Vol 20 No 1, p 71-77

SCHEMATIC EYE OF THE ADULT ARABIAN CAMEL (*Camelus dromedarius*)

O. El-Tookhy

Department of Surgery, Faculty of Veterinary Medicine, Cairo University, Egypt

ABSTRACT

Eye is a homocentric system of lenses, which when combined in action form a very strong system of short focal length. Schematic eye models have been constructed for human, and many animals' species but none has been published for the Arabian camel. This paper is aimed to build a schematic model of adult Arabian camel eye based on ecobiometric values of live camels and describe its visual properties. Results indicated that the total refracting power of the corneal and lens systems are 28.48D and 37.53D, respectively. The total refracting power of the whole optical system is 59.25D. The principle points ***H, H'*** are 3.46 and 4.6 mm and the nodal points, ***N, N'*** are 10.05 and 11.22 mm behind the anterior surface of the cornea. The focal points, ***F, F'*** are -13.42 and 28.09 mm and the focal lengths, ***f, f'*** are -16.88 and 23.47 mm. For the reduced eye; the average index of refraction inside the eye, ***n'***= 1.3908 and the combined total dioptric power is +66D. The principle point, and the nodal point, are located 4 mm and 10.63 mm behind the anterior surface of the cornea, respectively. The focal points ***F, F'*** are -13.42 and 28.1 mm, whereas the focal lengths ***f, f'*** are -17.46 and 24.1 mm.

Key words: Camel, cornea, lenses, refracting power, schematic eye

Investigating the eye through ocular biometry is useful for the assessment of ocular abnormalities such as phthisis bulbi, microphthalmia, pseudoexophthalmia, scleral ectasia, and congenital glaucoma (Brandão *et al,* 2007 and Potter *et al,* 2008). It also allows the calculations of intraocular lens dioptric power to be deployed in the eyes of animals that have undergone cataract surgery to achieve emmetropia (McMullen and Gilger, 2006; Zhou *et al,* 2006 and Carter *et al,* 2007). Additionally, ocular biometic values are frequently used for the construction of schematic eyes in optics (Görig *et al,* 2006).

A schematic eye is a self-consistent mathematical model of the optical system that simulate the real world performance of the eye and can be used for a range of research and development purposes. In schematic eyes model the compound optics of real eyes can be specified in terms of three cardinal points, making it possible to model paraxial ray paths and describe various optical characteristics of living eyes (Coile and O'Keefe, 1988). Schematic eyes have been designed for human, cow, horse, sheep, pig, dog, rabbit and rat (Hamidzada and Osuobeni, 1998). Efforts to design an optical model of an eye dates back to Newton's diagram of the sheep's eye around 1680s. The most widely used human schematic eye is still that of Gullstrand (1909), although more sophisticated models became available (Coile and O'Keefe, 1988).

Several papers are available that have presented quantitative information about the components of the Arabian camel optical system but to the author's knowledge it has not yet been brought together for the calculation of a schematic eye. Knowledge of the dimensions and ratios of the optical components of the camel eye will provide a resource for the theoretical study of its visual capability and drawing up a schematic eye for this animal. This paper is aimed to build a schematic eye model of the adult Arabian camel and describe its visual properties.

Materials and Methods

Steps were divided into collecting the inputs required to build the schematic model of the eye and then the calculations. Calculation of the schematic eye began with the use of thick lens theory to develop an equivalent thin lens for the cornea and for the crystalline lens. The calculation was completed when a further thin lens was derived to represent the behaviour of the whole eye by the combination of the equivalent thin corneal and crystalline lenses. The model is valid for the axial rays alone. Two eye models were developed; the schematic and the reduced one.

SEND REPRINT REQUEST TO O. EL-TOOKHY email: oeltookhy@gmail.com

Inputs for calculations

All data presented in the following pages were obtained from a previous ultrasonographic measurements conducted on the eyes of live, adult Arabian camels (El-Tookhy *et al,* 2012) unless otherwise is indicated with its corresponding reference. Optical geometrical equations in the following parts are derived from Hughes (1971) and Milton (2002).

