The early history of glaucoma: the glaucous eye (800 BC to 1050 AD)

Abstract: To the ancient Greeks, glaukos occasionally described diseased eyes, but more typically described healthy irides, which were glaucous (light blue, gray, or green). During the Hippocratic period, a pathologic glaukos pupil indicated a media opacity that was not dark. Although not emphasized by present-day ophthalmologists, the pupil in acute angle closure may appear somewhat green, as the mid-dilated pupil exposes the cataractous lens. The ancient Greeks would probably have described a (normal) green iris or (diseased) green pupil as glaukos. During the early Common Era, eye pain, a glaucous hue, pupil irregularities, and absence of light perception indicated a poor prognosis with couching. Galen associated the glaucous hue with a large, anterior, or hard crystalline lens. Medieval Arabic authors translated glaukos as zarqaa, which also commonly described light irides. Ibn Sina (otherwise known as Avicenna) wrote that the zarqaa hue could occur due to anterior prominence of the lens and could occur in an acquired manner. The disease defined by the glaucous pupil in antiquity is ultimately indeterminate, as the complete syndrome of acute angle closure was not described. Nonetheless, it is intriguing that the glaucous pupil connoted a poor prognosis, and came to be associated with a large, anterior, or hard crystalline lens.

Keywords: glaucoma, history of ophthalmology, couching

Introduction

The early history of glaucoma contains a number of mysteries. To the ancient Greeks, glaucoma described the appearance of the pupil, but historians have debated whether the term meant blue, gray, green, or gleaming. Which color was seen in antiquity? What pathology produced this appearance? Glaucoma became defined in antiquity and the Middle Ages as a disorder of the crystalline lens. How did the term evolve to represent an optic neuropathy associated with ocular hypertension?

Angle closure

Given that glaucoma came to be defined in antiquity as a disease of the crystalline lens, we hypothesized that its early history might be related to angle closure. Today, it is understood that the lens causes angle closure by inducing pupillary block. Angle closure is one of the more common causes of visual loss from glaucoma worldwide, and affects 0.4% of those with European ancestry over the age of 40 years, with higher prevalence rates in Asia. Angle closure must have occurred in antiquity, and its dramatic presentation would likely have caught the attention of medical writers. We reviewed early descriptions of glaucoma for findings consistent with angle closure: 1) loss of vision; 2) a swollen lens, anteriorly located; 3) a dilated, fixed, or irregular iris; 4) incurability, or at least difficulty in cure (which today would be understood as an optic neuropathy secondary to ocular hypertension); or 5) a glaucous (light blue, gray, or green) pupil (glaukos, the Arabic word zarqaa).
The last criterion, the presence of a glaucous pupillary hue, may surprise the reader. Examination of pupillary hue is simply not part of present-day ophthalmic training for the evaluation of angle closure. We have better tools, including ophthalmoscopy, slit lamp biomicroscopy, gonioscopy, and tonometry. But many early descriptions of glaucoma reported a greenish hue to the pupil. Historians have not agreed on the explanation for this green color. It has been suggested that examination with candle light was responsible. An alternative explanation involves deposition of “blood pigments” in the lens epithelium following intraocular hemorrhage. We propose that angle closure glaucoma might explain many cases of the green pupil, as seen in photographs of this disorder (Figures 1–4). The green color is seen due to the mid-dilated pupil exposing the cataractous lens. The lessening of the greenish hue with lowering of the intraocular pressure suggests a contribution from other factors, such as corneal edema.

The evolution of color terms
In antiquity, glaucoma was defined by the pupillary hue called glaukos. Could glaukos describe green objects? Studies on the evolution of color terms in language offer useful insights. Hugo Magnus, a 19th Century German ophthalmologist, provided missionaries, colonial officials, and other travelers with standardized color chips and a questionnaire to learn the color names used by 61 indigenous peoples from every inhabited continent. Magnus concluded in 1880:

Linguistic expressions for long wave colors are always much more sharply defined than those for short wave colors ... The most usual mixing is that of green with blue ... it often occurs that the colors of shorter wavelength are united with

the linguistic concept of dark or indefinite. Blue and violet (and even green) are designated black or grey.

