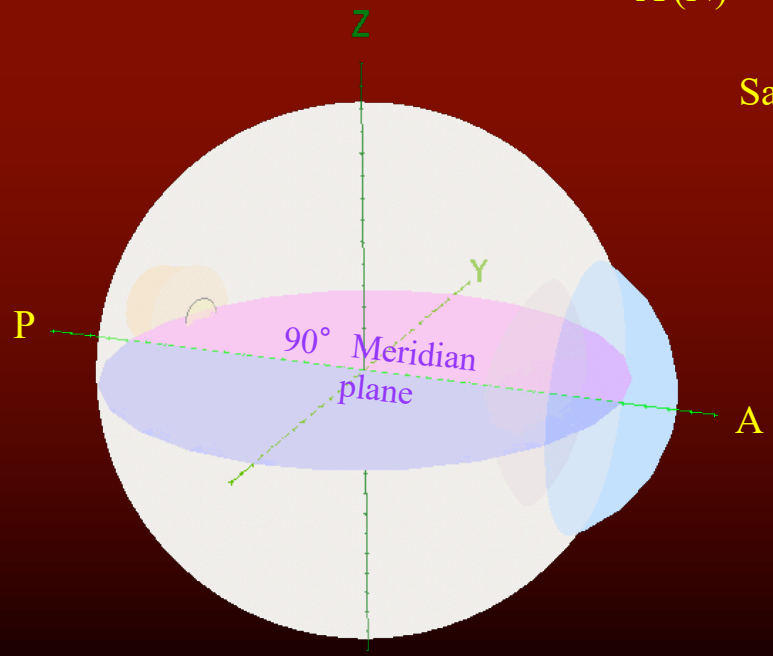
Compare to CT scanner terminology: Assume patient is HFS

(Head First Supine)

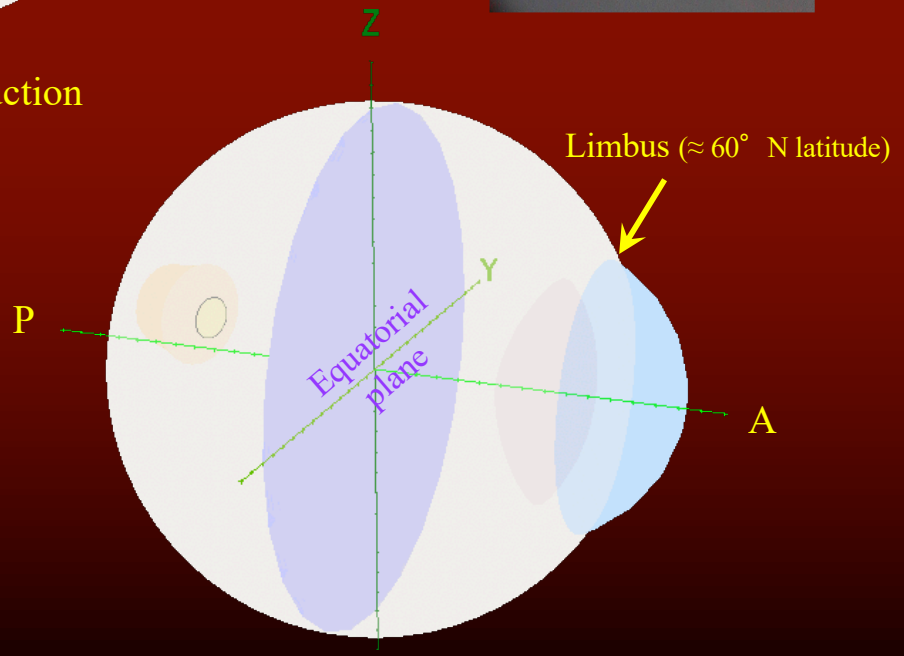


Sagittal reconstruction





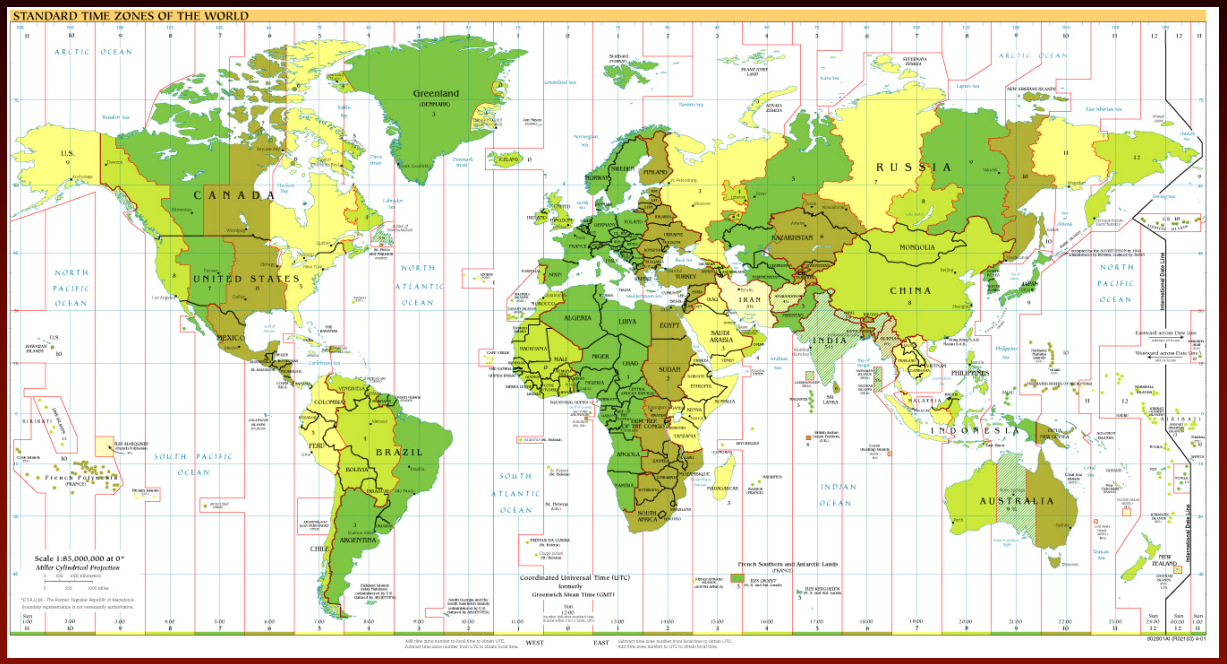
Axial reconstruction



Coronal reconstruction

USC

Familiar methods used to make 2D maps of the earth



Mercator projection

Polar projection

Considered by many to be the greatest cartographer of early modern times, Gerardus Mercator was born Gerhard Kremer of German parents in the town of Rapelmonde near Antwerp on March 5, 1512. Like many other intellectuals of his time, very early in his life he Latinized his German name, which meant 'merchant,' and changed it to the name by which we know him. Mercator means 'world trader.'

Mercator was a mapmaker, scholar, and religious thinker whose interests ranged from mathematics to calligraphy to the origin of the universe. In 1544 he fell victim to the Inquisition, partly due to his Protestant beliefs and partly due to suspicions aroused by his wide travels in search of data for his maps. He was fortunate to be released after seven months with the charges of heresy lifted — and head and limbs intact.

Mercator was one of the first mapmakers to cut up maps and bind them inside boards, later coining the term 'atlas' to refer to such collections of maps. He is best-known to us today for his celebrated cylindrical world map projection, first used in 1569, which enabled navigators to plot a long course in straight lines. One of the most revolutionary inventions in the history of cartography, Mercator's projection has greatly influenced our image of the world.

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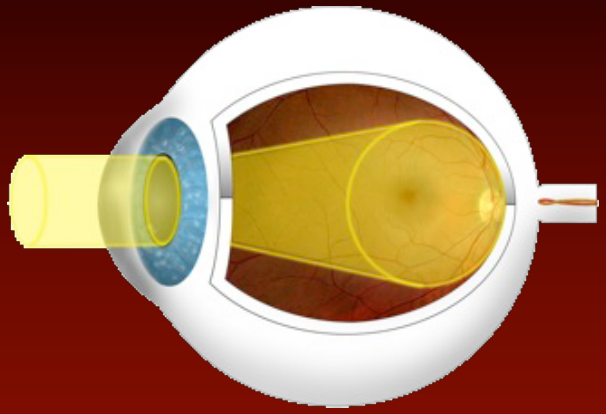
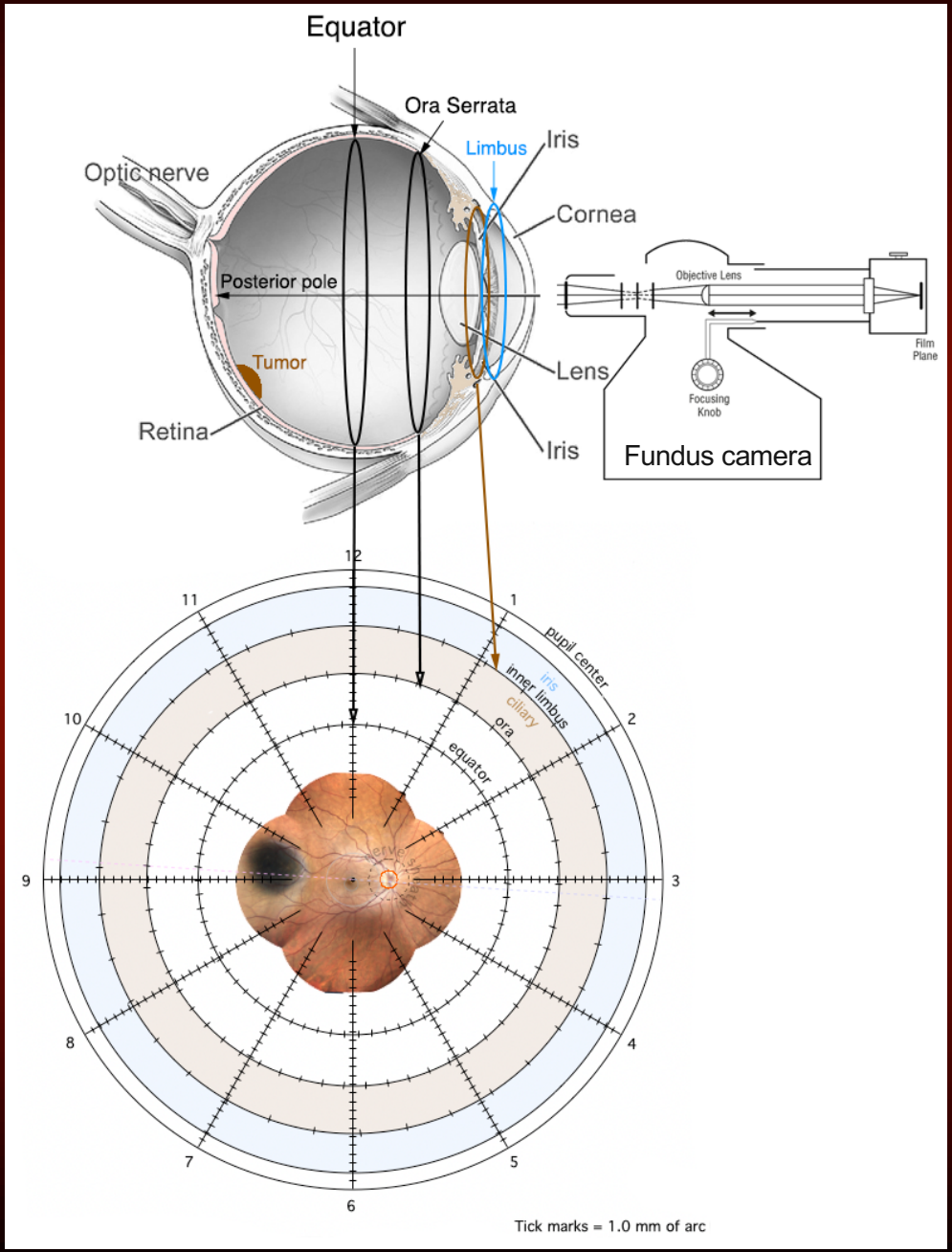
Because many important regions of interest in the eye are located near the posterior pole, a 2D projection that minimizes distortion near the posterior pole is desirable.

A fundus camera photographs the posterior polar region of the eye



In a 2D polar projection the pole is at the center of the diagram and objects close to it are minimally distorted. This is a polar map of the earth. The north pole is at the center of the map and the shape of regions close to the pole appear almost the way they do on a 3D globe. Shapes become circumferentially distorted as one approaches the equator.

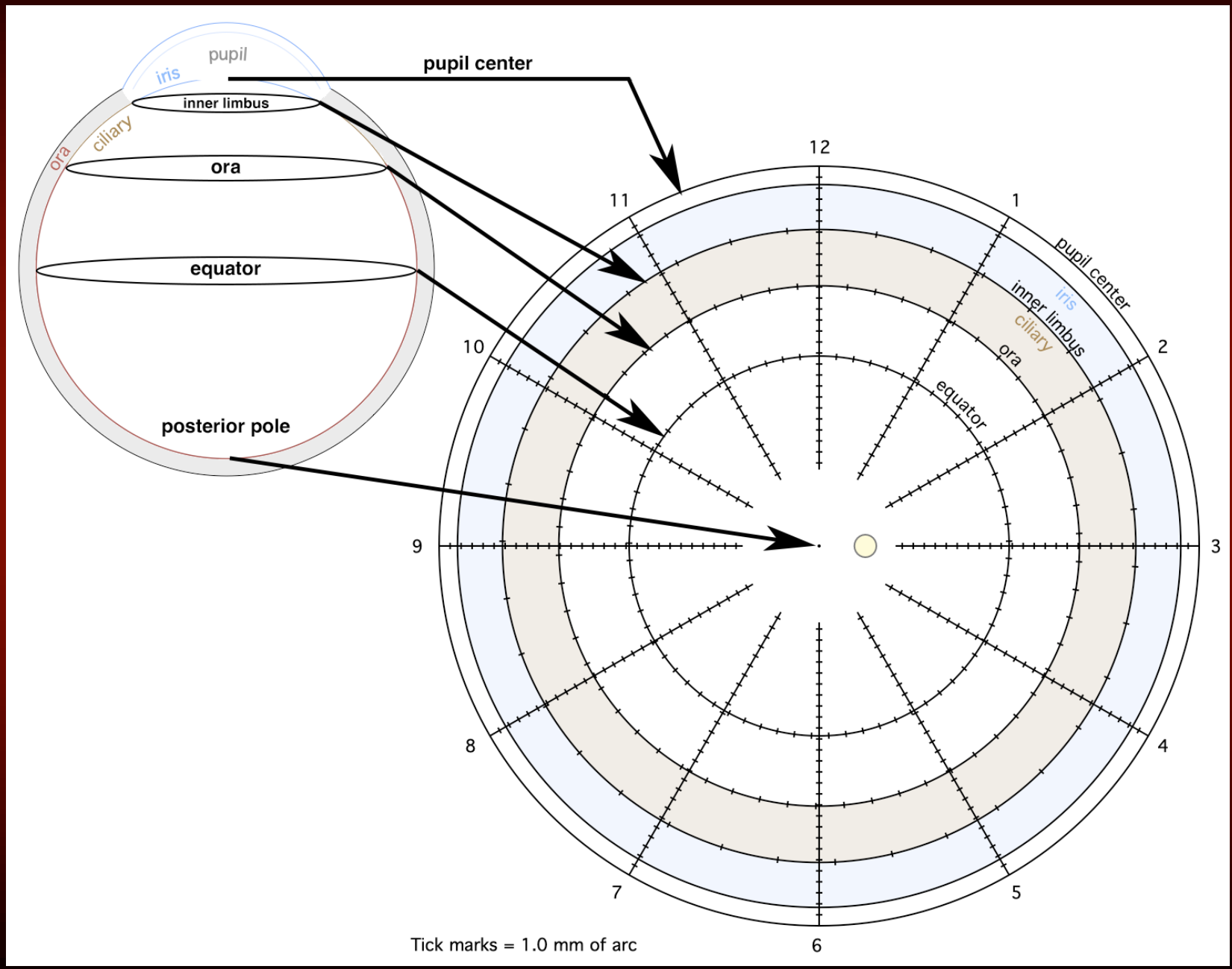


The retinal diagram, a familiar tool to ophthalmologists, is similar to a polar map of the earth. It is an azimuthal equidistant projection of the inner surface of the eye. In this diagram the posterior pole is at the center of the diagram and nearby regions of interest are minimally distorted.

On an equidistant projection, the projection of a mm of arc is consistent along a radial spoke from the posterior pole to the anterior extent of the diagram. As distance anterior to the equator on the diagram increases, the circumferential projection of a mm of arc increases in length because the diameters of projected anterior circles are larger than the projected diameter the equatorial circle.