1- Ocular tissue measurements (t):

Thickness (***t***) of different ocular structures were as follows: *Cornea* (t_1) = 0.9 mm, *Anterior chamber* = 2.35 mm, *Lens* (t_2) = 9.6 mm and *Vitreous* = 15.6 mm.

2- Index of Refraction (n):

The index of refraction for the air, cornea, aqueous humor, lens and vitreous have been given in Table 1.

Results

The calculations initially required finding the lenses equivalent to that of the corneal and lens systems based on their measurements and features (radius of curvature). Initially the schematic model was constructed then the reduced model was obtained.

I-Schematic model

I.1- Radius of Curvature (r):

The corneal tissue thickness at the centre measured 0.9 mm. The height (***h***) was calculated by measuring the depth of the anterior chamber (2.35 mm) till the corneal surface (anterior = 0.9+2.35=***3.25*** and posterior = 0.0+2.35=2.35mm) till the vertical horizontal line representing the base of the corneal-arc measured from 2 limbal points (w =16.5 mm). The formula for the radius of curvature is:

$$r = (4h^2+w^2)/8h \quad \text{.............................. (1)}$$

By applying these numbers in the above equation, the radii of curvature for the anterior, posterior cornea were ***12.096*** (***r_1***) and ***15.656*** (***r_2***), respectively.

Similarly, the radius of curvature of the lens comprises the distance from the center of lens to it's anterior and posterior surfaces (from the anterior capsule to its mid point = 6.25 mm and 3.65 mm from mid-point to the posterior capsule, and lens diameter = 15.9 mm). Using equation (1), the radius of curvature of the anterior and posterior lens were ***8.181*** (***r_3***) and ***-10.483*** (***r_4***), respectively.

I.2- Refracting power (F):

The refracting power of the anterior surface of the cornea ***F_1*** is calculated as:

$$F_1 = (n_2-n_1)/r_1 \quad \text{.............................. (2)}$$
$$= (1.3775-1)/12.096 = +\mathbf{31.21D}$$

Whereas the refracting power of posterior surface of the cornea ***F_2*** equals:

$$F_2 = (n_3-n_2)/r_2 \quad \text{.............................. (3)}$$
$$= (1.3339-1.3775)/15.656 = \mathbf{-2.78D}$$

According to Gullstrand's equation, the reduced interval (thickness, ***t***) between the two corneal surfaces ***C_1*** is:

$$C_1 = t_1/n_2 \quad \text{.............................. (4)}$$
$$= 0.9E\text{-}03/1.3775 = \mathbf{6.53^{E-4}}$$

Therefore, The total refracting power of the corneal system

$$F_3 = (F_1+F_2) - (C_1 * F_1 * F_2) \quad \text{.............................. (5)}$$
$$= (31.21-2.78) - (6.53^{E-4}*31.21*2.78) = \mathbf{28.48D}$$

Similarly, the refracting power of the anterior surface of the lens ***F_4*** is calculated as:

$$F4 = (n_4-n_3)/r_3 \quad \text{.............................. (6)}$$
$$= (1.5178-1.3339)/8.181 = 22.48D$$

Whereas the refracting power of posterior surface of the lens ***F_5*** equals:

$$F_5 = (n_5-n_4)/r_4 \quad \text{.............................. (7)}$$
$$= (1.3338-1.5178)/-10.483 = \mathbf{17.55D}$$

Using equation (4), the reduced interval between the two lens surfaces ***C_2*** is:

$$C_2 = t_2/n_4 \quad \text{.............................. (8)}$$
$$= 9.6^{E-3}/1.5178 = \mathbf{6.32^{E-3}}$$

Table 1. Summary of the refractive indices of different ocular media.

Refractive indices (n)			Calculation	Reference
Air	n1	1	–	Hamidzada & Osuobeni, 1998
Cornea	n2	1.3775	averaged value of 1.382 of cow and 1.373 of pig	Coile and O'Keefe, 1988
Aqueous	n3	1.3339	exact value of cow and pig	Coile and O'Keefe, 1988
Lens	n4	1.5178	averaged value of 1.5268 of cow and 1.5088 of pig	Coile and O'Keefe, 1988
Vitreous	n5	1.3338	averaged value of 1.3337 of cow and 1.3339 of pig	Coile and O'Keefe, 1988

Table 2. Distances from the anterior corneal vertex to different ocular points, the radii of curvature and the obtained powers of the different ocular structures.