Berlin and Kay have noted that “there appears to be a fixed sequence of evolutionary stages through which a language must pass as its basic color vocabulary increases”. In general, terms for white, black, and red precede the introduction of terms for (and distinction of) green, yellow, and blue. According to some scholars of English, blue was used more expansively and encroached upon its spectral neighbors violet and green until the 18th Century. Thus, it is reasonable to suspect that the ancient Greek term glaukos might have encompassed blue, gray, and green.

Application of color terms to the eye
Moreover, existing color terms were not always applied to the eye. For example, we reviewed every use of the term “eye(s)” in the King James translation of the Bible, first completed in 1611.
We conclude that this translation reflects the most advanced stage of color language evolution, according to the system of Berlin and Kay. Nonetheless, throughout the text, eyes are described as bright or dark without mentioning specific hues (eg, Zechariah 11:17, Matthew 6:22, 1 Corinthians 15:52).

In present-day English books, when an eye color is described, the color is specified as green about 12% of the time. Thus, the present-day reader might find it implausible that a culture could fail to agree that an eye color resembles the color of green leafy plants. But this comparison appears to be a relatively recent event in English as well. Using computerized searches, we previously reported that eyes were not typically described as green or brown before 1840. English speakers were generally content to describe eyes as “bright” or “blue”, or else “dark” or “black”. Of course, Shakespeare wrote of “greene-eyed ielousie” in The Merchant of Venice and of “the greene eyd monster” when describing jealousy in Othello. Despite these metaphors, it was unusual for the early 19th century writers to describe eye color as literally green. For example, in 1822, the reviewer of a novel which described a dwarf as having “large, green, goggle eyes”, noted,

… we endeavoured, for some moments, to conceive what like a green eye might be; and we had almost decided that the author had given this colour to the Dwarf’s eyes, merely to distinguish them from the eyes of all other mortals.

Similarly, the Greeks had terms for the color of green plants, such as χλωρός (kloros), used by Homer. In addition, prasinos, the color of the leek, was used by Aristotle and is the present-day Greek term for green. Yet our review of hundreds of ancient color descriptions shows that the Greeks did not describe eyes as prasinos or kloros. With respect to an eye disease affecting the elderly, the Greeks might have had a logical reason to avoid using the term kloros. They strongly associated old age and disease with dryness, and youth and vitality with moisture. Kloros, the color of lush vegetation, represented moisture and therefore, youth. Similarly, in Latin, viridis for the green of vegetation, was not used to describe eye color.

The ancient Greek author describing a green eye would likely use the term glaukos. The primary alternative would be “glassy”. Indeed, the eye and its structures were occasionally compared with the color of glass. The vitreous humor (hyaloïdes in Greek) is so named because it was thought to resemble glass. Nonetheless, the Latin vitreus, as a general color term, is typically interpreted as a greenish hue. The reason is that ancient or Roman glass was often green, due to contamination by iron. Sometimes, glass was blue-green, blue, amber, or other colors, depending on contaminants and additives. The glaucous and glassy hues overlapped. In the 1st Century AD, a glass bottle was described as γλαυκής (glaukes). Apsyrtos of Bithynia (fl 3rd Century AD), wrote (Apud Hippocrates Berolinensis 11.1),

When γλαύσκαμα [glaucoma] occurs, lancing is useless because [the disease] is incurable. It is a result of a so-called glazing of the eye (νάγλωσα, [hyaloma, glassy disease]) rather like a λάκι (leuke) pebble.

Nonetheless, comparison of eye appearance with glass was infrequent.

**Objects described as glaukos**

In summary, glaukos might have included green and might have been applied to the eyes, despite the availability of other green color terms. But what do we learn from a direct analysis of the term glaukos? In the Iliad, Homer (fl 7th or 8th Century BC) repeatedly described the goddess Athena as γλαυκόπις (glaukopis), and described the sea as γλαυκή (glauke). Maxwell-Stuart has prepared a 254-page compendium of hundreds of uses of glaukos and related terms by 120 Greek authors between Homer and the 5th Century of the Common Era. We quantitatively analyzed these uses (Table 1). In short, the best translation for glaukos during this period might be “the color of eyes which are not dark”.