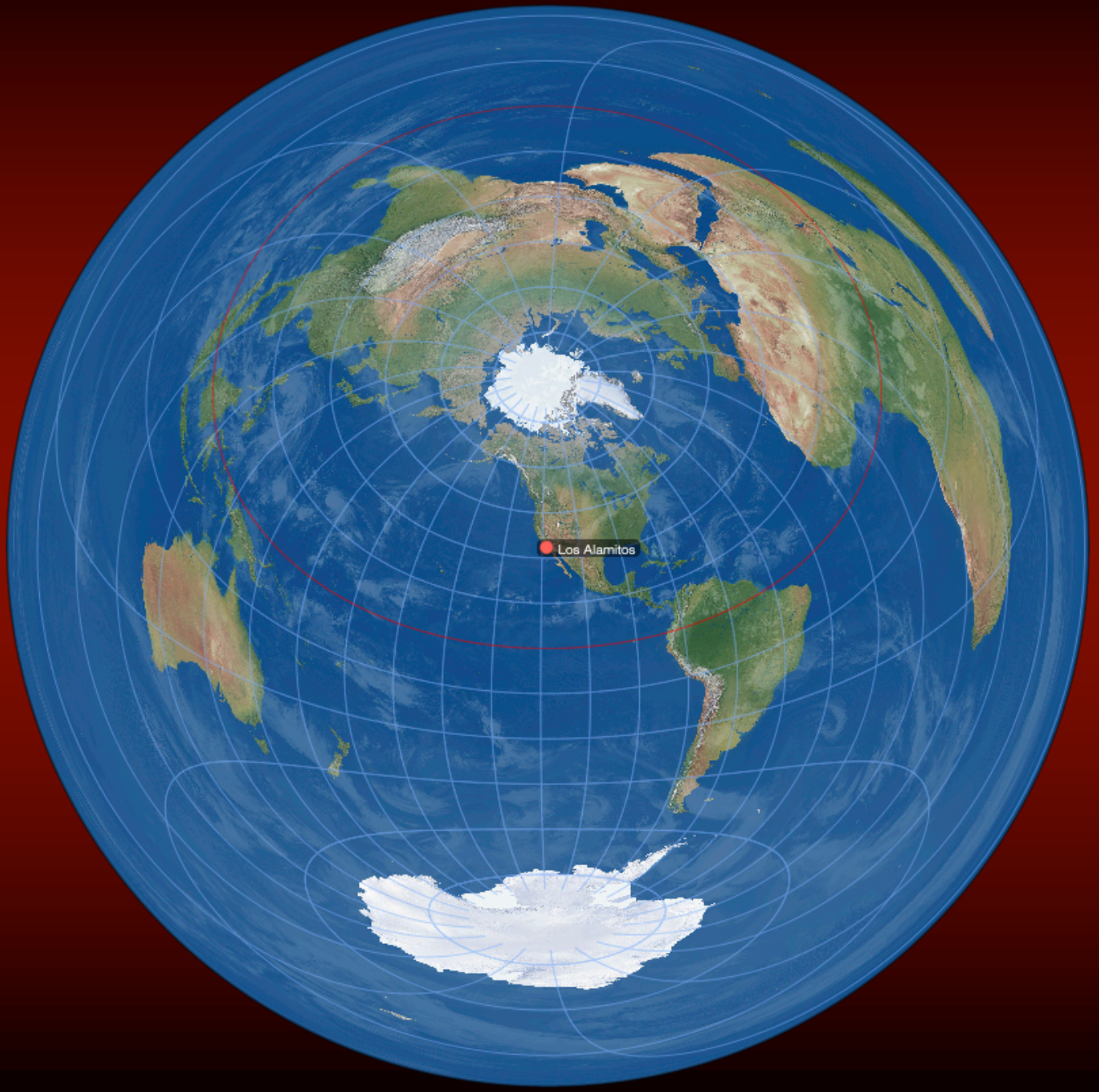
For example, the diameter of the circle that maps the inner limbus appears to be quite large on the retinal diagram, while, in fact, the inner limbus diameter is much smaller than the inner equatorial diameter in 3D space.

A complete azimuthal equidistant projection maps a spheroidal surface from pole to pole. Posterior centric projections in Plaque Simulator treatment plans can map the inner surface of the sclera between the posterior pole and the inner limbus (retinal diagram style) or can be extended all the way to the pupil center.



The emblem of the United Nations is an azimuthal equidistant projection of the earth centered on the North Pole.

This is an azimuthal equidistant projection of the earth centered on Los Alamitos California, whose antipodal point is in the south Indian Ocean.



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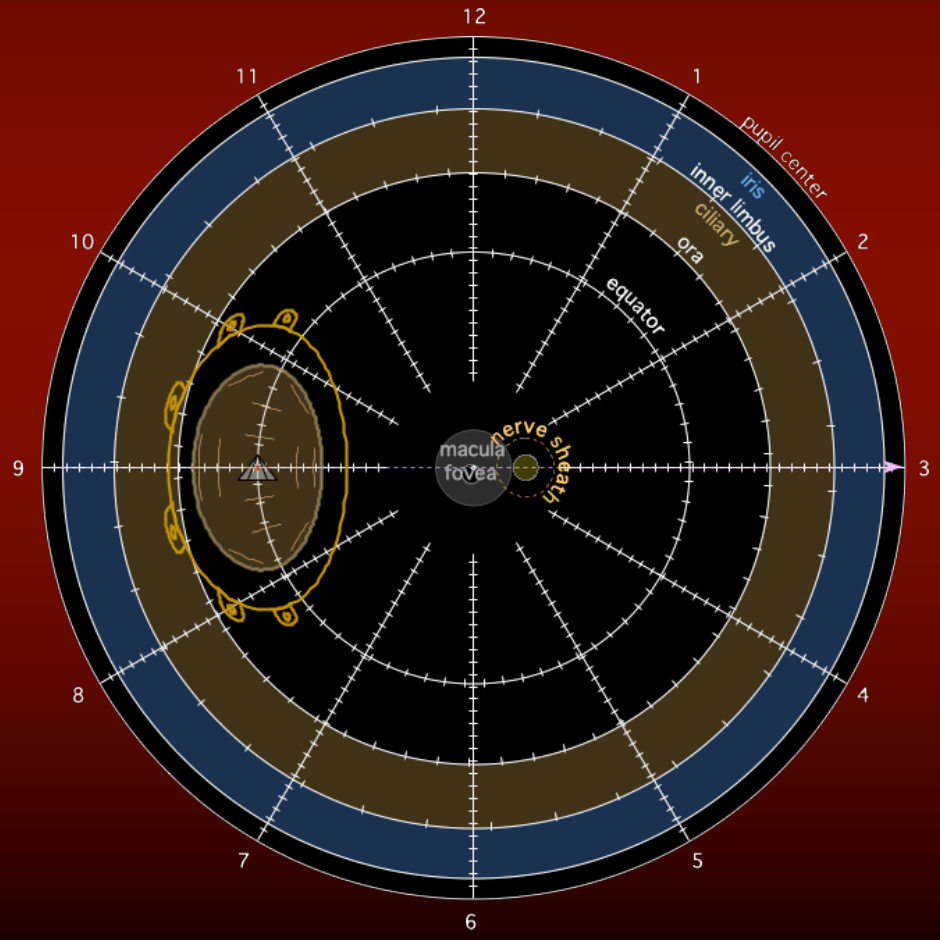
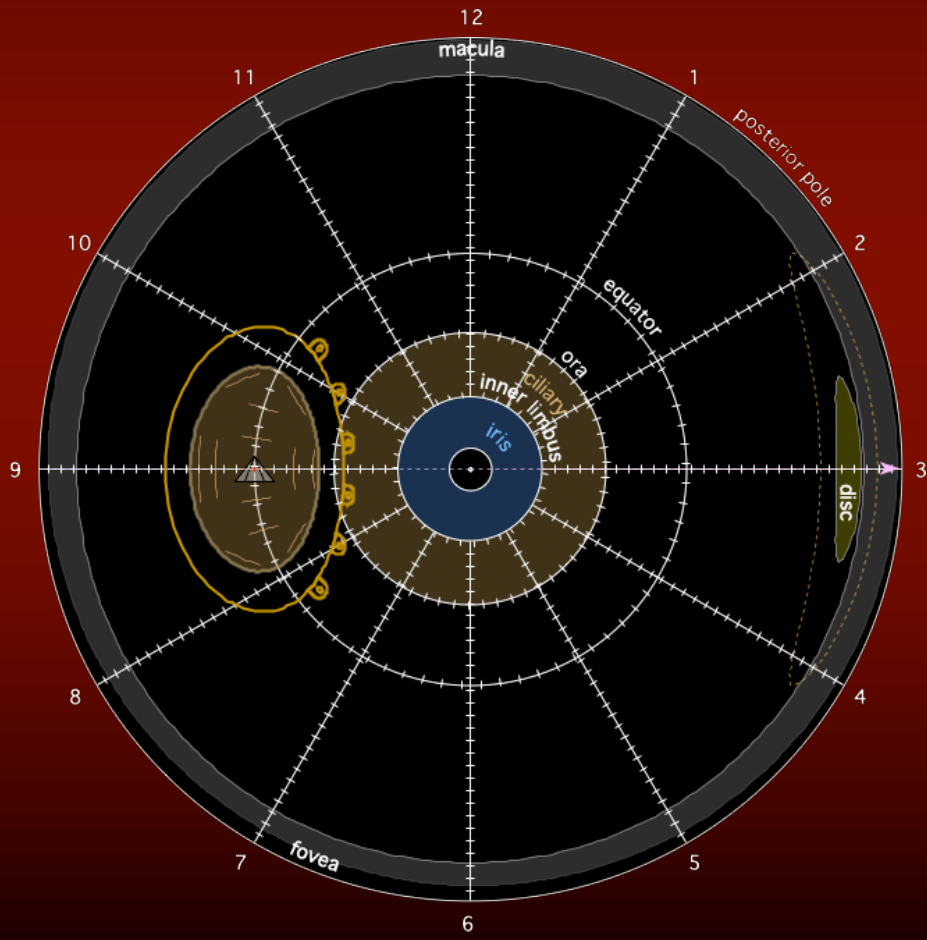
Ocular Azimuthal Equidistant Projections

Posterior Centric
(typical retinal diagram)



Anterior Centric



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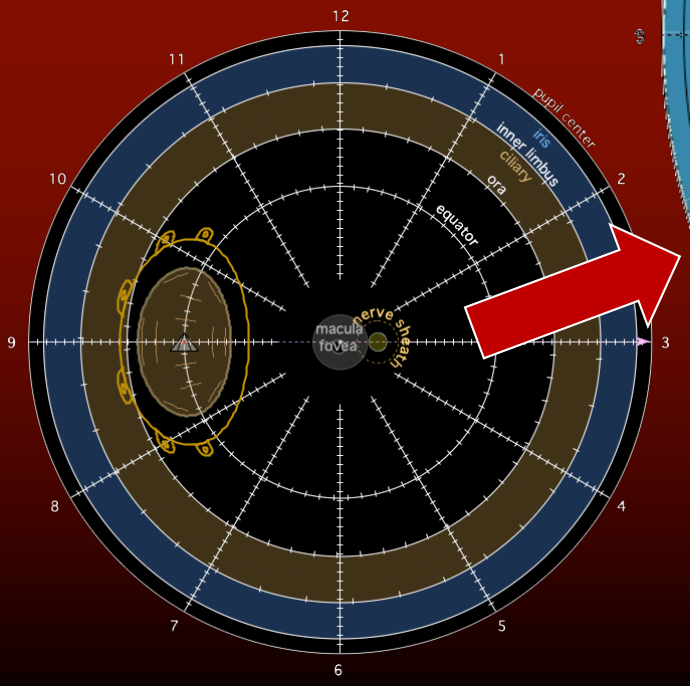
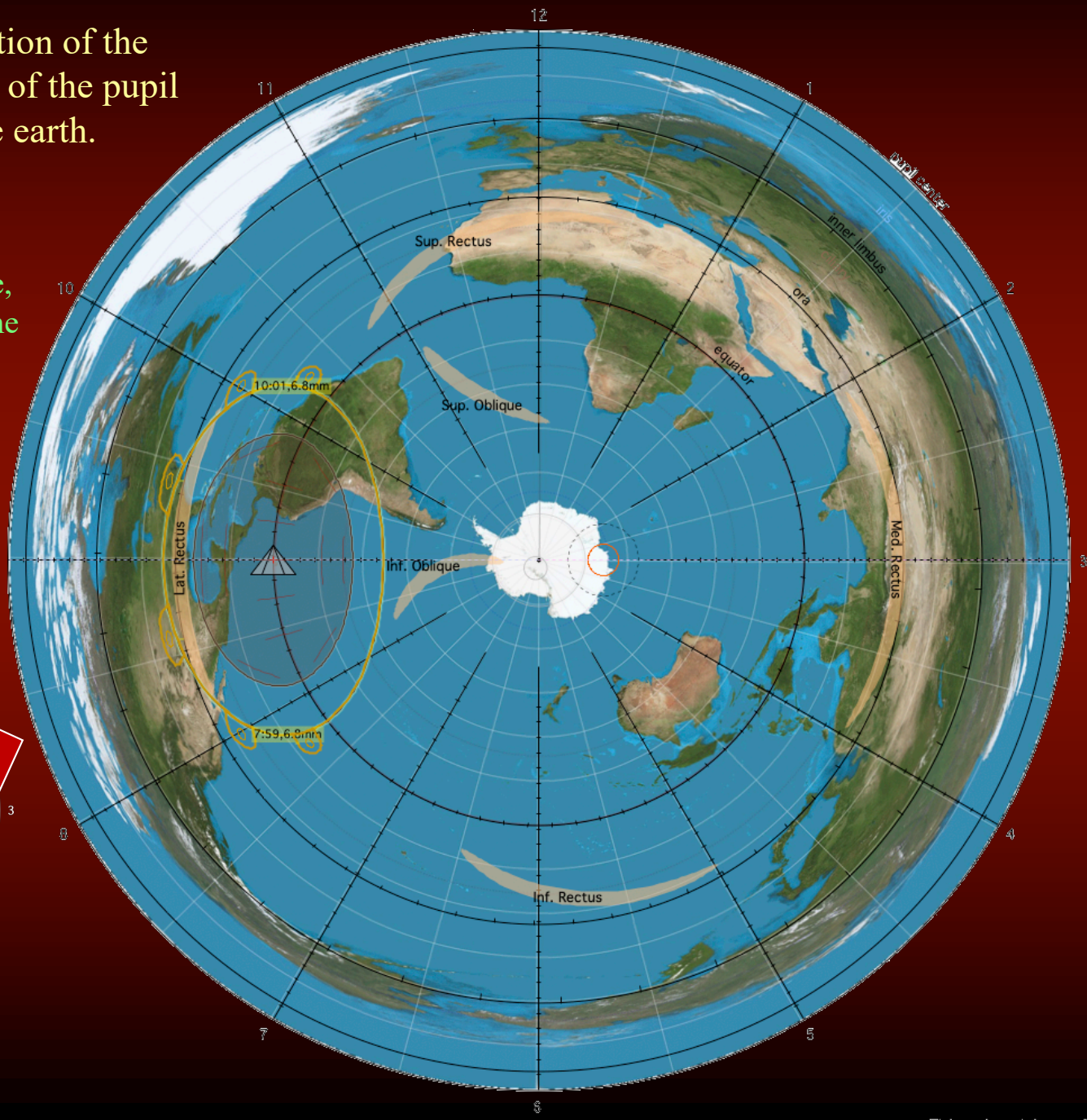
USC

A posterior centric retinal diagram superimposed over an azimuthal equidistant projection of the earth centered on the South Pole.

The outermost circle is the projection of the antipodal points; *id est*, the center of the pupil of the eye or the North Pole of the earth.

From this projection, we can map and calculate the area of continents on the outer surface of the earth, and, likewise, we can map and calculate the area of the tumor base, fovea and macula on the inner surface of the sclera and plot a histogram of dose to those areas.





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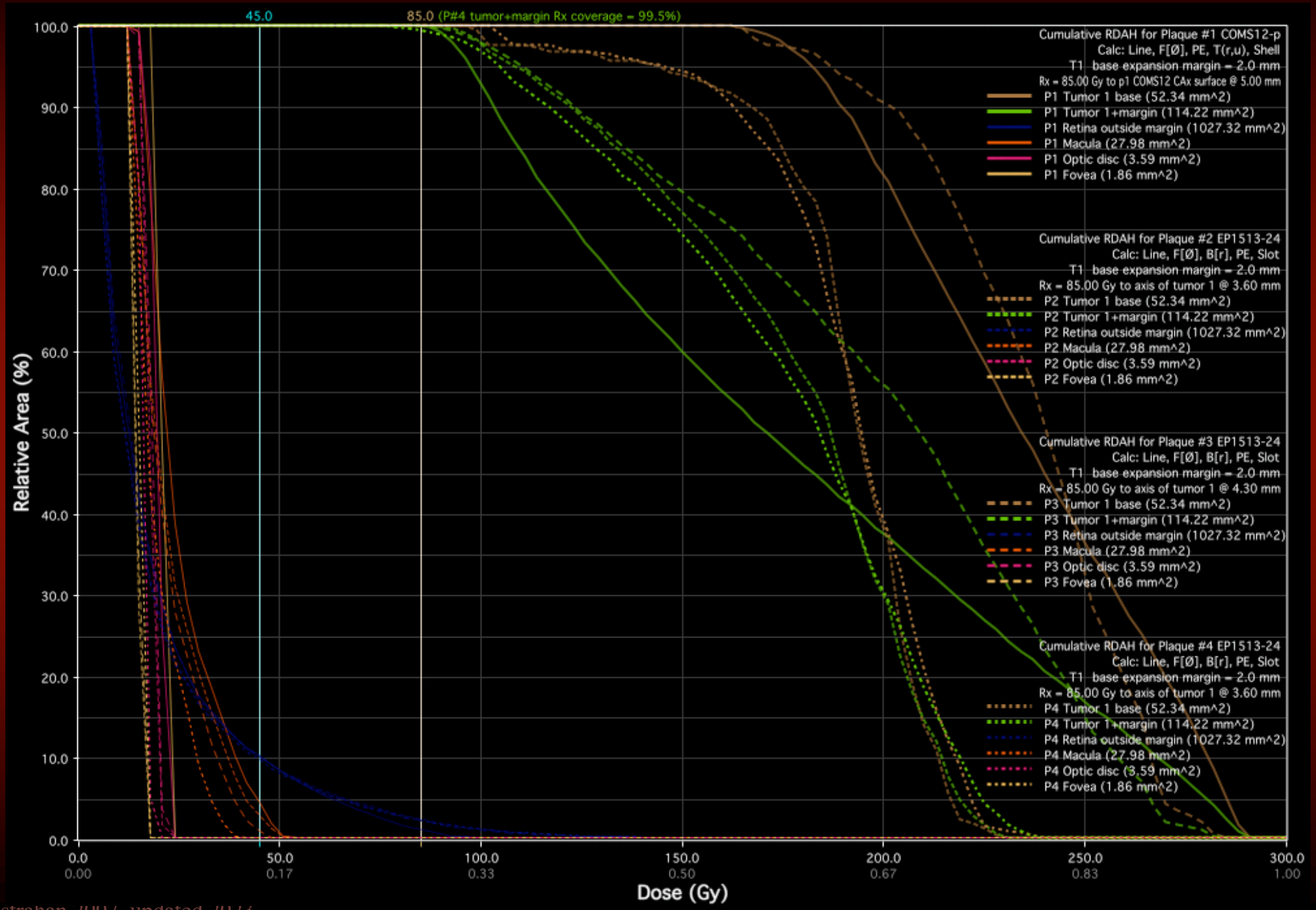
The retinal dose-area histogram (RDAH) provides a quantitative metric to compare treatment plans.