Distance from Anterior cornea vertex to		
Posterior Cornea	t_1	0.9
Anterior Lens		3.25
Posterior Lens	d_1	12.85
Retina	d_2	28.45
Radii of curvature		**r**
Anterior Cornea	r_1	12.096
Posterior Cornea	r_2	15.656
Anterior Lens	r_3	8.181
Posterior Lens	r_4	-10.483
Powers		
Anterior Cornea	F_1	31.2087
Posterior Cornea	F_2	-2.7849
Total Cornea	F_3	28.481
Anterior Lens	F_4	22.4789
Posterior Lens	F_5	17.5522
Total Lens	F_6	37.5356
Whole Eye	F_t	59.2546

Table 3. Summary of principle points and focal length of optical system of the camel eye.

Anterior principle point		
Cornea	Hc_1	-0.0612
Lens	Pe	6.2432
eye	H	3.4555
Posterior principle point		
Cornea	Hc_2	-0.8595
Lens	P_e'	19.2278
eye	H′	4.6253
Anterior focal point	F	-13.4208
Posterior focal point	F'	28.0961
Anterior focal length	f	-16.876
Posterior focal length	f'	23.4708
Anterior nodal point	N	10.05
Posterior nodal point	N'	11.219

The total refracting power of the lens system

$$F_6 = (F_4 + F_5) - (C_2 * F_4 * F_5) \quad \text{.............................. (9)}$$
$$= (22.48+17.55) - (6.32^{E-3}*22.48*17.55) = \mathbf{37.54D}$$

I. 3- Total refracting power of the optical system (F_t):

This combines the corneal and lens powers. The total refracting power of the optical system as a whole can be calculated by:

$$Ft = (F_3+F_6) - (C_2*F_3*F_6) \quad \text{.............................. (10)}$$
$$= (28.48+37.54) - (6.32^{E-3}*28.48*37.54) = \mathbf{59.25D}$$

I. 4- Principle points (P):

The anterior principle point of the corneal system

$$P_1 = (C_1*F_2)/F_3 \quad \text{.............................. (11)}$$
$$= (6.53^{E-4}*(-2.78))/28.48 = \mathbf{-6.39^{E-5}mm}$$

The posterior principle point

$$P'_1 = (C_1*F_1*n_3)/F_3 \quad \text{.............................. (12)}$$
$$= (6.53^{E-4}*31.21*1.3339)/28.48 = \mathbf{9.55^{E-4}mm}$$

The anterior principle point of the lens system

$$P_2 = (C_2*F_5*n_3)/F_6 \quad \text{.............................. (13)}$$
$$= (6.32^{E-3}*17.55*1.3339)/37.54 = \mathbf{2.85mm}$$

The posterior principle point of the lens system

$$P'_2 = (C_2*F_4*n_3)/ (F_6) \quad \text{.............................. (14)}$$
$$= (6.32^{E-03}*22.48*1.3339)/37.54 = \mathbf{-4.27mm}$$

The principle point utilises the distance from the anterior corneal vertex till the posterior lens capsule d2 = (0.9+2.35+9.6 = 12.85mm); the anterior principle point

$$P_e = (d_2*F_5*n')/F_6 \quad \text{.............................. (15)}$$
$$= (12.85*17.55*1.39075)/ 37.54= \mathbf{6.24mm}$$

The posterior principle point

$$P_e' = (d_2*F_4*n_4)/F_6 \quad \text{.............................. (16)}$$
$$= (12.85*22.48*1.39075)/ 37.54= \mathbf{19.23mm}$$

The obtained data were summarised in table (2).