Almost 80% of prose authors used glaukos and related terms to describe eye color.

Glaukos continued to be used to describe the sea, particularly in verse (Table 1). Whether the term originated in
pre-Homeric times with the sea or with eye color is a matter of conjecture. Its predominant use to describe eye color in prose suggests that, like the color term “hazel” in English, glaukos would evoke imagery of the eye. Only about 20% of prose authors used glaukos or related terms to represent diseased eyes. Thus, the term usually described the color of a healthy eye. As it is not always clear if descriptions of animals as glaukos relate to the coat or to the eyes (Table 1), the association with the eyes may be even stronger. Only two authors (2%) used the term to describe the owl (Table 1).

Aristotle is commonly understood to have written of transformation of the infant’s eyes from “blue” to a darker color with time. In fact, he described infant eyes as γλαυκότερα (glaukotera) and γλαυκά (glauka). Given that when a newborn’s eyes do transform to a darker color, they usually start as blue or light gray, we might surmise that if an eye had appeared green in antiquity, in a healthy or diseased state, glaukos is at least a plausible descriptor.

Some have suggested that glaukos in the period of Homer suggested merely a brightness, such as glaring, with an implication regarding hue coming closer to the meaning implied in the Common Era. However, our analysis of color terminology shows no shift in usage with the Common Era, once one separates prose from verse (see Supplementary material). Moreover, although a specific range of hues was encompassed by glaukos, the term was not applied to hues indiscriminately. For instance, red objects were not described as glaukos. Of course, these data cannot provide insight into the origin of the term glaukos during pre-Homeric times, whether in relation to the sea or to the eye.

### The glauous eye in the Hippocratic era

During the era of Hippocrates (c. 460-c. 370 BC), the lens was not described, and couching was not reported in Greece. However, the color of the eye was held to portend prognostic significance. Hippocrates wrote (Prorrheticon 2.20-Litré 9.48): “Pupils which have become γλαυκόπτερα [glaukoumenai] or ἄργυροείδες [argyroidees, silvery] or κυανεῖ [kyanei (the cognate of cyan)] are useless”.

Hippocrates referred to glaukos as a disease of the elderly (Aphorisms III.31.6): “To olde men doth happen... moistnesse and humidities of the bellie, eyes, and nostrills, dimnesse of the sight, Glaucoma [γλαύκωμα], and dulnesse of hearing.

The philosopher Aristotle (383-322 BC) discussed eye color in De Generatione Animalium (779a.26 to 780b.2-3). He categorized eye color as follows:

The eyes of human beings show great variety of colour; some are γλαυκοί [glauki] some χαροποί [charopoi,
The eye color was determined by the amount of water in the eye, in the same way that a shallow body of water appears bright, while a deep sea appears dark:

Clear (εὐδιόπτων, [eudipton]) sea-water appears γλαυκόν [glaukon], that which is less clear, murky (ὕδατοιδες, [hydai- todes]), and that through which one cannot see clearly because of its depth, μέλαν [melan] and καυνοιδες [kyanoides].

Aristotle observed: “The eyes of all infants are γλαυκότερα [glaukotera] immediately after they are born”.

In general, glaukos in this era likely represented a light-colored media opacity. Aristotle’s emphasis on inadequate depth of water within the eye could suggest intraocular pathology, such as cataract. A subsequent observer from the era of couching, Rufus of Ephesus, stated that what the ancients called glaukosis was simply hypochyma, defined as the structure displaced by couching. There is no reason to question this assessment, in general, although corneal edema or opacities could have been described on occasion.