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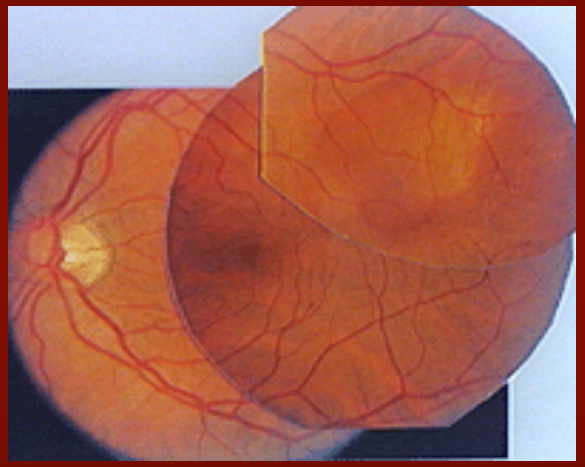
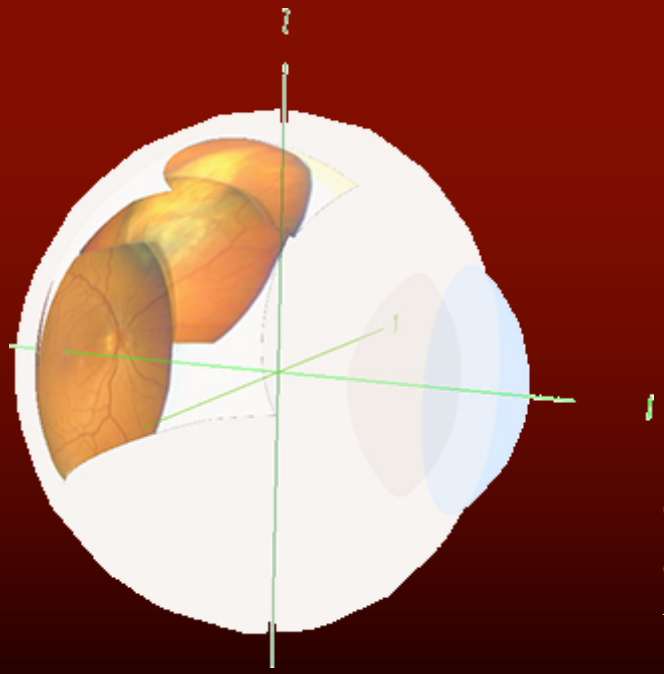
A collage or montage of fundus photos can be used to map the retinal surface

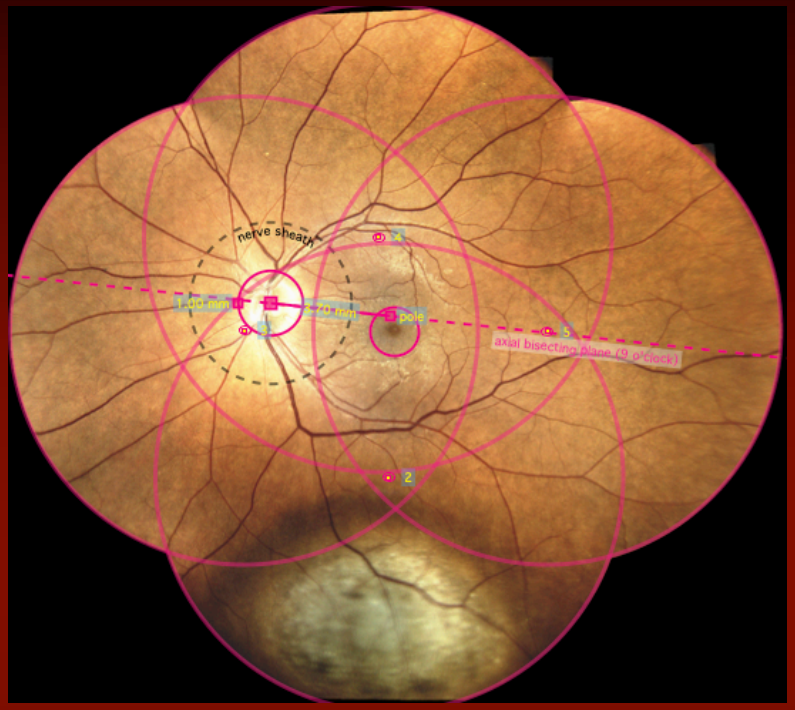
In the late 1980s at the University of Southern California we constructed fundus collages from hand-trimmed photographic prints. The resulting collages were initially digitized using a video camera and later a flatbed scanner.



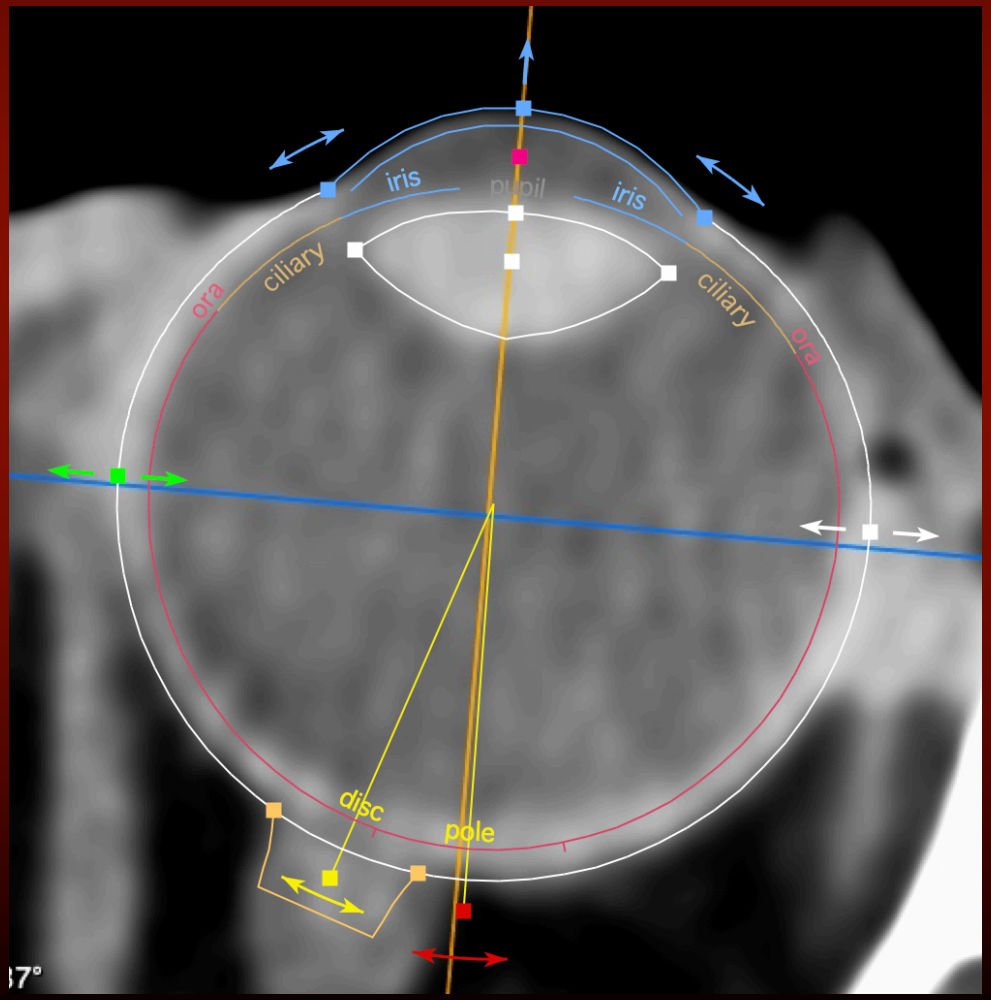


Once calibrated, the collage of photos was painted as a "texture" onto a 3D computer model (derived from CT reconstructions) of the eye's inner surface to facilitate 3D treatment planning.

The digital fundus montage is a composite photo of the posterior retinal surface.

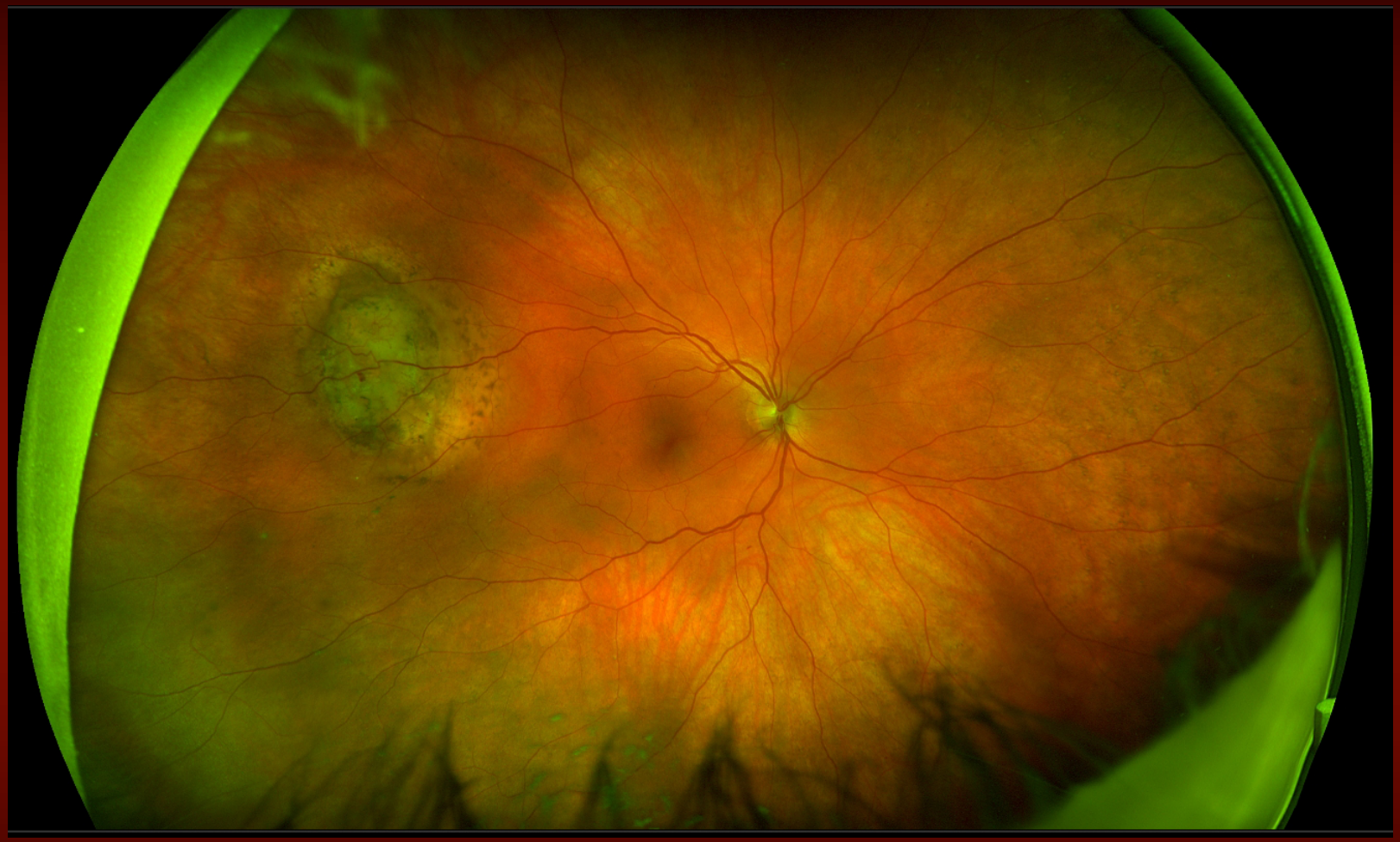


Fundus photography allows us to map the portion of a tumor that can be photographed with respect to distinctive anatomic landmarks such as the optic disc and fovea.



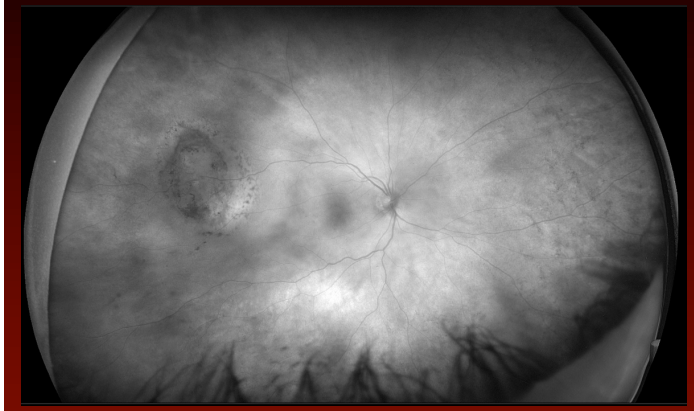
In order to calibrate a fundus montage we need to know the radius of curvature of the spheroidal surface and the distance between the center of the optic disc and the posterior pole. These parameters can be determined from 3D modeling using multiplanar and spherical surface reconstructions of the eye from CT and MRI.

A newer, wide angle technology for imaging the inner surface of the eye is Scanning Laser Ophthalmoscopy (SLO).

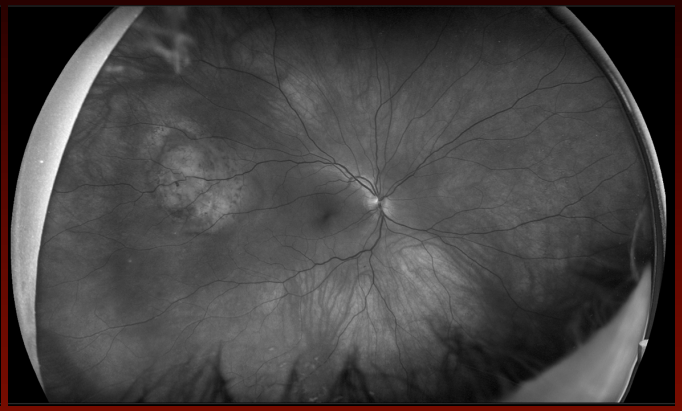


SLO utilizes horizontal and vertical scanning mirrors to scan a specific region of the retina and create raster images viewable on a monitor. While it is able to image the retina in real time, it has issues with reflections from eye astigmatism and the cornea. Eye movements additionally can confound the data.

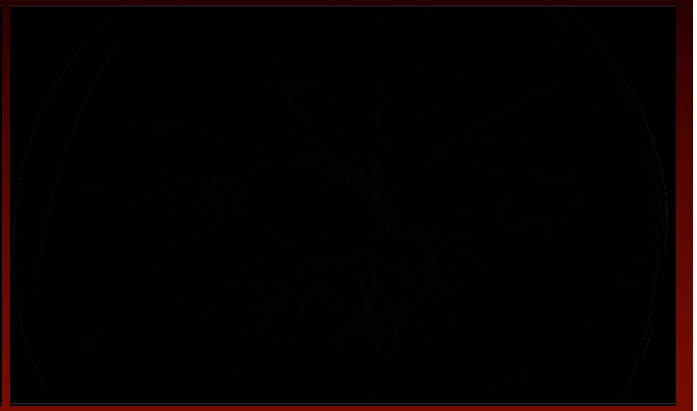
Unlike conventional fundus cameras that use a light source containing different wavelengths, color SLOs use lasers of two or sometimes three different wavelengths to obtain an image of the ocular fundus. Each wavelength reaches a different layer of the retina. This is an example of an SLO that uses only 2 laser colors, red and green.



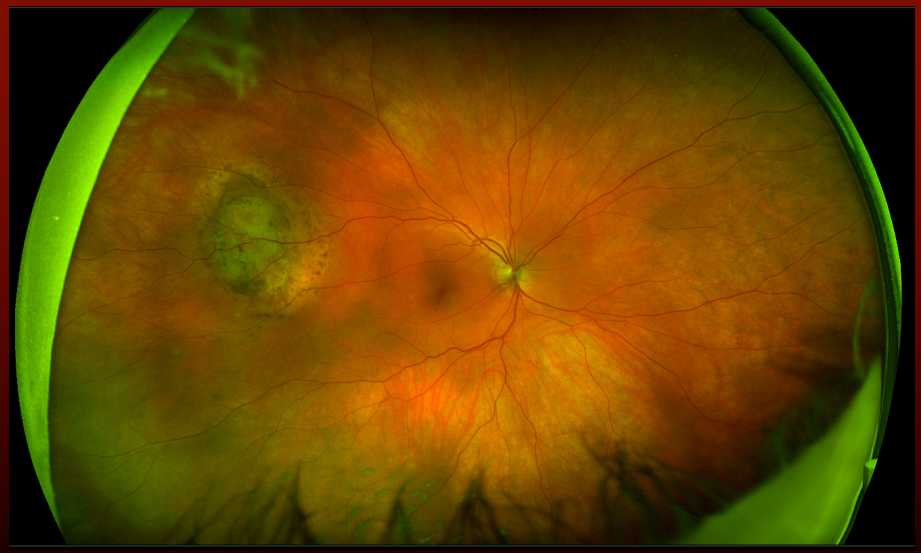
Long wavelengths (**RED**) produce images of the deeper layer of the retina.



Intermediate wavelengths (**GREEN**) produce images of the intermediate layers.



Short wavelengths (**BLUE**) would produce images of the superficial layer of the retina.



Color SLO images created by superimposing each wavelength are of better image quality and provide more information at different depths in the retina than conventional fundus cameras.