I. 5- Focal length of the whole optical system (f):

The focal length is the distance between the centre of the lens and the point in space at which light rays passing through the lens converge. The anterior focal length f of optical system

$$f = n_1/F_t \quad \text{.............................. (17)}$$
$$=1/59.25 = \mathbf{-16.88mm}$$

Posterior focal length ***f′*** of the optical system

$$f' = n_3/F_t \quad \text{.............................. (18)}$$
$$=1.3339/59.25 = \mathbf{23.47mm}$$

I. 6- Cardinal points

There are six cardinal points (*H, H′, F, F′, N, N′*) on the axis of a thick lens from which its imaging properties can be deduced. The calculations were as follows:

I. 6.1- Principle points (H):

The anterior principle point of the optical system utilises the distance from the anterior corneal vertex to the posterior lens capsule d_1 (12.85 mm); the distance from the anterior corneal vertex to the retina d_1 (28.45 mm) and the average combined index of refraction of the inside of the ***n′***.

$$H = (t_2 * d_1) / (n' * F_t) \quad \text{.................................} \quad (19)$$

$$= (9.6*28.45)/(1.3339*59.25) = \mathbf{3.46mm}$$

The posterior principle point of the optical system

$$H' = (d_1 * d_2) / (n_3 * F_t) \quad \text{.................................} \quad (20)$$

$$= (12.85*28.45)/(1.3339*59.25) = \mathbf{4.6mm}$$

II.6.2- Focal points (F):

Anterior focal point F of the optical system

$$F = H + f \quad \text{.................................} \quad (21)$$

$$= 3.46-16.88 = \mathbf{-13.42mm}$$

The posterior focal point F′ of the optical system

$$F' = H' + f' \quad \text{.................................} \quad (22)$$

$$= 4.6 + 23.47 = \mathbf{28.09mm}$$

II.6.3- Nodal points (N):

The anterior nodal point

$$N = F + f' \quad \text{.................................} \quad (23)$$

$$= -13.42+23.47 = \mathbf{10.05mm}$$

The posterior nodal point

$$N' = F' + f \quad \text{.................................} \quad (24)$$

$$= 28.17 + (-16.88) = \mathbf{11.22mm}$$

II- Reduced eye

To make simple optical calculations a reduced eye, based on Gullstrand's model, was developed that approximately matches the ocular dimensions but simplifies the calculations by combining all the refractive indices into one, and all the refracting surfaces into one power and location.

The average combined index of refraction of the inside of the eye; ***n′* = 1.3908**.

In this thin lens model, the combined total dioptric power = cornea total power +lens total power; as obtained from equations 5&9 (*28.48+37.54=* ***+66D***).

The combined principle point was obtained from the results of equations 19&20. ***P***, lays ***4 mm*** ((3.46+4.6) /2) behind the anterior surface of the cornea.

The anterior focal point lies at 13.42 mm in front of the corneal surface whereas the posterior focal point lies at 28.1 mm behind the anterior surface of the cornea (equations 21&22). Therefore, the anterior focal length equals ***17.46mm*** (13.46+4.0) and the posterior focal length equals ***24.1mm*** (28.1-4).

The Nodal points, ***N*** and ***N′***, lays ***10.05*** and ***11.22 mm*** behind the anterior surface of the lens respectively (equations 23&24); therefore the combined nodal point (***N***) is ***10.63 mm*** ((10.05+11.22)/2) behind the anterior surface of the cornea. A diagrammatic representation of the obtained values has been sketched (Figs 1 and 2).

The retinal image size ***R*** is easily calculated from the reduced model by multiplying the distance from the posterior nodel point to the retina (17.6 mm) by the angle, in radians, subtended by the object, where 1 radian = 57.296 degree. Therefore, an object with a ray subtending with and angle 0.1 radian will have retinal image size of ***1.76 mm***. If the same object moves closer, the subtending angle will increase, the larger the retinal image size as in Fig (3). Retinal magnification factor (***RIM***) for 1° in visual field was calculated as ***(f′-N′)/F′= (23.47-11.22)/28.09=0.436 mm/ degree.***