The glaucous eye in the period of couching

Couching was apparently known in the Greek world in the 3rd Century BC, when Chrysippus mentioned the surgery. But in the Common Era, there are complete descriptions of couching, and of the crystalline lens. Couching was thought to remove a thickened substance which had settled in front of the crystalline lens. The Romans called this substance suffusio, the Greeks called it hypochyma, and later authors in Arabic called it ma’ (water).

Notably, the glaucous color was associated with a poor result from couching, and gradually evolved to be ascribed not with hypochyma, but with pathology of the crystalline humor. Theories of eye color related to the vitreous, the lens, or the iris. The first complete description of couching, along with a discussion of the crystalline lens, came from the Roman encyclopedist Cornelius Celsius (c 25 BC–50 AD), in De Medicina (VII.7.13-14). Eye color derived from the glass-like vitreous:

Contained in that hollow is what, from its resemblance to glass [vitri], the Greeks call hyaloides; it is humour, neither fluid nor thick, but as it were curdled, and upon its colour is dependent the colour of the pupil, whether black [niger] or steel-blue [caesius].

Indeed, many of the colors of Roman glass (green, blue, amber) do resemble various shades of iris color.

The word caesius, describing a light-colored eye, usually in people, was often the Latin translation of glaukos, and in fact, was used to describe the goddess Minerva, the Roman counterpart to Athena. Caesius eyes have been described in translation as blue, gray, and occasionally green.

Celsius also described couching, which he believed displaced a pathologic fluid (suffusio), which had hardened anterior to the crystalline humor. Celsius believed the crystalline humor was the seat of vision, ie, the essential receptive organ. He described factors which predicted the outcome of couching:

… a humour forms underneath the two tunics … and this as it gradually hardens [indurescens] is an obstacle to the visual power within. And there are several species of this lesion; some curable, some which do not admit of treatment. For there is hope if the cataract [suffusio] is small, … if it has also the colour of sea water [marinae aquae] or of glinting steel [ferri nitentis], and if at the side there persists some sensation to a flash of light. If large, if the black part of the eye has lost its natural configuration and is changed to another form, if the colour of the suffusion is sky blue [caeruleus] or golden [aur] … then it is scarcely ever to be remedied. Generally too the case is worse when the cataract has arisen … from severe pains in the head … And in the cataract itself, there is a certain development. Therefore we must wait until it is no longer fluid, but appears to have coalesced to some sort of hardness [duritie].

In present-day English, cerulean denotes exclusively a shade of blue, but the ancient caeruleus resembled glaukos in spectral range. Caeruleus was generally a blue or gray hue, and was used to describe eyes or the sea. Caeruleus could also describe green objects, such as plants. Compared with glaukos, caeruleus often implied a darker hue due to its association with deeper water. On the other hand, caeruleus was used to describe the lighter eyes of the Germans. Like glaukos eyes in Greece, the lighter eyes of Northern Europeans with caeruleus eyes might have negative connotations in Rome, as barbaric or uncivilized. In Celsius, then, we have the suggestion that no light perception (optic neuropathy), an irregular pupil, a glaucous-like hue, and pain are
poor prognostic indicators, but these are presented as isolated findings, rather than as part of a complete syndrome.

Demosthenes Philaletes (early 1st Century AD) wrote an influential work, Ophthalmicus, portions of which survived through subsequent authors, such as Aetius of Amida (Apud Aetium: Libri Medicinales 7.52). In Demosthenes’ work, some glaucoma is attributed to pathology of the crystalline humor.

The name glaucoma [γλαυκώμας, glaucoma] is employed in two senses. Glaucoma [Γλαύκωμας] proper is a coloration of the crystalline humor to a sea-blue [γλαυκόν, glaukon], together with a drying and hardening [θῆξις, pexis] of that structure. The other kind of glaucoma [γλαυκόκενσ, glaukoses] arises from cataract [πυρόχυματος, hypochyma-ton] formation, the exudation becoming hardest and most dry in the pupil. This latter kind is incurable.35

To the ancient Mediterranean authors, a pupil the color of the sea (eg, marinae aquae of Celsus, or θάλαςςίζει, thalassizei of Demosthenes) represented a favorable prognosis33–35 and probably implied a blue color.38