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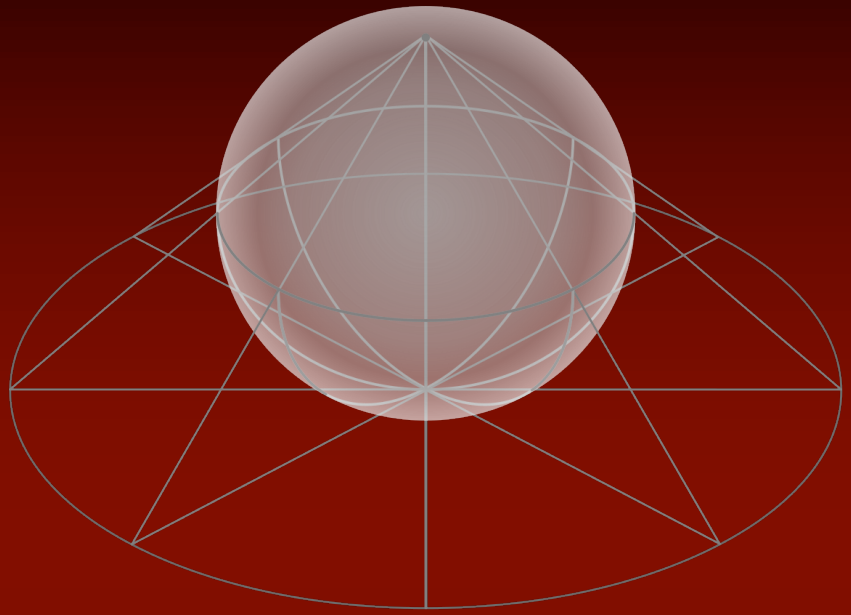
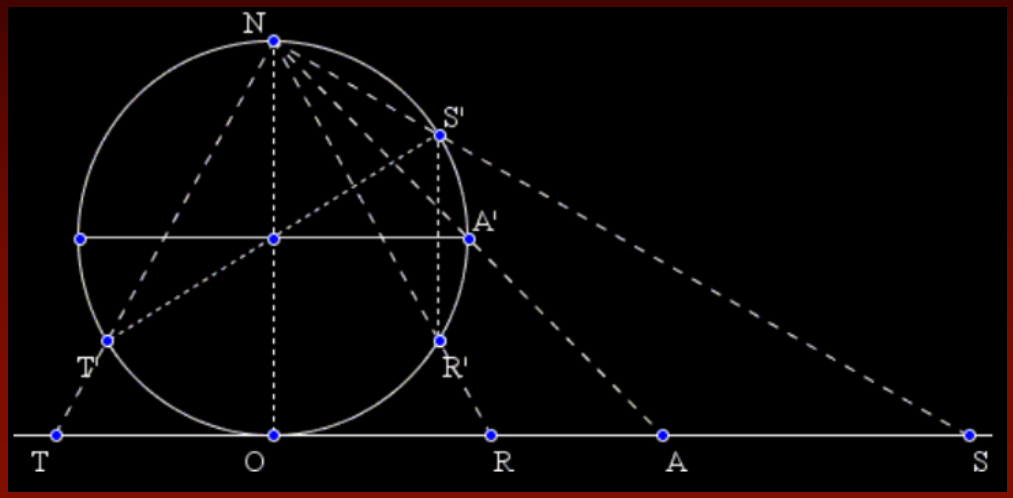
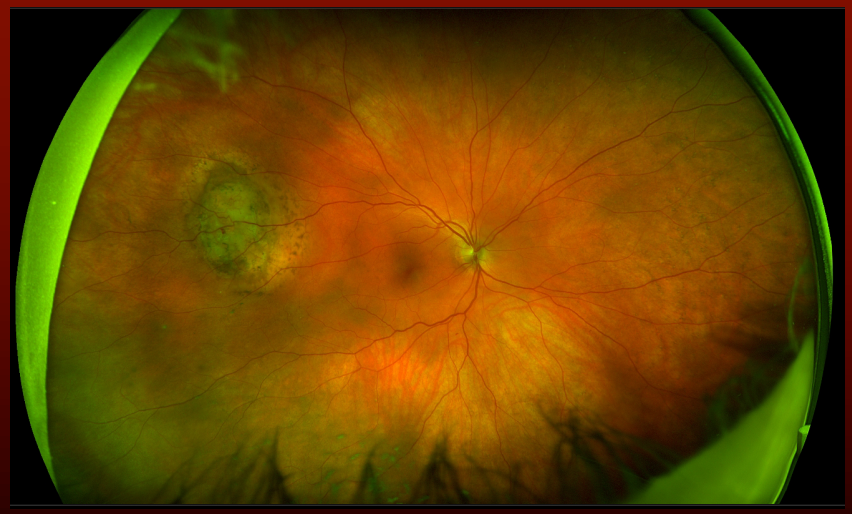
SLO systems often present the inner surface of the eye as a stereographic projection.







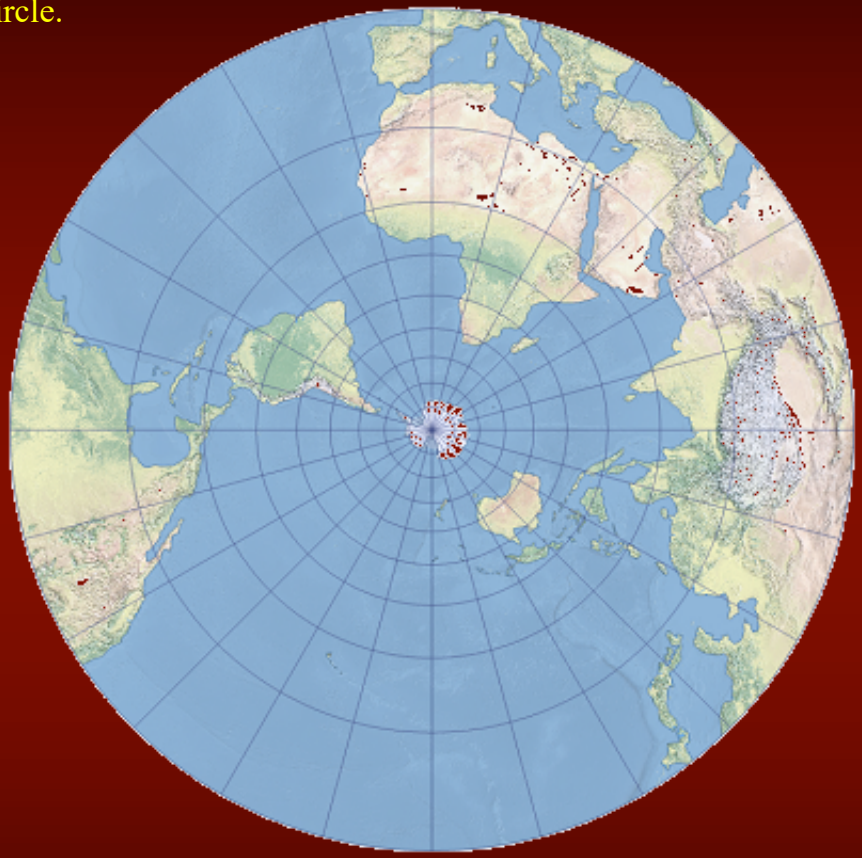
LIKE the azimuthal equidistant projection, the stereographic projection preserves longitudinal angle.

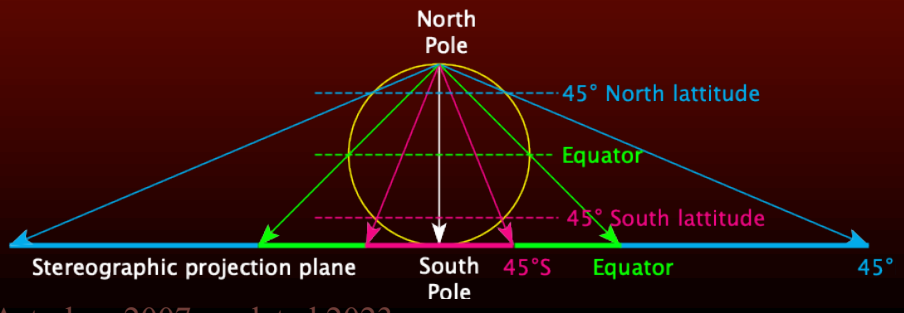
UNLIKE the azimuthal equidistant projection, radial distances on the eye surface are not equidistant when projected onto the plane of the stereographic projection.

Comparison of stereographic and azimuthal equidistant projections

Similar to SLO “optomap”

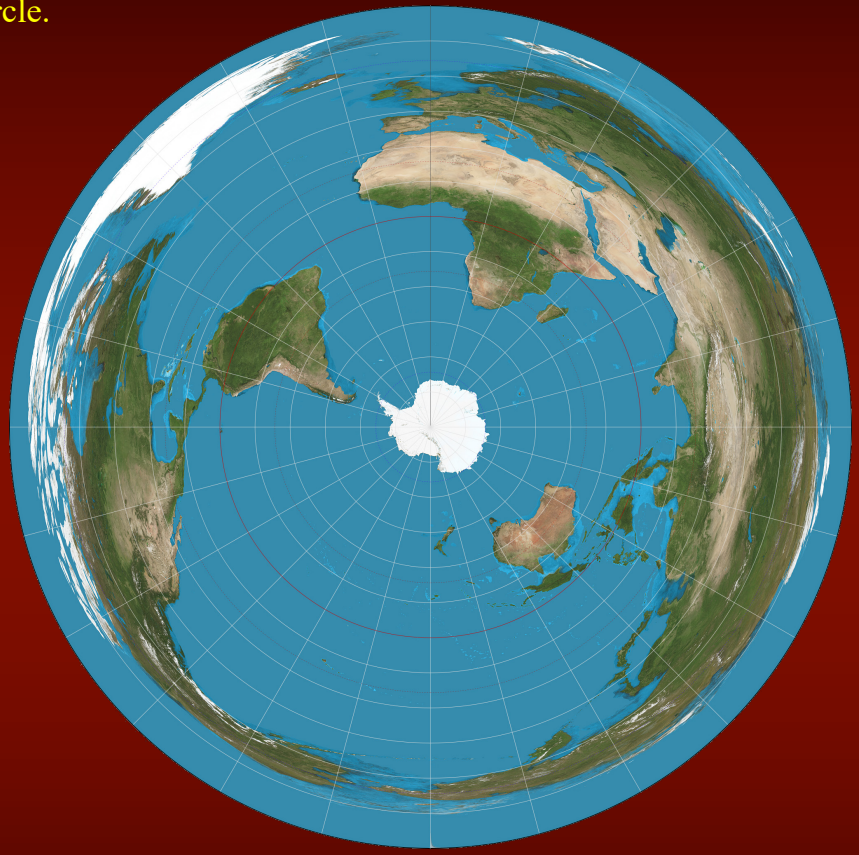
This stereographic projection maps the earth from the south pole at its center to 45 degrees north latitude which is projected as the outermost circle.

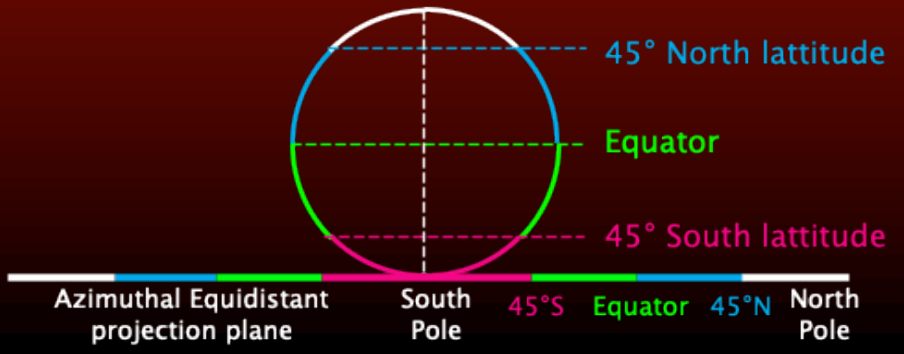




Similar to retinal diagram

This azimuthal equidistant projection maps the earth from the south pole at its center to the north pole which is projected as the outermost circle.





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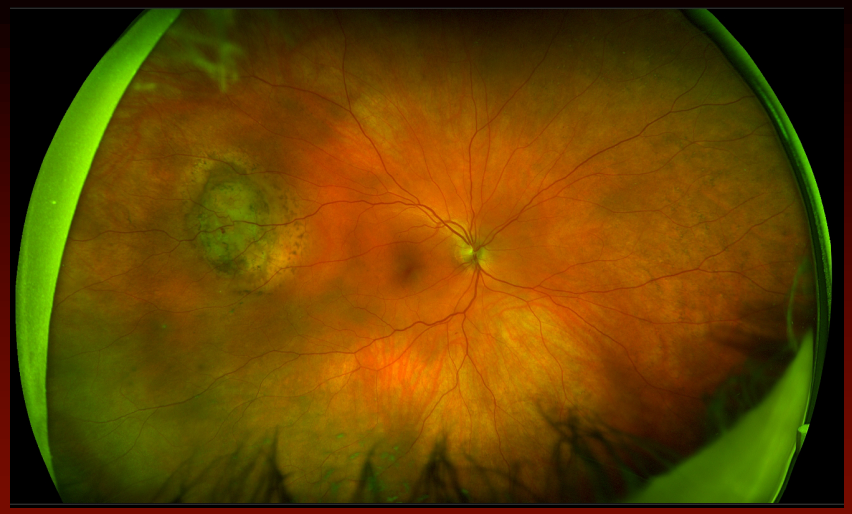
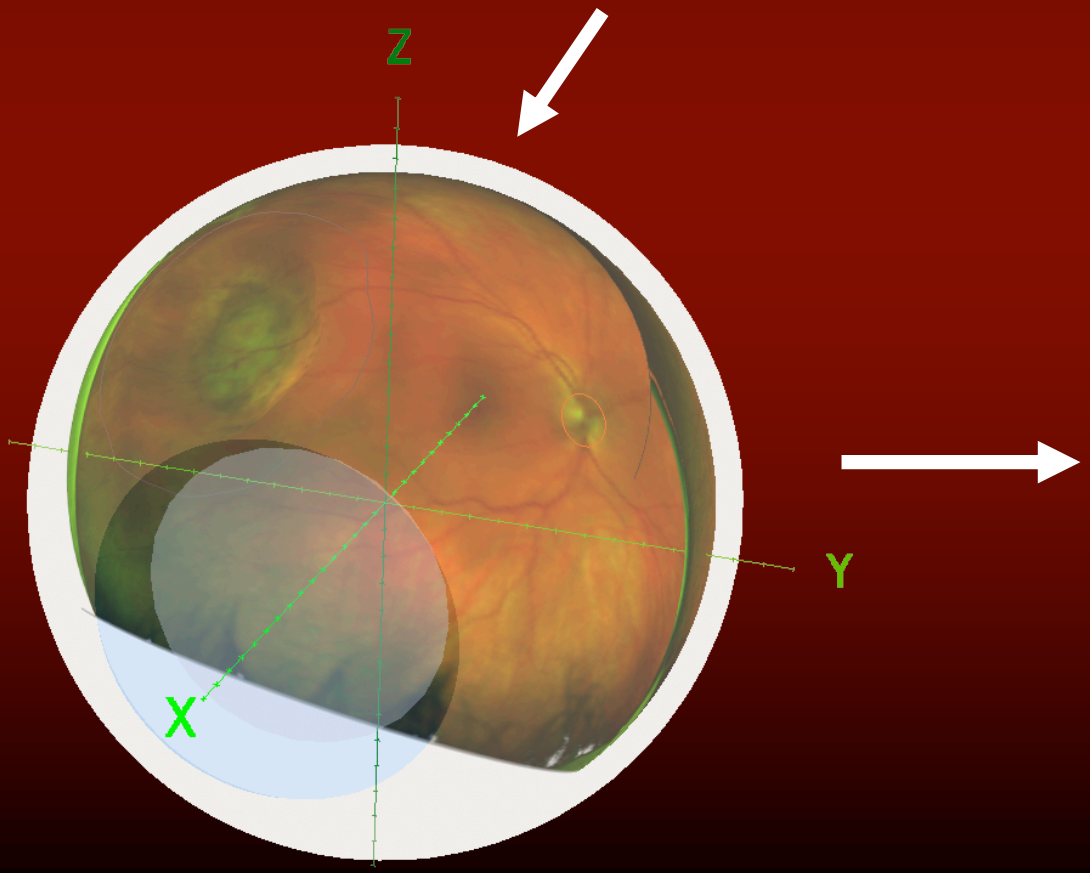
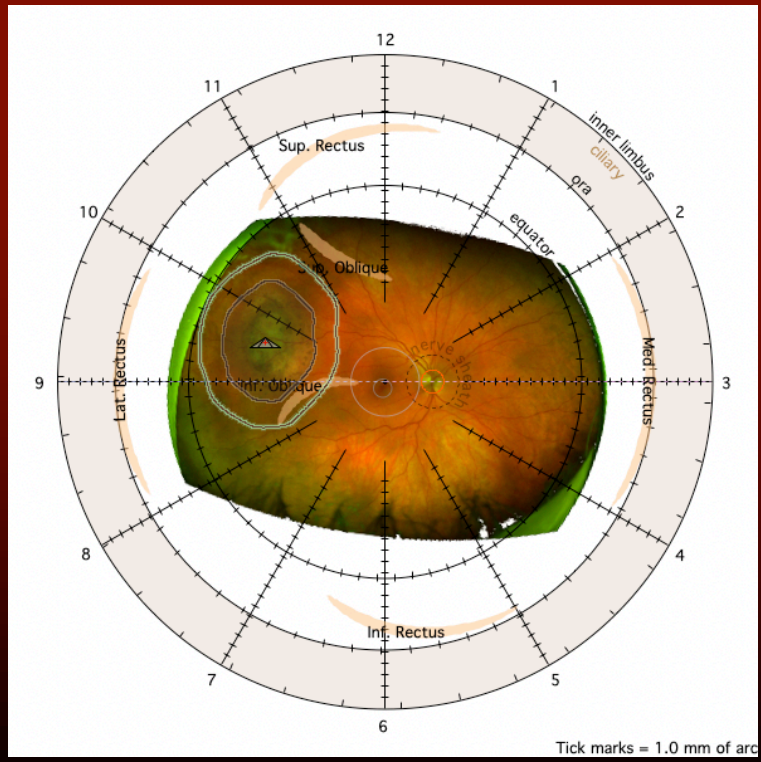


If we know the dimensions of the eye (e.g. from 3D CT modeling), the stereographic projection can be mapped back to the spheroidal surface from which it originated.

From the spheroidal surface, the image can be projected onto the retinal diagram as an azimuthal equidistant projection.