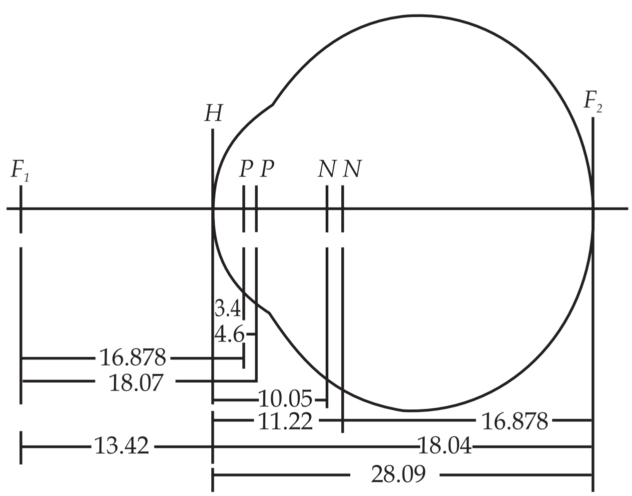

Fig 1. The schematic eye of adult Arabian camel.

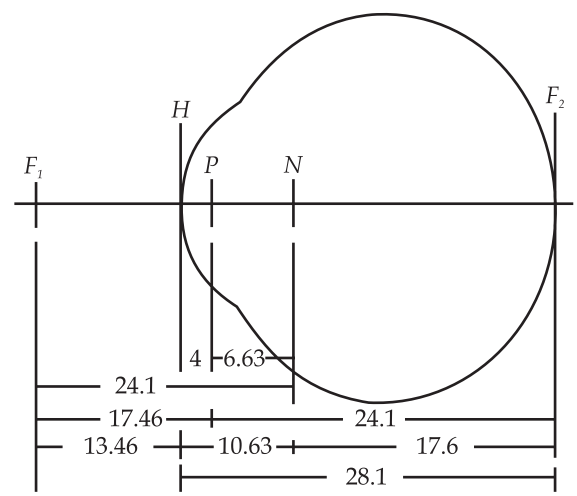

Fig 2. The reduced eye of adult Arabian camel.

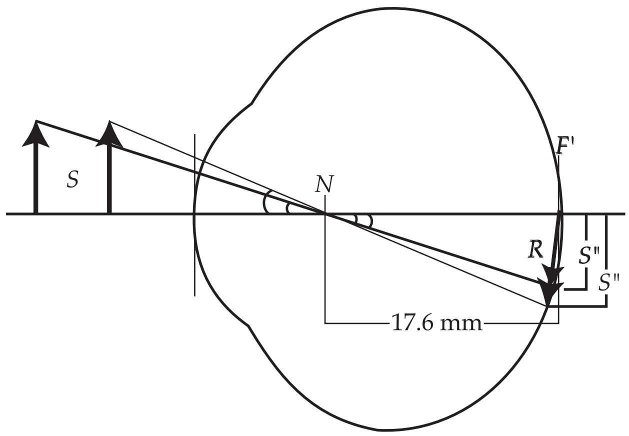

Fig 3. The reduced eye of adult Arabian camel showing the increase of retinal image size as the distance between the object and the nodal point decreases.

Discussion

The development of schematic eye since Vakkur and Bishop (1963) formed the basis of the science of physiological optics and the design of spectacles and the use of optical instruments in ophthalmology. Some authors suggested that ocular measurements should be incorporated into mathematical models, comparing and contrasting the optical performance of the eye before and after surgery (Patel *et al,* 1995). Several models have appeared over the last century, with different levels of complexity ranging from those with reduced or single refracting surfaces, to others that allow refractive index variation within the lens and have conicoidal rather than spherical retinal surfaces (Bakaraju *et al,* 2008).

The dimensions of ocular tissues vary from infantile to adult animals. These changes are probably the necessary concomitant of the increase in size of the eye during growth. Therefore, in this research, optical data from adult camels were used. The ocular measurements used in this work were obtained from a previous ocular ecobiometry conducted on the eyes of adult Arabian camels (El-Tookhy *et al,* 2012). Calculations were performed using standard Gaussian equations.