Next, we see in the writings of Rufus of Ephesus (80-150 AD) that glaucoma has become firmly associated with the crystalline lens (Fragmenta 116): “...γλαυκόματα [glaukomata] are changes in the crystalline fluid altering the influence on moisture to γλαυκόν [glaukon] ... All γλαυκόματα are incurable.”21 Glaucous was also one of the standard eye colors, which was due to the iris (Nomina Corporis, 25): “In accordance with the colour of the iris [Ipn], one says that [the eye] is μέλανα [melana, black], πυρρόν [pyrron, flame-colored, russet], γλαυκόν [glaukon] or χαροπόν [charopon, amber]”.21 Rufus’ image of a rainbow (Ipn) is the origin of the present-day anatomical term iris.36

Galen of Pergamon (c 129–199 AD) was one of the most prolific and influential ancient medical authors. His theory of eye colors was similar to that of Aristotle, in that a lesser amount of fluid in the eye resulted in a brighter hue (glaukos), while more fluid would be darker, just as is deep water. Galen added that the crystalline humor, unknown in Aristotle’s time, was itself a light source, and the glaukos hue was more likely if the crystalline was thicker, anteriorly located, or hard. This could be seen in the corneal reflection, which Galen believed to emanate from the crystalline humor. Galen wrote in Ars Medica (section 9, K.1.330) a passage also recorded by Oribasius:21,38

As far as the color [χρῶν, chroan] of the eye is concerned we have to differentiate the following: The eye will appear blue [γλαυκός, glaukos] either because of the size and the brightness of the crystalline lens or because the lens is located more anteriorly; similarly it can be due to not enough or not pure enough watery fluid in the pupil. If all these conditions are fulfilled the eye will appear in a saturated blue [γλαυκόκτατος, glaukotatos]. If some of the conditions are present but others not then the eye will demonstrate variations of blue [γλαυκόπτης, glaukoptet]. A black [Μέλας, melas] eye has either a small crystalline lens or the lens is deeply located or has incomplete brightness; it can also be due to an ample amount of aqueous fluid or because the fluid is not pure.39

In the same passage, Galen wrote that the crystalline humor contributes to the dryness of the eye if the crystalline is too hard (σκληρότερον, scleroteron) or exceeds the amount of thin liquid (aqueous).38

It is not clear that this theory explaining light-colored eyes necessarily implies a pathologic change (though that may have been intended in some instances). Elsewhere, Galen noted that the glaucous hue could be a pathologic change:

Damage to the eyes occurs when too much fluid is drawn off during couching for cataracts, and the symptom called by doctors γλαυκοφέντις [glaukosis] is a dryness and disproportionate coagulation [θῆξις, pexis] of crystalline fluid.21,40

In summary, the period of couching sees a progression of the unfavorable glaucous hue moving posteriorly to be firmly associated with the crystalline humor. In Galen’s writings, the glaucous hue is associated both with a larger, anterior, and hard crystalline humor and, elsewhere, with damage to the eyes. Celsus had noted a glaucous hue, optic neuropathy, pain, or pupil irregularities as poor prognostic indicators. Although a comprehensive description of the syndrome is lacking, it is intriguing that the glaucous hue was repeatedly described as implying a more severe type of pathology and came to be associated with the crystalline humor.

Medieval works in Arabic

During the Middle Ages, the ancient concept of glaucoma was translated into Arabic works, which were subsequently translated into Latin several centuries later. Five early authors who wrote in Arabic played important roles. Three were Christians who practiced in Baghdad:

1) Yuhanna ibn Masawaih (777–857 AD), known to later Latin writers as Mesue;41
2) Hunain Ibn Ishaq (809–877 AD), originally of Southern Mesopotamia42 and known later as Johannitus, who was the student of Masawaih but eventually eclipsed him
influence. Hunain systematically translated the ophthalmic works of Galen and other classical authors into Arabic, and Hunain’s ophthalmic treatise was widely cited;