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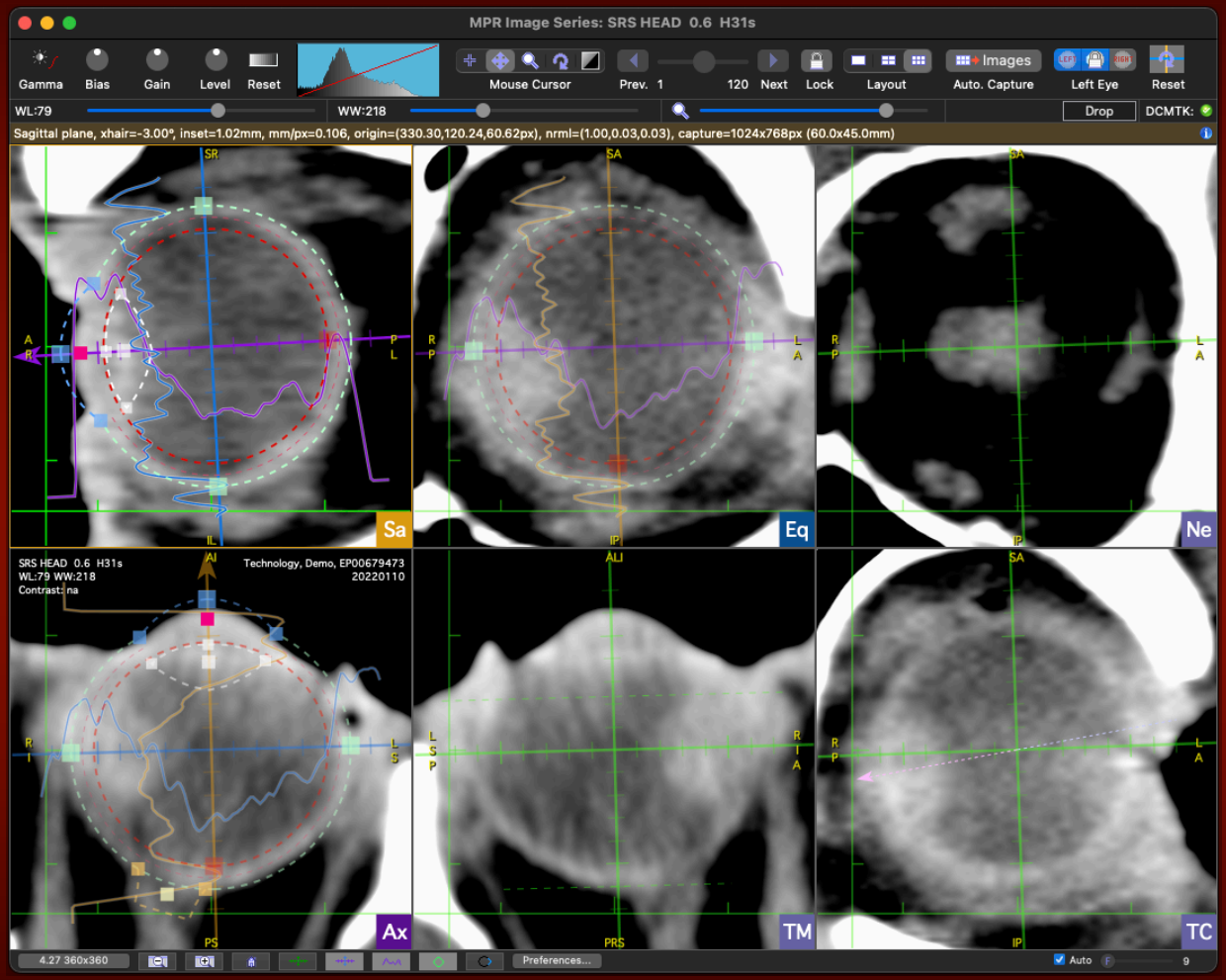
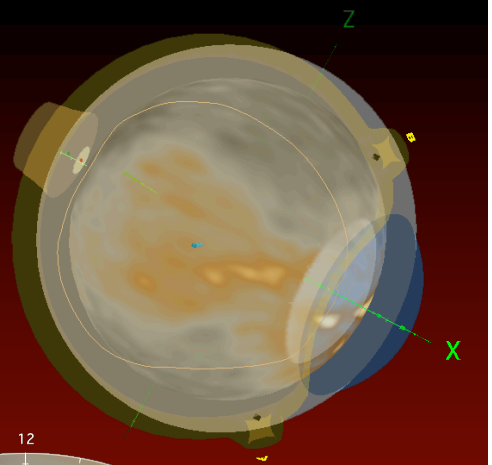
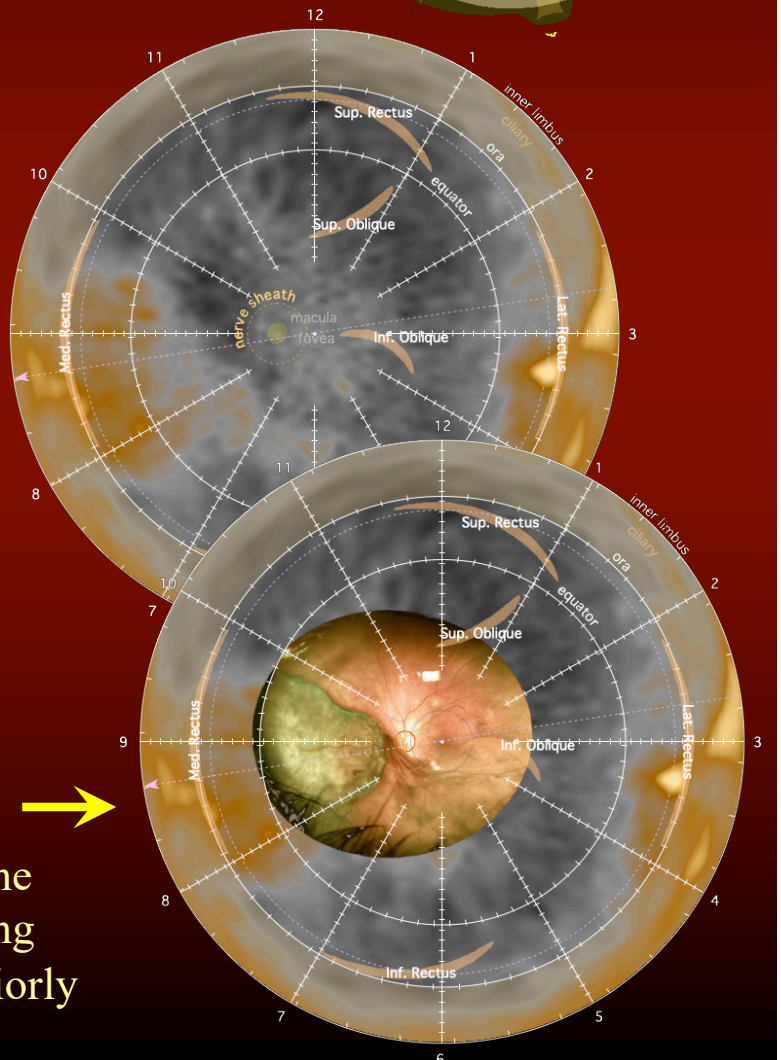
Reconstruction of an oblate-spheroidal surface slightly inset from the inner scleral surface from 3D CT (or MRI) enables mapping portions of the tumor base located too anteriorly to photograph by optical methods onto the azimuthal equidistant projection and for 3D visualization.



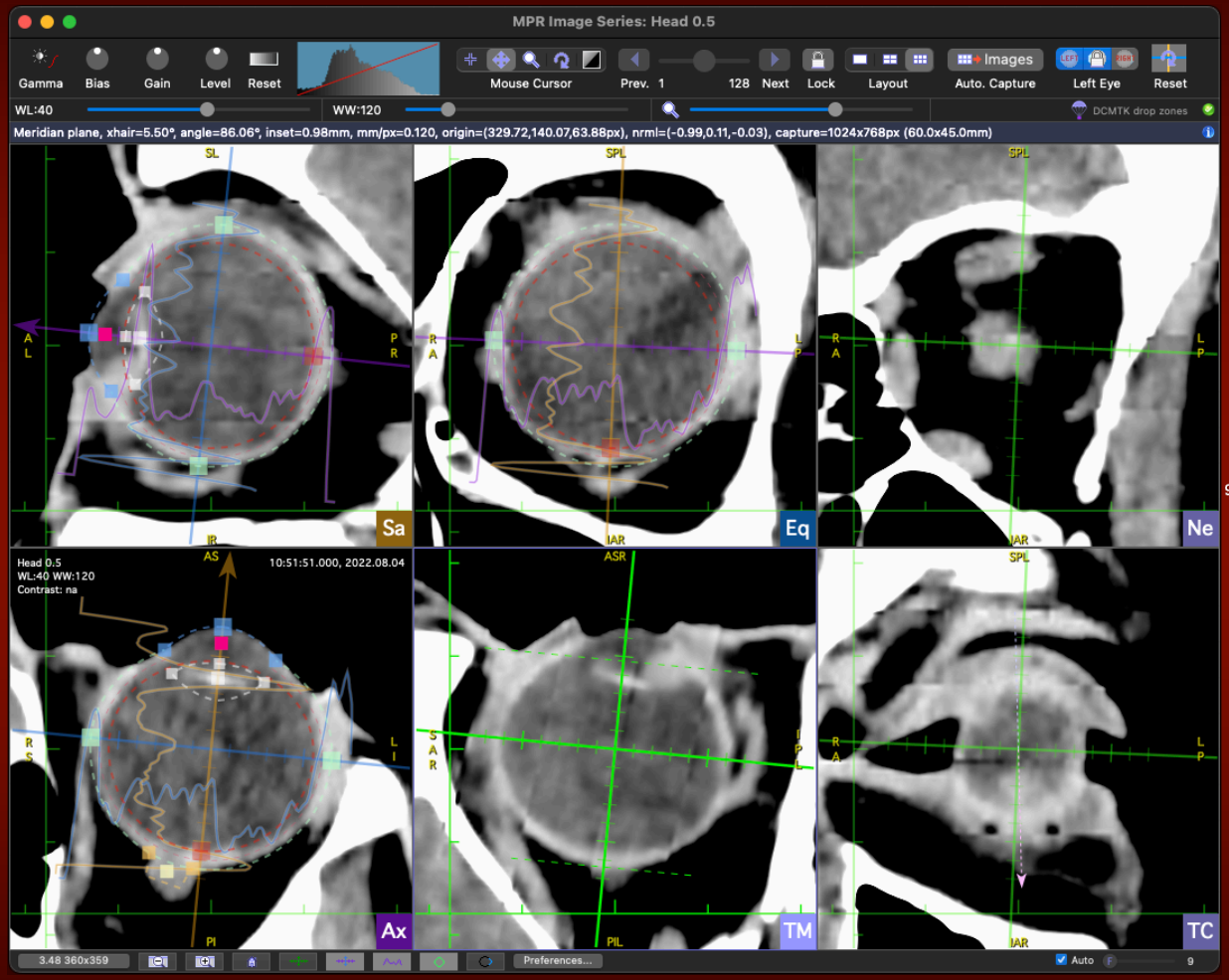


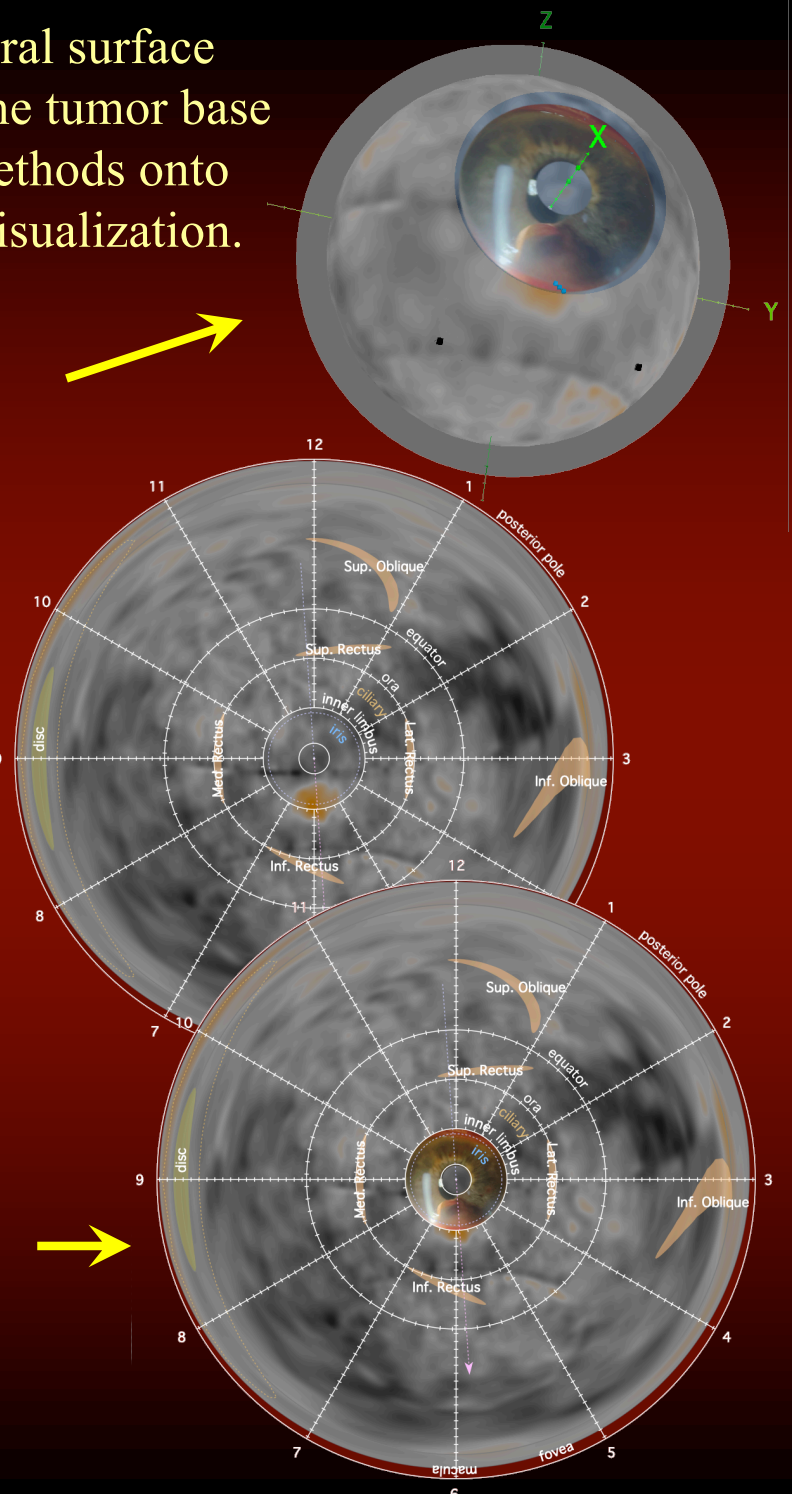


This tumor is centered a bit anterior to the equator and extends to the limbus. Its tall apex optically shadows the posterior of the eye giving the photographic impression that its base extends a bit more posteriorly than it actually does.

USC

Oblate-spheroidal reconstruction of the inner scleral surface from CT (or MRI) enables mapping portions of the tumor base located too anteriorly to photograph by optical methods onto the azimuthal equidistant projection and for 3D visualization.





This is an example of an iris tumor photograph and spheroidal surface reconstruction mapped to an anterior centric azimuthal equidistant projection.

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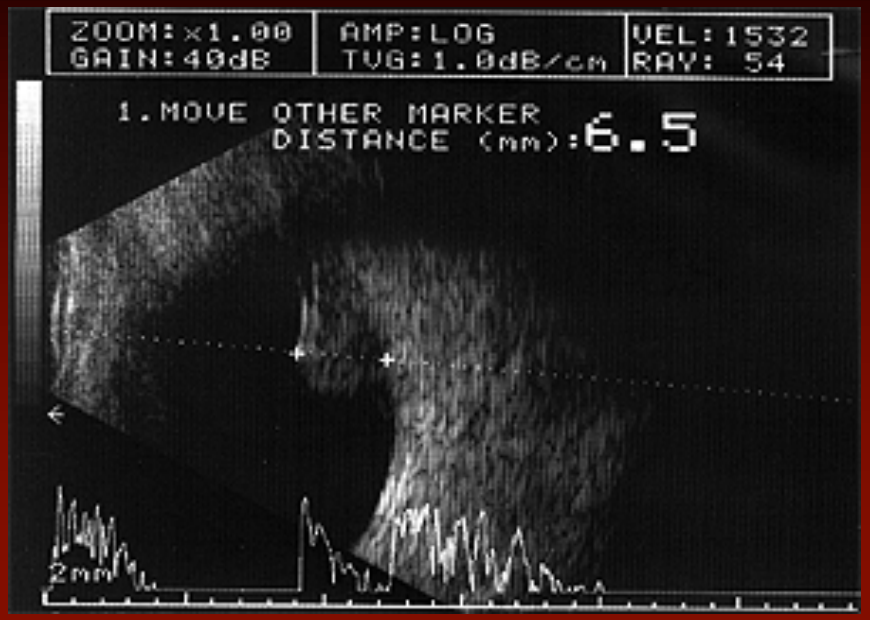
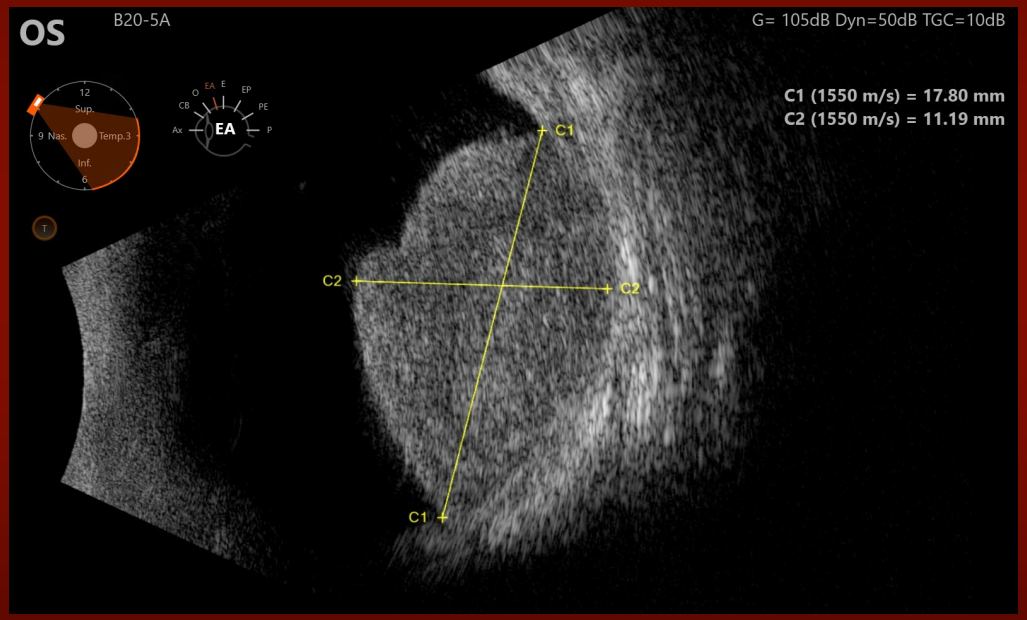
Ultrasound B-scan measurements help to measure the size and shape of the tumor and further refine the 3D computer model.