The basics of optics largely depend on the index of refraction (***n***) which is the ratio of the speed of light through a vacuum and the speed of light through the medium in question. Normally, the speed of light in vacuum (air) is 3×10^8 m/s. When passing through other media, the speed of light changes depending on the density of that medium. Hamidzada and Osuobeni (1998) stated that the index of refraction in camel eye is similar to that of the cow and pig. Coile and O'Keefe (1988) listed the ***n*** values of different ocular media for different domestic animals. The n value for the aqueous of both cow and pig was 1.3339. For the vitreous, the ***n*** values were 1.3337 for the cow and 1.3339 for the pig. These values were used in this study for calculations. Hamidzada and Osuobeni (1998) reported different values for the Arabian camels being 1.499 for the aqueous and 1.497 for the vitreous. When these values were used in our study, the schematic model was inconsistent. The axial length stated by Osuobeni and Hamidzada (1999) was 31.05mm. Our calculated axial length based on their ***n*** values gave 34.4mm. On the other hand, our obtained ecobiometric value of the axial length was 29.1mm (El-Tookhy *et al,* 2012) and the calculated schematic value was 28.1mm which is more consistent.

The refractive index of the cornea was 1.3775, yet it was reported to be not uniform. The varying refractive index does not significantly affect the total dioptric power of the cornea but has the potential to significantly contribute to the overall optical performance of the eye in relation to refractive surgery (Patel *et al,* 1995).

The anterior and posterior corneal curvatures were less in camels (12.1 and 15.7, respectively) than in horse (17.2 and 18.25), close to the cow (15.82 and 15) but larger than those of the pig (9.01 and 8.95) as reported by Prince *et al* (1960); Tanimura (1970) and Coile and O'Keefe (1988). The influence of the corneal thickness on the corneal power is linear and very small. If, for example, the thickness reduces to zero or doubles its value, the power reduces or increases slightly. The error is greater for a more curved cornea (Olsen, 1986).

In camels, as nearly in all animals, most of the refractive power of the eye comes from cornea (48%) and in particular from its front surface. This is due to both, strongly curved corneal surface and the refractive index differential being the highest here (1 vs. 1.3775). Within the eye, refractive indices vary between 1.3338 and 1.5171, thus having only secondary effect on the optical power in agreement with the results published by Coile and O'Keefe (1988). The calculated dioptric power of the camel cornea was approximately 28.48 diopters (D) which was more than in horse (19.6D) and cow (20.99D) but less than that of the pig (37.12D). The calculated dioptric power of the camel lens was approximately (37.54D) which is more than in horse (23.83D) and cow (33.4D) but less than that of the pig (52.8D).

Similarly, the calculated total power of the camel eye was approximately (29.25D) which was more than in horse (38.5D) and cow (47.7D) but less than that of the pig (78.2D) (Coile and O'Keefe, 1988). These three power parameters can be explained by the varying size of the globe in these animals (29.1mm in camel, 41.4mm in horse, 36mm in cow, and 21.87mm in pig) as there is an inverse relation between the power and the globe size.

It was noted that the decrease in radius of curvature increases the refracting power of the tissue. In this model, the anterior and posterior radii of curvature of the cornea were 12.09 and 15.67, respectively and the anterior and posterior corneal refracting powers were 31.21 and 2.78D, respectively. Comparatively, horse has an anterior and posterior corneal radius of curvature of 17.2 and 18.3 with corneal dioptric values of 21.5 and 1.9D whereas pig has an anterior and posterior corneal radius of curvature of 9 and 8.9 with corneal dioptric values of 41.2 and 4.2D (Coile and O'Keefe, 1988). This applies also to the lens anterior and posterior parameters

Similarly, it was also noted that the increase in depth of the anterior chamber reduces the total optical power. In this model, the anterior chamber depth was 2.35 mm and the total optical power was 59.25. Horse has a deeper anterior chamber 6.07 mm with a total dioptric value of 38.5 (Prince *et al,* 1960; Tanimura, 1977 and Coile and O'Keefe, 1988).