3) Ali ibn Isa el-Kahhal (c 940–1010 AD), a dedicated oculist, known later as Jesu Hali, identified with anterior prominence of the lens and could occur in an acquired (pathologic) manner.\(^{44,47,50,52}\)

The Arabic works contain unambiguous comparisons of eye color, at least in a diseased state, to the color of green plants (\textit{akhdar}).\(^{53}\) Specifically, cataracts were described as green (\textit{akhdar}).\(^{42–44,47,52}\) Avicenna recorded that green (\textit{akhdar}), yellow, gypsum, and black cataracts did not improve with couching.\(^{50}\)

### Solidification of intraocular fluids and palpation of the eye

Both \textit{hypochyma} (\textit{suffusio, ma}) and glaucoma were thought to be due to a hardening or thickening of an intraocular humor (liquid). This process of hardening of the \textit{hypochyma} was described by the Greeks as \(\pi\varepsilon\varepsilon\zeta\zeta\zeta\) (\textit{pexis}).\(^{25}\)

In its first sense, \textit{pexis} refers to “a fixing, fastening, joining, cementing”,\(^{54}\) and is the root of the suffix \textit{pexy}, as in “retinal cryopexy”.\(^{16}\) Here, \textit{pexis} is used in its second sense as “coagulation, curdling, congelation, hardening”.\(^{54}\)

Celsius stated that couching should not be performed until the \textit{suffusio} had matured, or become adequately hard (\textit{duritie}). He did not specify how this hardening would be checked.

Later, Ibn Isa (Jesu Hali) made explicit that determination of cataract maturity required palpation of the eye.

Press his eyelid with your thumb ... then open the eye and note the position of the cataract. In case it is not sufficiently matured or consolidated there will seem to be variations in its apparent breath and shape.\(^{43,45}\)

Although not previously emphasized by historians, Ibn Sina (Avicenna) came to the opposite conclusion as Ibn Isa (Jesu Hali): the cataracts which were immobile during palpation due to hardening were less suitable for surgery.\(^{47,50,52}\)

Nonetheless, these authors agreed that one could evaluate the hardness of an intraocular humor by examination of its movement during ocular palpation.

Glaucoma, in the writings of Demosthenes and Galen,\(^{30}\) was also believed to involve hardening (\textit{pexis}), in this case of the crystalline humor. Galen also used the term \(\sigma\zeta\lambda\pi\rho\omicron\omicron\omicron\zeta\nu\nu\omicron\) (\textit{scleroteron}) to describe the hardening of the crystalline. Perhaps by analogy with \textit{hypochyma} (\textit{suffusio, ma}), it was inevitable that palpation of the eye would eventually be proposed for the evaluation of glaucoma. However, this development does not appear to have occurred until the 18th Century.
Conclusion

Descriptions of glaucoma from antiquity through the early Middle Ages suggest certain aspects consistent with angle closure. Although not emphasized by present-day ophthalmologists, angle closure often produces a greenish hue to the pupil, due to the mid-dilated pupil and prominent cataractous lens. To the Greeks, the term glaukos was most commonly used to describe healthy, light-colored irides, but was used to a lesser extent to describe pathologic ophthalmic states. If either a healthy iris or a diseased pupil had appeared green, the term glaukos would likely have been used. During the period of Hippocrates, the description of a diseased eye as glaukos indicated a media opacity that was not dark. During the early Common Era, when couching was performed in Mediterranean Europe, descriptions of glaucomatous eye disease evolved. Celsus noted optic neuropathy, pain, a glaucomatous-like hue, and pupil irregularities as poor prognostic indicators, but not as part of an integrated syndrome. Galen noted the glaucomatous hue being associated with a prominent, anterior, or hard crystalline humor, and elsewhere, with vision loss. The Arabic authors translated glaukos as zarqa, which also was commonly used to signify the color of irides that were not dark. Both the lesion displaced by couching and glaucoma were believed to result from the hardening of an intraocular humor (liquid). As the former was evaluated by ocular palpation, it is perhaps logical that glaucoma would eventually be evaluated in a similar manner.

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