Ultrasound and 3D model circa 1992



Ultrasound circa 2020s

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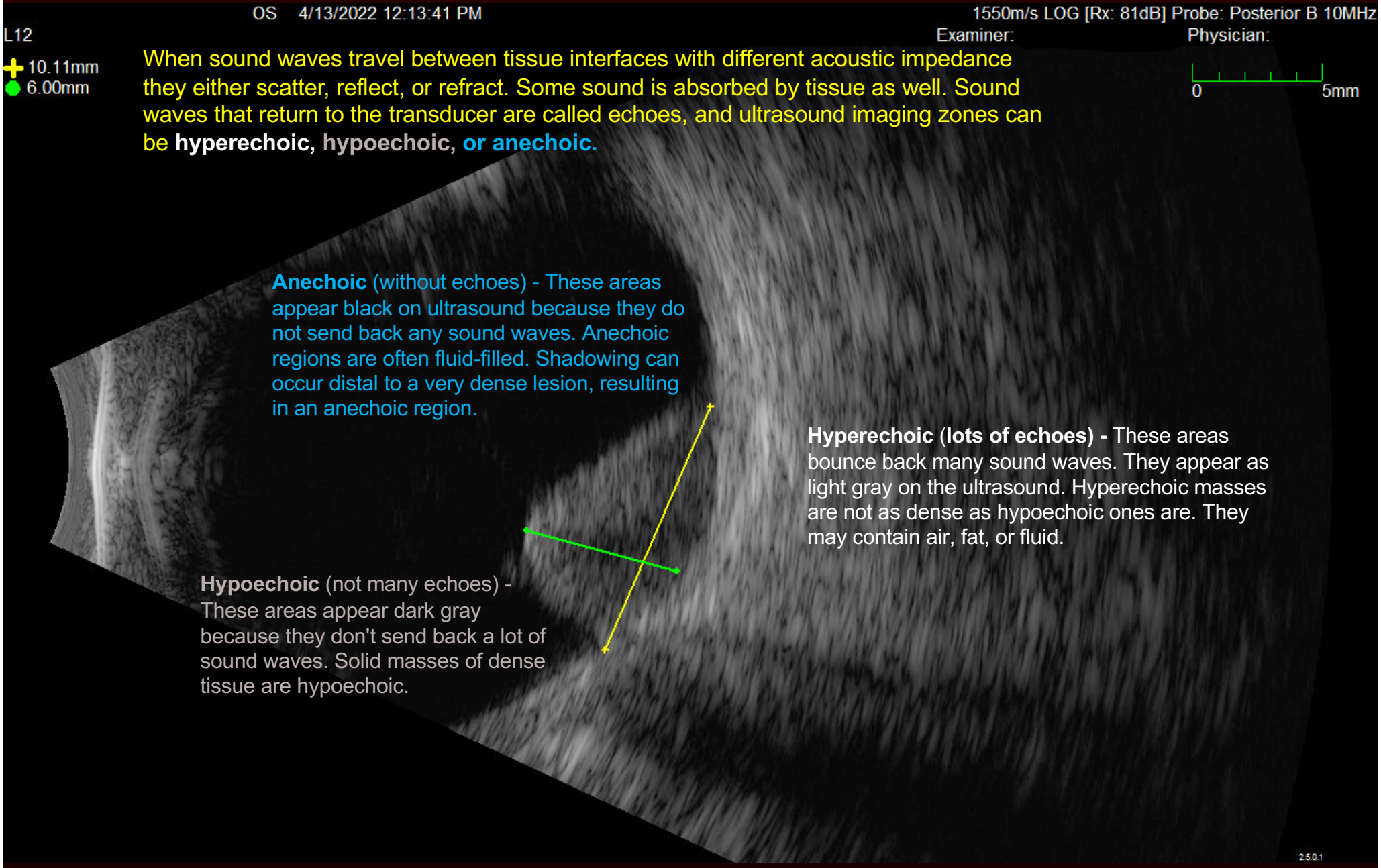
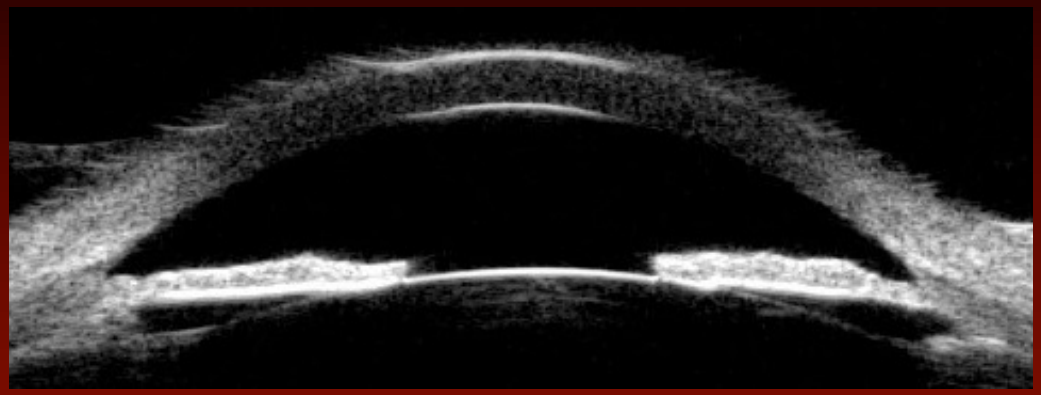
Ultrasound B-scan measurements.

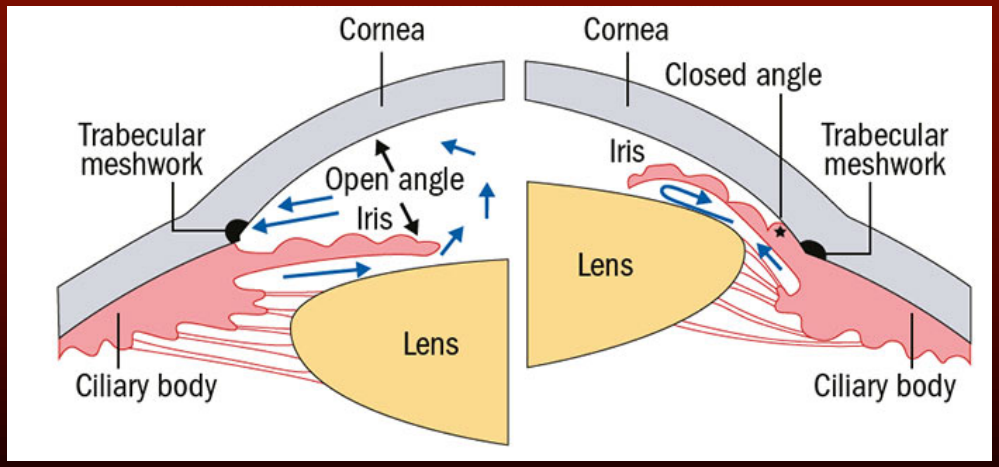


Other ultrasound measurements.

Ultrasound Biomicroscopy (UBM) is a technique primarily used for imaging of the anterior segment (AS) of the eye. Compared to regular ultrasound modalities such as A-scan or B-scan (10 MHz), UBM uses a much higher frequency transducer (35-100 MHz). UBM can be used for imaging much of the anatomy of the anterior segment, as well as associated pathologies such as angle closure glaucoma, ciliary body cysts, and cancers.



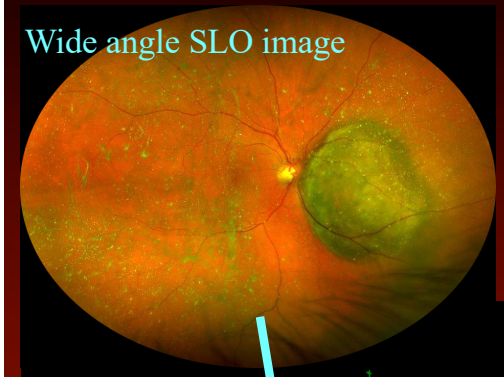
UBM is particularly important in the diagnosis and management of ocular surface tumors. It can improve detection of invasion to adjacent structure since it is able to identify the posterior margin identification, even in densely pigmented tumors or cases with corneal opacities in anterior chamber tumors.

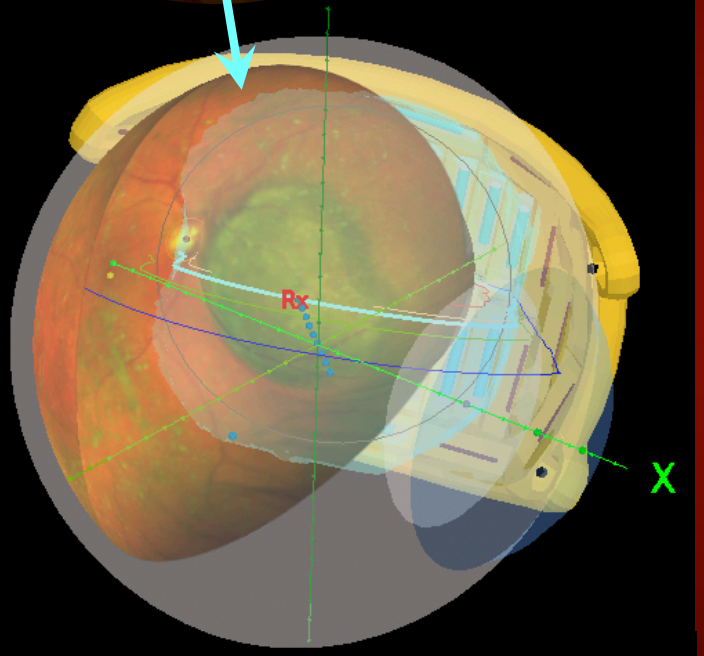


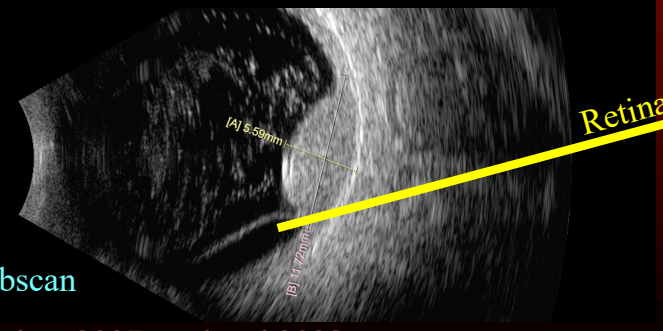
A schematic diagram of the anterior eye in open angle (left) and closed angle (right) showing how the displacement of the lens and the iris obstructs the fluid outflow across the Trabecular meshwork in the case of closed angle glaucoma.

Sometimes, CT imaging can be misleading…

Wide angle SLO image

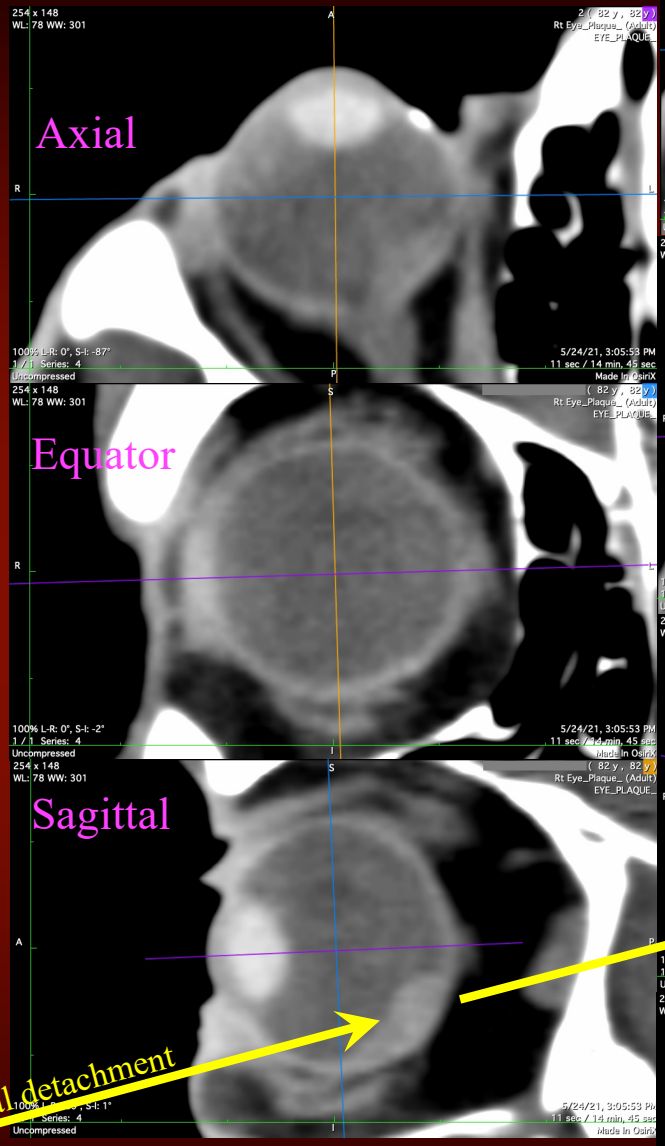


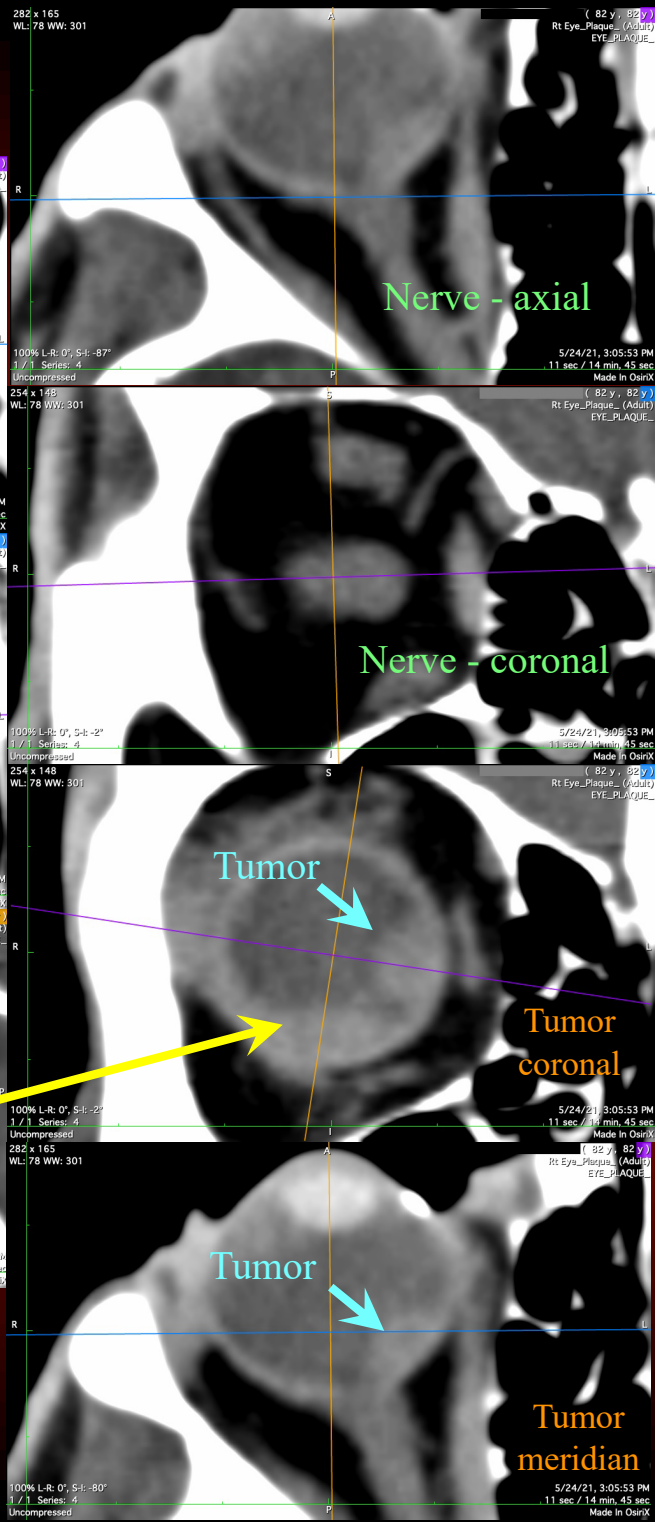




US bscan

Retinal detachment





Retinal detachment looks very much like tumor in CT.

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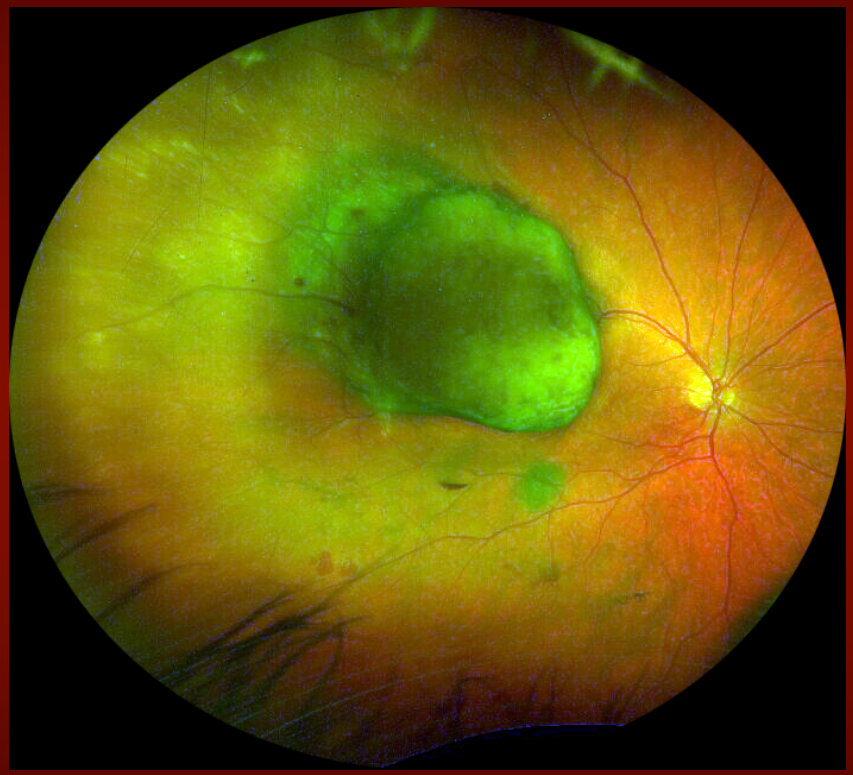
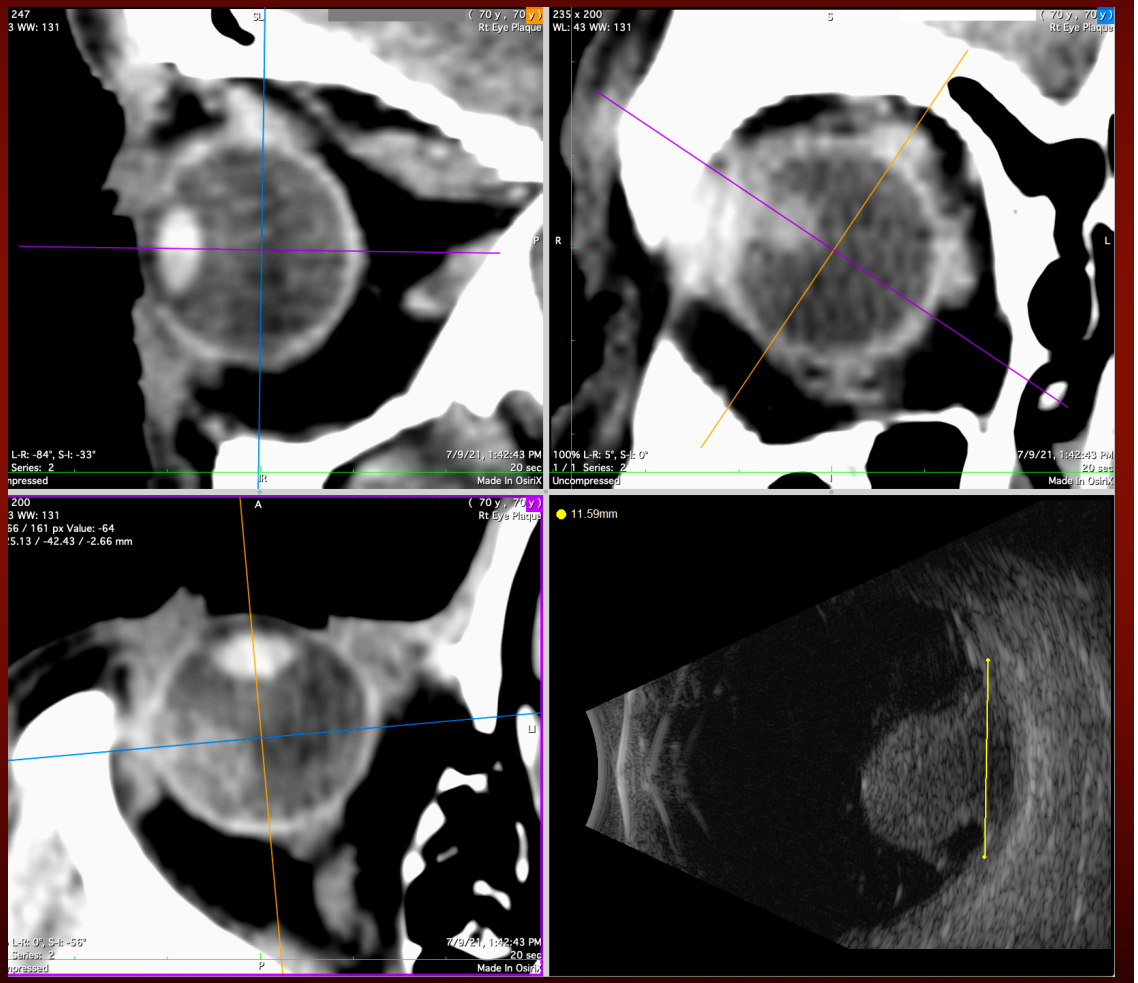
Sometimes, fundus photography can be misleading…

At first glance, this SLO image appears to be of a posterior tumor that extends to the fovea.