In the 18th century, Listing and Gauss, while studying refractive lens combinations, concluded that for a homocentric lenses system, there exist three cardinal points, situated on the principle axis of the system. The cardinal points are often used to characterise a thick lens or an optical system (Khurana, 2003). They consist of the anterior and posterior principle points (***H*** and ***H′***), anterior and posterior focal points (***F*** and ***F′***), and the anterior and posterior nodal points (***N*** and ***N′***). A ray incident on a lens from the front focal point ***F***, will exit the lens parallel to the axis, and an incident ray parallel to the axis refracted by the lens will converge onto the back focal point ***F′***. The extension of the incident and emerging rays in each case intersect, by definition, the principal planes. The principal planes cross the axis at the principal points, ***H*** and ***H′***.

In this camel model, the anterior principal points, ***H*** and ***H′***, were found to be 3.46 and 4.6 mm which is less than that of the horse, 6.9 and 7.1 mm; cow, 5.6 and 6.7 mm; but longer than those of the pig, 3.7 and 4 mm. Similarly, the anterior focal points, ***F*** and ***F′***, were found to be 13.42 and 28.09 mm which is less than that of the horse (19.46 and 42.14 mm); cow (14.3 and 35.8 mm); but longer than those of the pig (-8.76 mm and 21.54) (Tanimura, 1977 and Coile and O'Keefe, 1988).

The typical stigmatic optical system has two nodal points: an incident nodal point and an emergent nodal point. A ray through the incident nodal point emerges from the system through the emergent nodal point with its direction unchanged. In the presence of astigmatism nodal points are not possible in most cases. Two nodal points were found in the camel mathematical model at ***N***=10.05 and ***N′***=11.22 mm from the anterior corneal vertex. Both nodal points of a single refractive or reflective surface are located at the center of curvature of the surface, whereas in a complex optical system, the angular subtense of an image as seen from the rear nodal point equals the angular subtense of the object as seen from the front nodal point (Harris, 2010). These points are essential in determining the focal length of the optical system. In the camel model, the anterior focal length was found to be 16.88 mm which is less than that of the horse (25.94 mm); cow (20.98); but longer than that of the pig (12.79 mm) (Prince *et al,* 1960; Tanimura, 1977 and Coile and O'Keefe, 1988).

In a single spherical refracting surface such as the reduced eye, the two principal points coincide with each other and with the vertex of the surface (***P***). Also, both nodal points are coincident with each other and with the centre of curvature (***N***) of the refracting surface. For the reduced camel eye model; the average index of refraction inside the eye, ***n′***= 1.3908 and the combined total dioptric power was +66D. The principle point ***P***, and nodal point, ***N***, are 4 mm and 10.63 mm, respectively, behind the anterior surface of the cornea. The focal points ***F*** and ***F′*** are -13.42 and 28.1 mm, whereas the focal lengths ***f*** and ***f′*** are -17.46 and 24.1 mm.

The retinal image size obtained from the camel reduced eye model was 16.89. This is less than in horse (25.9); cow (20.98) but larger than in pig (12.79). Curtin (1985) stated that the stronger the lens, the smaller the retinal image size will become. This coincides with our findings as the camels have an optical system with a higher dioptric power than horse, cow and sheep but with smaller retinal image size. The retinal image magnification (RIM) indicates the visual acuity (García *et al,* 1996). It was calculated according to the equations of Drasdo and Flower (1974). The necessary elements for calculating the magnification were the axial length of the eye and the position of the posterior nodal point (Lapuerta and Schein, 1995). In camels the RIM was 0.436 mm/degree. The RIM value was 0.44 in horse, 0.36 in cow and 0.22 in pig (Coile and O'Keefe, 1988 and Khurana, 2002).

Conclusion

The data obtained from the schematic model shows that camels with their relatively small sized-eyes compared to than horse and cow necessitated the existence of an optical system with a higher dioptric power to achieve image focusing over a short focal length.

References

Bakaraju RC, Ehrmann K, Papas E and Ho A (2008). Finite schematic eye models and their accuracy to in-vivo data. Vision Research 48:1681-1694.

Brandão CVS, Chiurciu JLV, Ranzani JJT, Mamprim MJ, Zanini M and Crocci JA (2007). Tonometry, pachymetry and globe axial length in glaucomatous dogs submitted to intravitrealuveal ablation. Brazilian Journal of Veterinary and Animal Science 59:914-919.