In actuality, this is a “mushroom” shaped tumor, whose apex is optically overshadowing the posterior of the eye.



Planar reconstructions of 3D-CT and ultrasound b-scans help to resolve these optical “illusions” that result from the spherical geometry of the eye.

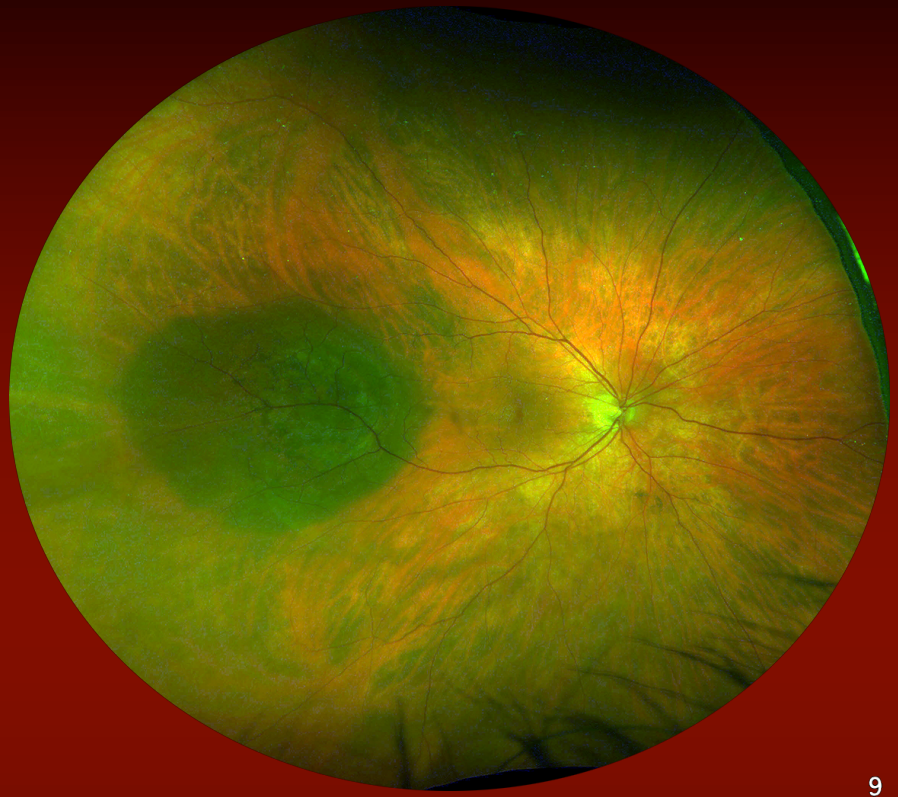
USC

Build a 3D model of the eye using CT (or MR) reconstructions and Ultrasound images

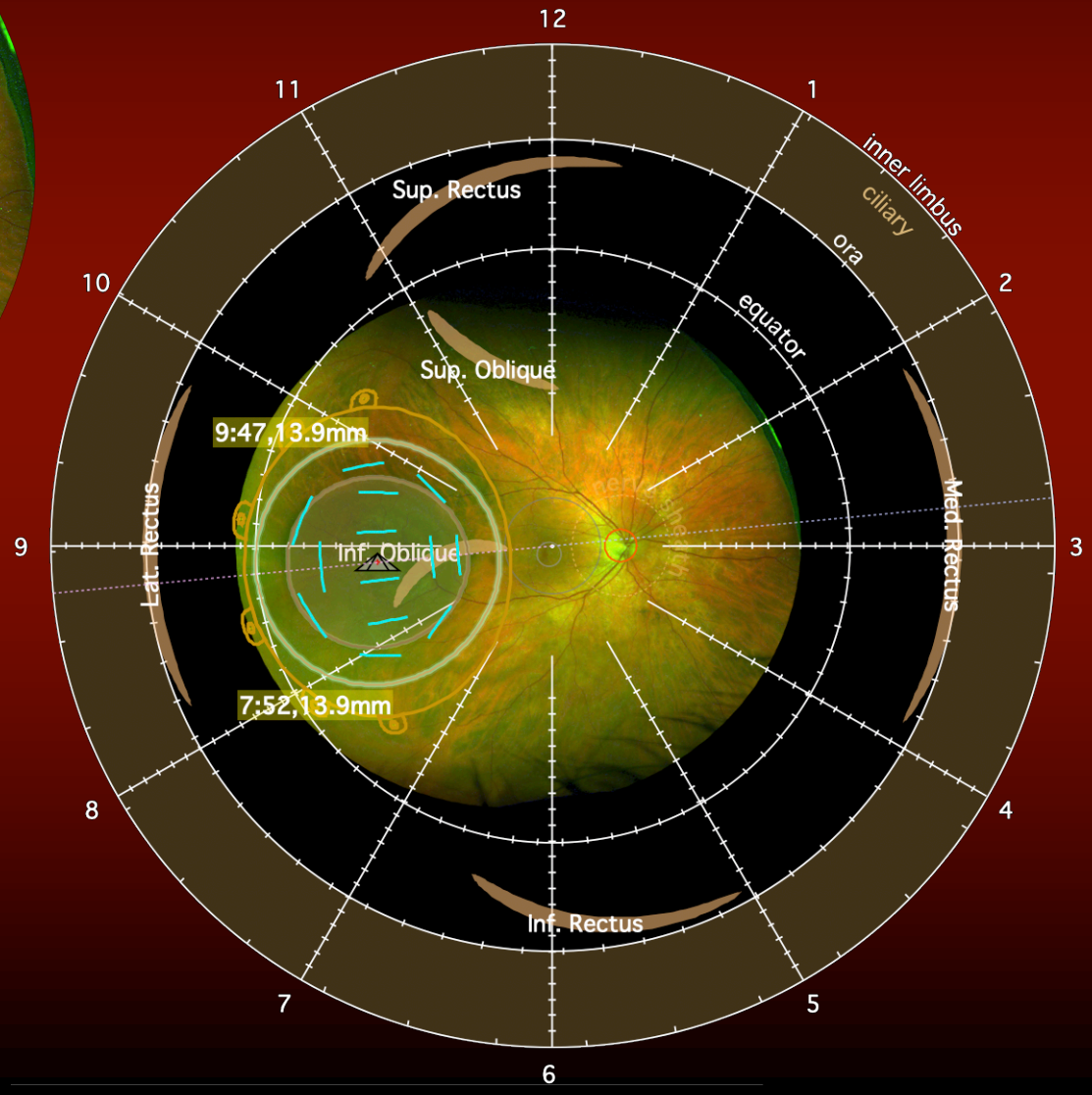
Locate the tumor base using fundus photography

Choose a plaque and calculate suture coordinates on the eye

Why calculate suture coordinates on the eye prior to surgery?



This 3 mm tall tumor has an 11 x 9 mm base and is centered posterior to the equator of a right eye at about 9 o'clock.

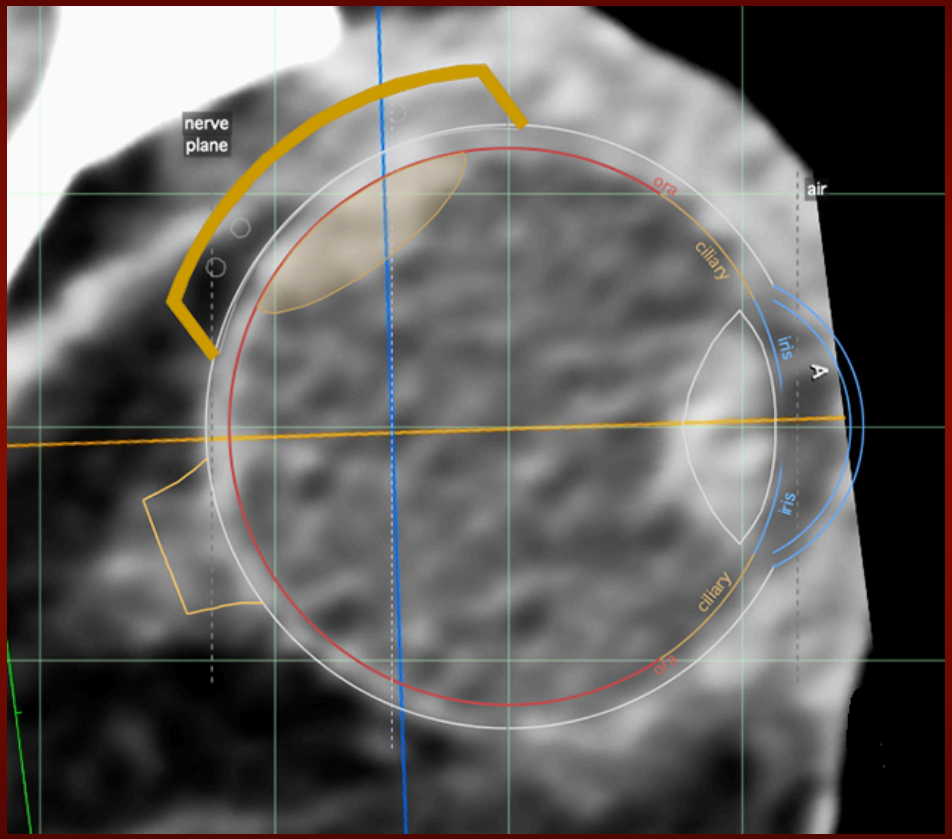


According to the COMS planning protocol we would add 4 mm to the largest tumor diameter and choose a COMS 16 mm plaque.

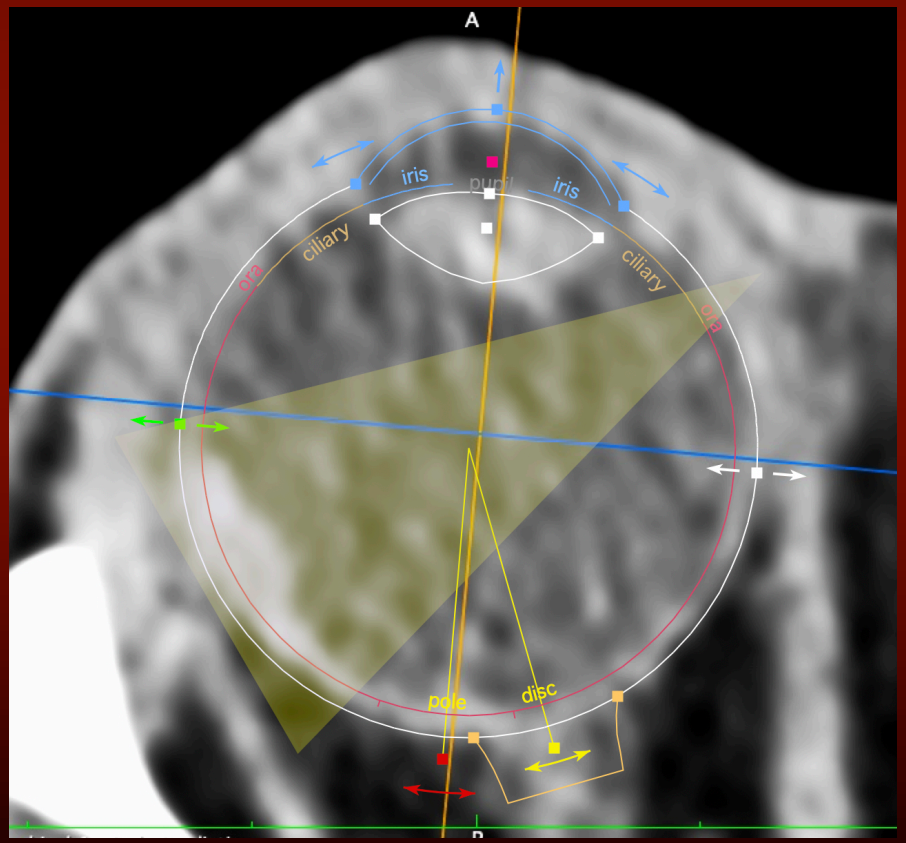
The tumor, plaque and its 4 most anterior suture eyelets lie directly under the lateral rectus muscle.

If we don't know the suture coordinates prior to surgery, the lateral rectus muscle might have to be detached because…

(1) thicker plaques (e.g. COMS models are 2.8 to 4 mm thick) may be difficult to fit under muscles, and…



(2) the muscle may obscure viewing a shadow cast by transillumination of the tumor that is required to determine where to put the plaque.



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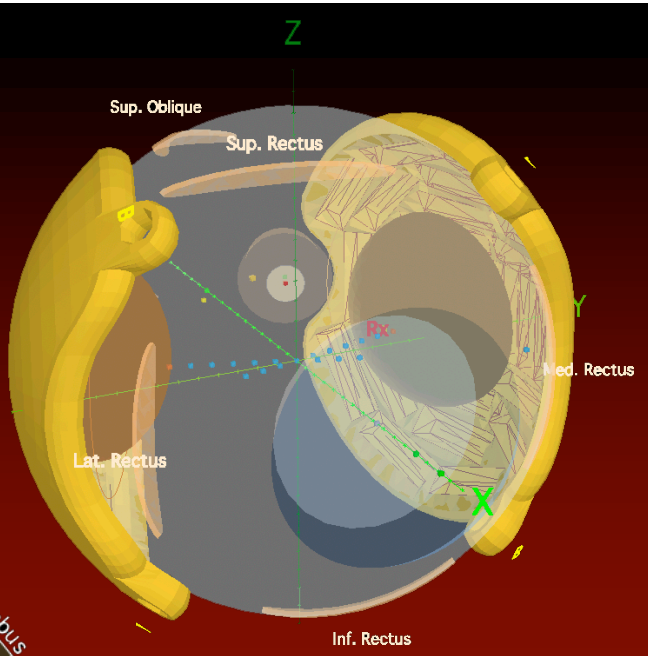
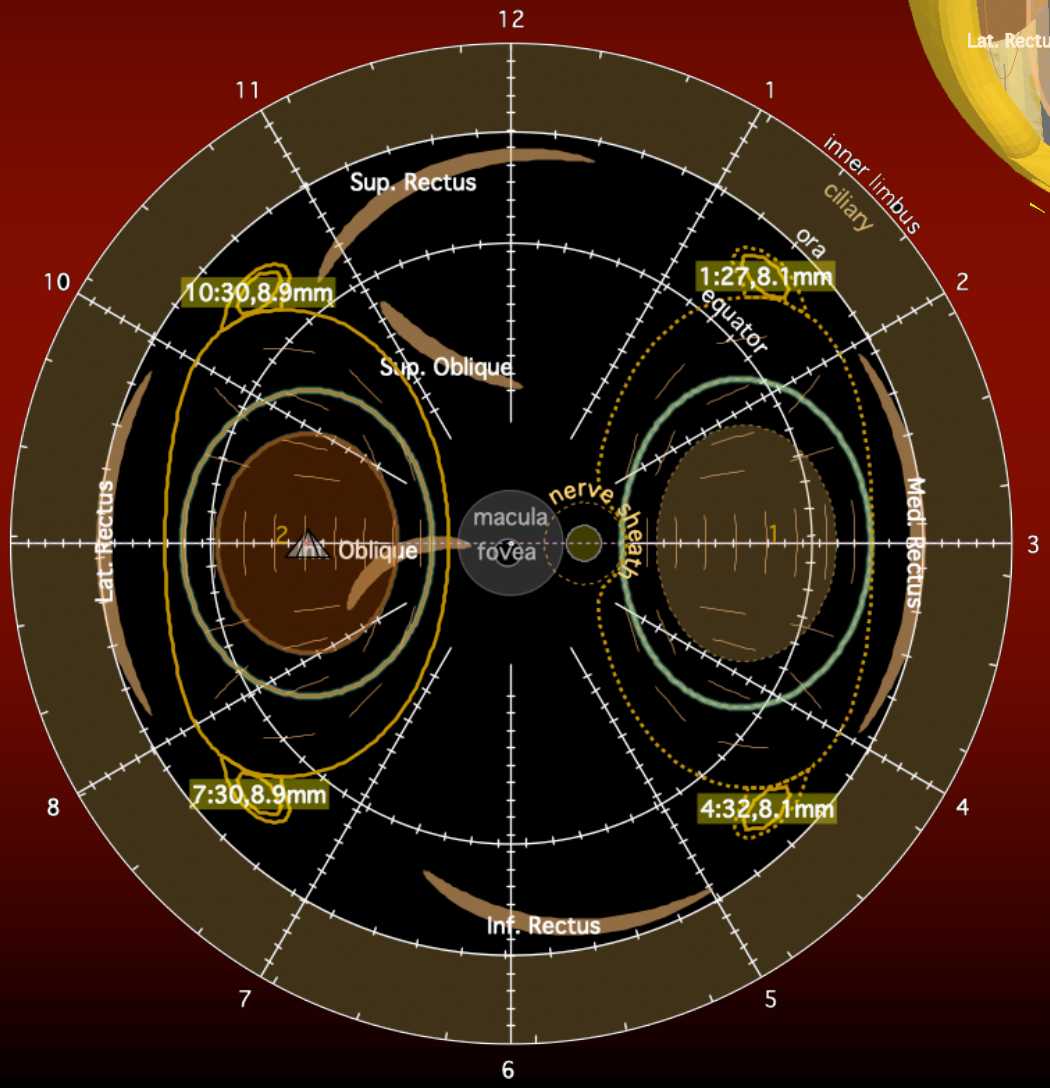
However… given the ability to model suture coordinates prior to surgery, we may be able to avoid detaching the lateral rectus muscle via judicious plaque selection.



For example, the model EP2027 is a 1.5 mm thick plaque designed to slide under the lateral rectus muscle and suture in the gaps between muscles.



The model EP2026 is a 1.5 mm thick plaque designed to slide under the medial rectus muscle and suture in the gaps between muscles

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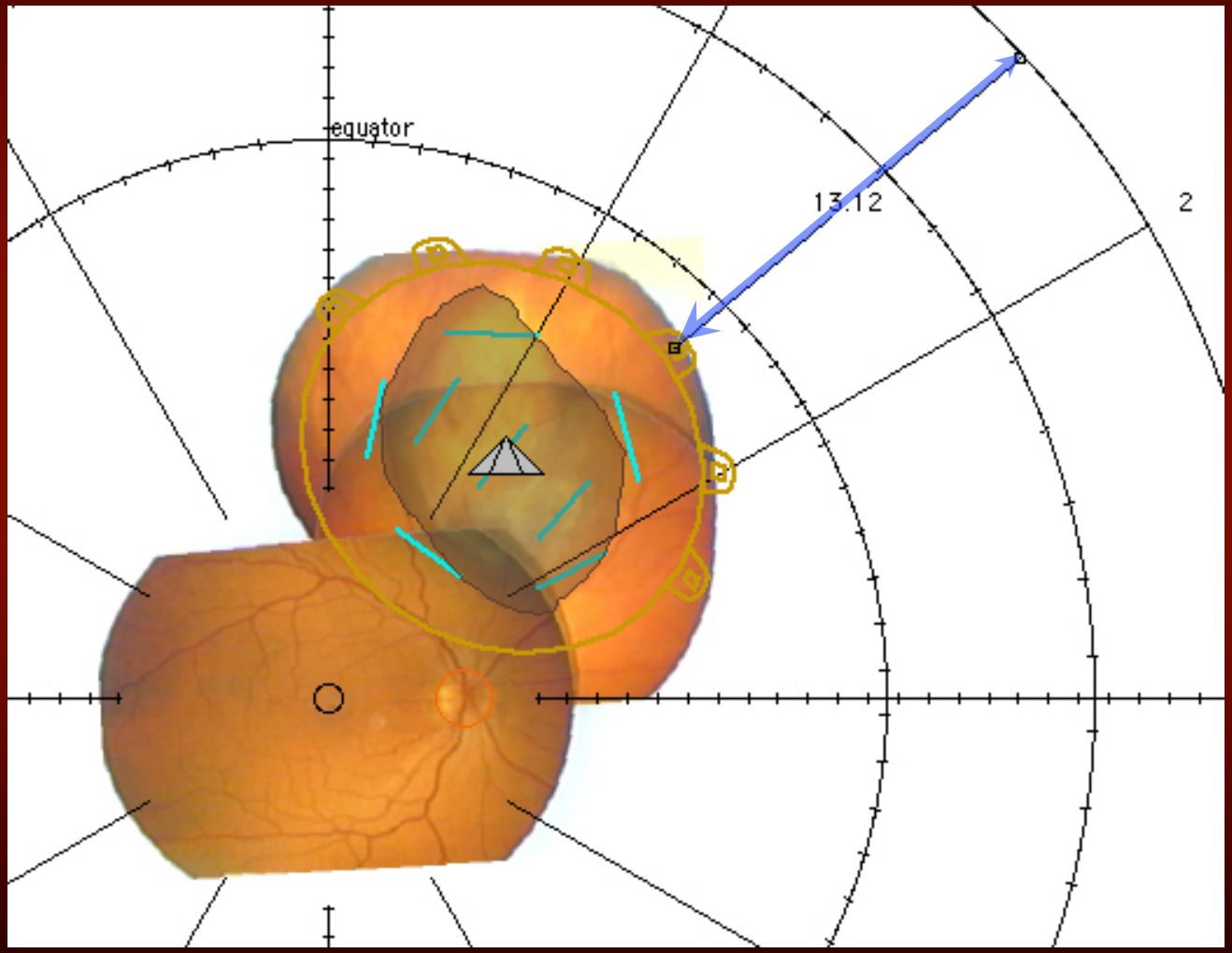
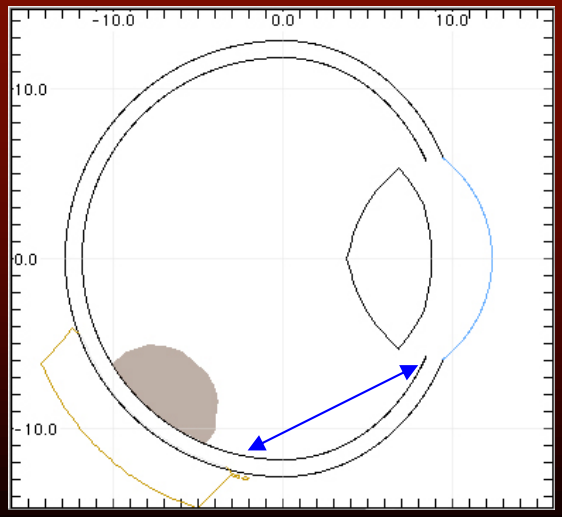
Because the thickness of the sclera is about 1 mm, the 3D model of the plaque and its suture eyelets can be projected onto the retinal diagram with only slight distortion.



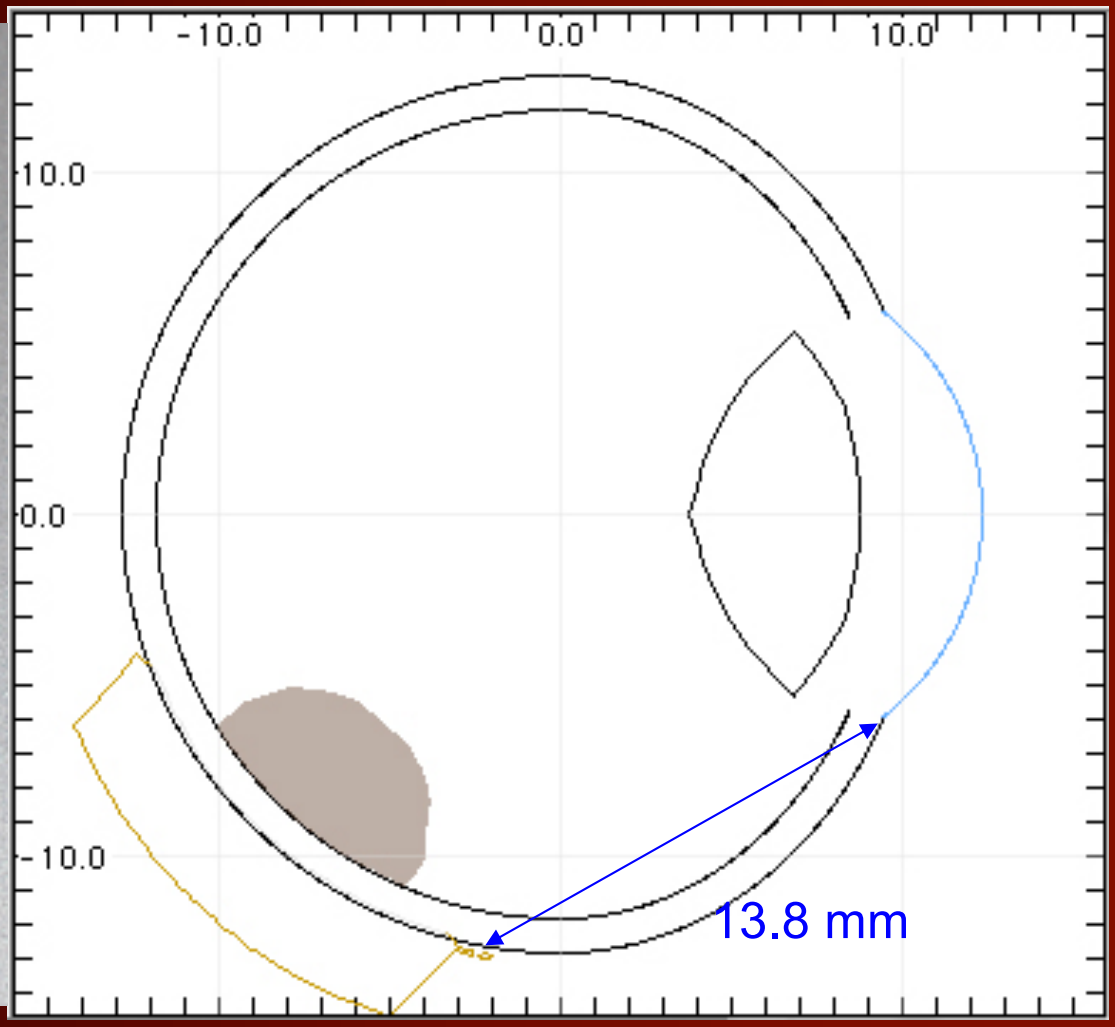
The size and location of the plaque and its eyelets are determined by dosimetric considerations. The number of suture eyelets varies with plaque design.

This suture eyelet has coordinates of 1:30 o'clock on the retinal diagram and is 13.12 mm from the inner limbus. (plots circa 1992)



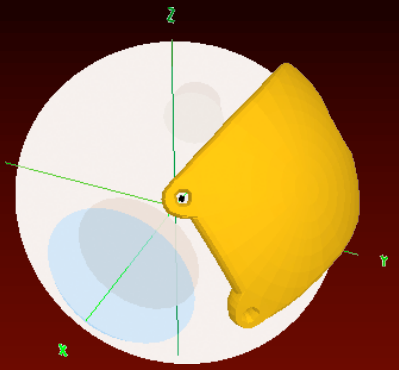
When measured on the external sclera the distance from the limbus to a point under the suture eyelet is 13.8 mm. This is the distance the surgeon can most easily measure. The clock hour is the same as noted on the retinal diagram.

So the final surgical coordinates for this particular eyelet are 1:30 o'clock and 13.8 mm from the limbus.



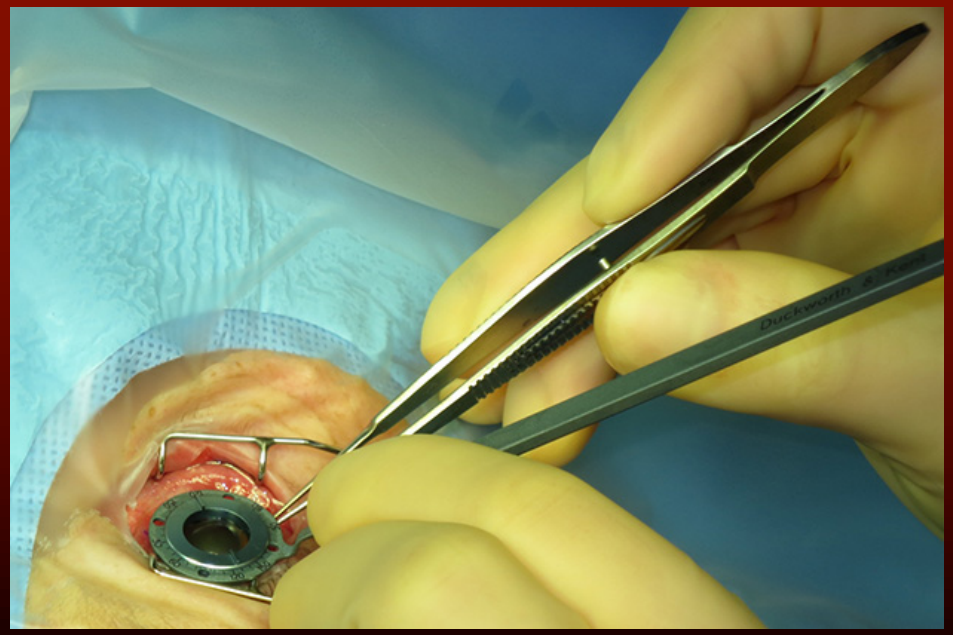
USC

Calculate suture coordinates
for example
1:00 and 2:30 o'clock



Toric axis marker

convert clock hours to toric angles



Mark coordinates on eye

Position plaque

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Benefits of 3D modeling and calculating suture eyelet coordinates:

(1) The entire base of equatorial and anterior tumors can be mapped using a combination of fundus photography and oblate-spherical reconstruction from CT.

(2) Casting a shadow of the tumor using transillumination to determine plaque location only at the time of surgery becomes redundant.

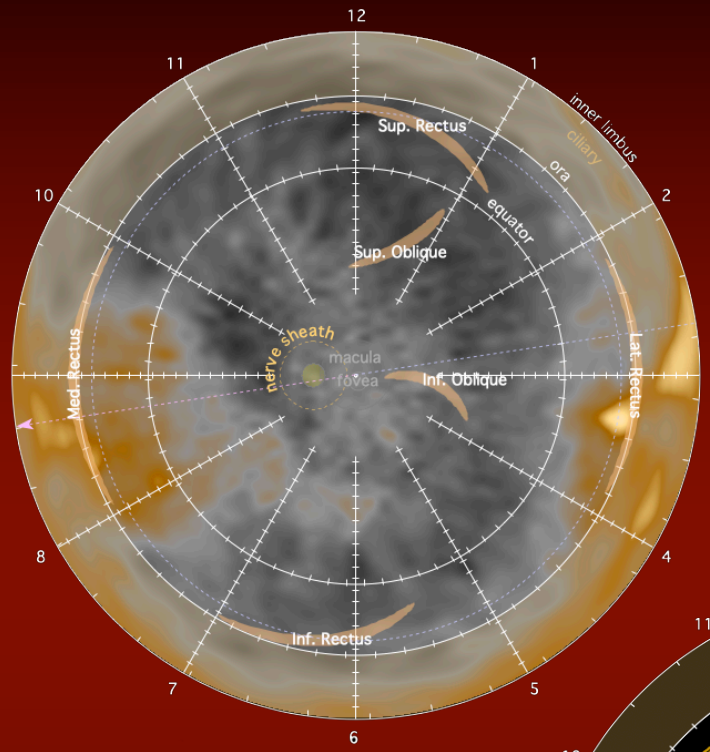
(3) Detaching muscles can sometimes be avoided via judicious plaque selection.

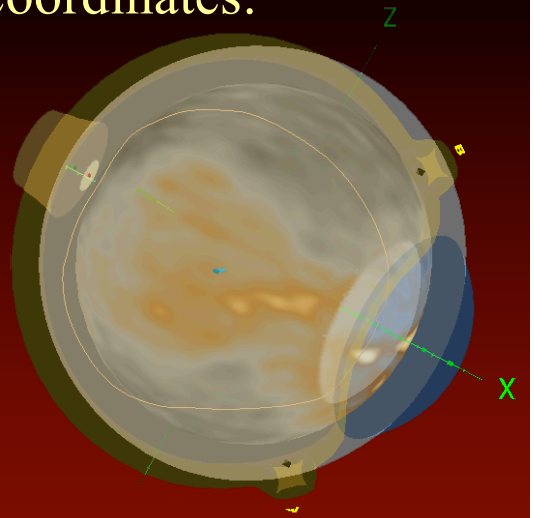
(4) The location and angular orientation of every radionuclide source with respect to the suture coordinates is modeled.

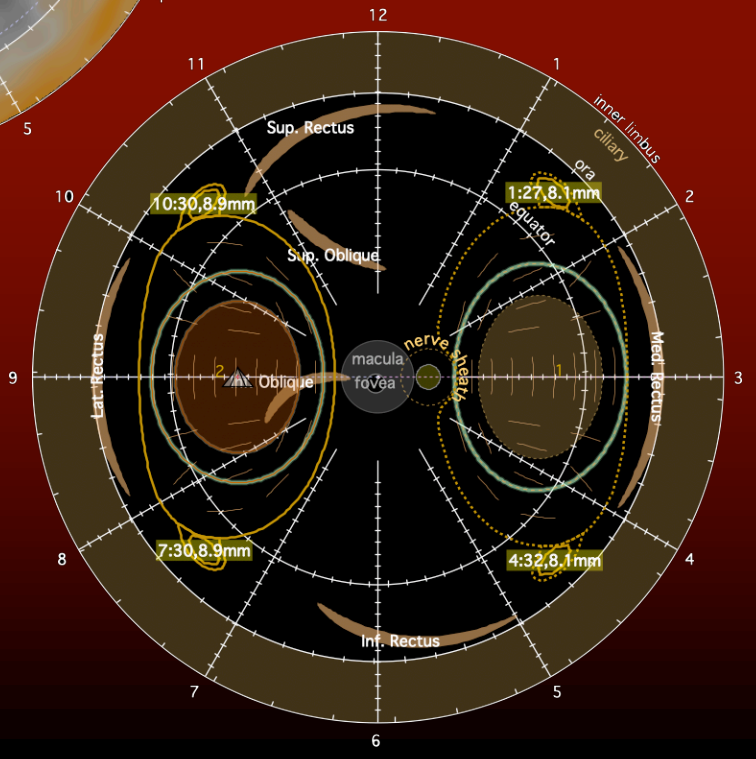
(5) We can optionally load only those source positions that conform to the tumor base and PTV margin.

(6) We can assure dosimetric coverage of the tumor and reduce the dose to critical sites such as nerve and fovea by way of intensity modulation resulting from source anisotopy, collimation and strength.

(7) Dose to critical ocular regions such as nerve and macula can be calculated accurately for dose-response studies.







Astrahan 2007, updated 2023