Carter RT, Murphy CJ, Stuhr CM and Diehl KA (2007). Bilateral phacoemulsification and intraocular lens implantation in a great horned owl. Journal of the American Veterinary Medical Association 230:559–561.

Coile DC and O'Keefe LP (1988). Schematic eyes for domestic animals Ophthalmic and Physiological Optics 8(2):215-219.

Curtin BJ (1985). The Myopias: Basic Science and Clinical Management. Philadelphia: JB Lippincott.

Drasdo N and Flower (1974). Non-linear projection of the retinal image in a wide-angle schematic eye. British Journal of Ophthalmology 58:709-713.

El-Tookhy O, Al-Sobayil FA and Ahmed AF (2012). Normal ocular ecobiomety of the dromedary camels. Journal of Camel Practice and Research 19(1):13-17.

García M, González C, Pascual I and Fimia A (1996). Magnification and visual acuity in highly myopic phakic eyes corrected with an anterior chamber intraocular lens versus by other methods. Journal of Cataract Refractive Surgery 22(10):1416-22.

Görig C, Varghese T, Stiles T, Broek J van den, Zagzebski JA and Murphy CJ (2006). Evaluation of acoustic wave propagation velocities in the ocular lens and vitreous tissues of pigs, dogs, and rabbits. American Journal of Veterinary Research 67:288-295.

Gullstrand A (1909). Appendix in Helmholtz' Physiologische Optik, 3rd edition, translated by Southall, J.P.C. Optical Society of America (1924).

Hamidzada WA and Osuobeni EP (1998). Ultrasound velocity in the aqueous and vitreous humour of the one-humped camel (*Camelus dromedarius*). Clinical and Experimental Optometery 81(5):222-227.

Harris WF (2010). Nodes and nodal points and lines in eyes and other optical systems. Ophthalmic and Physiological Optics 30(1):24-42.

Hughes A (1971). A schematic eye for the rabbit. Vision Research (12):123-138.

Khurana AK (2002). Theory and Practice of Optics and Refraction, 2nd edition. Rakmo Press.

Khurana AK (2003). Ophthalmology. New Age International Publisher Ltd, 3rd Edition.

Lapuerta P and Schein SJ A (1995). Four-surface schematic eye of macaque monkey obtained by an optical method. Vision Research 35(16):2245-54.

McMullen RJ Jr and Gilger BC (2006). Keratometry, biometry and prediction of intraocular lens power in the equine eye. Veterinary Ophthalmology 9:357-360.

Milton K (2002). Introduction to Geometrical Optics., 2nd edition. World Scientific Publishing Co.

Olsen T (1986). On the calculation of power from curvature of the cornea. British Journal of Ophthalmology 70(2): 152-154.

Osuobeni EP and Hamidzada WA (1999). Ultrasonographic determination of the dimensions of ocular components in enucleated eyes of the one-humped camel (*Camelus dromedarius*). Research in Veterinary Science 67(2):125-129.

Patel S, Marshall J and Fitzke FW (1995). Refractive index of the human corneal epithelium and stroma. Journal of Refractive Surgery 11(2):100-105.

Potter TJ, Hallowell GD, Bowen IM (2008). Ultrasonographic anatomy of the bovine eye. Veterinary Radiology and Ultrasound 49:172-175.

Prince JH, Diesem CD, Eglitis I and Ruskell GL (1960). Anatomy and Histology of the Eye and Orbit in Domestic Animals. Springfield, IL Charles C. Thomoson.

Tanimura I (1977). Comparative morphology of the bulbus oculi of the domestic animals revealed by scanning electron microscopy. Japanese Journal of Veterinary Sciences 39:643-656.

Vakkur GJ and Bishop P (1963). The schematic eye in the cat. Vision Research 3:357-381.

Zhou X, Qu J, Xie R, Wang R, Jiang L, Zhao H, Wen J and Lu F (2006). Normal development of refractive state and ocular dimensions in guinea pigs. Vision Research 46: 2815-2823.