Prevalence of ocular pathology in adult captive cheetahs

(*Acinonyx jubatus*)

by

Christie Boucher

Submitted in partial fulfilment of the requirements for the degree of

**MMedVet(Ophthal)**

Companion Animal Clinical Studies
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Dissertation

Prevalence of ocular pathology in adult captive cheetahs

(*Acinonyx jubatus*)

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DEDICATIONS

I dedicate this thesis to my husband, my strong pillar, who understands me, who encouraged, supported and helped me to pursue my dreams.

To my kids, Charlie and Celeste who ensure that I keep my life balanced. Thank you for helping me to see the world through your eyes.

‘The eyes tell more than words could ever say’
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The Department of Companion Animal Clinical Studies and Roy Johnston for their assistance in the funding of this project.

Peter Caldwell and the staff of Old Chapel Veterinary Clinic for always being willing to help with the data collection and cheetah examinations.

Ann van Dyk for encouraging the research to be performed on her cheetahs, to which she has dedicated her life.

AfriCat Foundation for all the help, support and dedication to this project.

My parents, parents in law and friends, for their moral and emotional support.
DECLARATION

I, Dr Christie Boucher, the author of the thesis title: “Prevalence of ocular pathology in captive adult cheetahs (Acinonyx jubatus)”, received ethics clearance for this project (V038-14) from the University of Pretoria Animal Ethics Committee on the 30th of June 2014 (Appendix 4).

I have upheld the ethical standards required in the University of Pretoria’s Code of ethics for researchers and the Policy guidelines for the responsible research.

I hereby declare that the research presented in this dissertation was conceived and executed by myself, under the guidance of my supervisor, Dr I Venter.

Neither the substance, nor any part of the dissertation has been submitted in the past for a degree at the University of Pretoria or any other University.

This dissertation is presented as partial fulfilment of the requirements for the degree Master of Science in Veterinary Science.

The content of this thesis is original and has not been plagiarised.

Signature: __________________

Date: 2017-03-31
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Objective: To determine the prevalence of ocular pathology in captive adult cheetahs.

Materials and Methods: An ophthalmic examination was performed on 73 cheetahs, between the ages of 1 to 14 years, while undergoing immobilisation for their routine health check. The population of adult cheetahs within the Ann van Dyk Cheetah Centre and the AfriCat Foundation was used for the research project.

Results: The most prevalent pathological lesions were cataracts (10%). Most of the cataracts were found bilaterally, at the posterior extremity of the lens, in young cheetahs (1 - 6 years), from the Ann van Dyk Cheetah Centre, while only one unilateral cataract was found at the AfriCat Foundation. Three siblings, from Ann van Dyk Cheetah Centre, were found to have the same type of cataracts and fundic lesions. These fundic lesions resembled retinal dysplasia. No fundic pathology was found in the cheetahs at the AfriCat Foundation. A unique retinal pigment was observed in 71.8% of the cheetahs. This was equally distributed throughout both centres.

Conclusions: These types of cataracts and fundic lesions could indicate hereditary, congenital or nutritional causes. This is a concern because of the future implications it could have on breeding programs and the cheetah species. Regular detailed ophthalmic examination in the cheetah can help with the early diagnosis and treatment of ocular lesions and may prove beneficial to the management of breeding programmes.
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<td>AF</td>
<td>AfriCat Foundation</td>
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<tr>
<td>AvDCC</td>
<td>Ann van Dyk Cheetah Centre</td>
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<td>ACD</td>
<td>Anterior chamber depth</td>
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<td>AGL</td>
<td>Axial globe length</td>
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<tr>
<td>ALT</td>
<td>Axial lens thickness</td>
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<td>CPV</td>
<td>Canine parvovirus</td>
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<td>CNS</td>
<td>Central nervous system</td>
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<tr>
<td>CITES</td>
<td>Convention of International Trade in Endangered Species of Wild Fauna and Flora</td>
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<td>D</td>
<td>Dioptre</td>
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<tr>
<td>DHA</td>
<td>Docosahexaenoic acid</td>
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<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
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<tr>
<td>ELISA</td>
<td>Enzyme-linked immunosorbent assay</td>
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<tr>
<td>ERG</td>
<td>Electroretinogram</td>
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<tr>
<td>FA</td>
<td>Fatty acid</td>
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<tr>
<td>FCRD</td>
<td>Feline central retinal degeneration</td>
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<td>FCoV</td>
<td>Feline corona virus</td>
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<td>FHV-1</td>
<td>Feline herpes virus 1</td>
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<td>FIV</td>
<td>Feline immunodeficiency virus</td>
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<td>FIP</td>
<td>Feline infectious peritonitis</td>
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<td>FLV</td>
<td>Feline leukaemia virus</td>
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<td>FPLV</td>
<td>Feline panleukopenia virus</td>
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<td>g</td>
<td>Gram</td>
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<td>IFA</td>
<td>Immunofluorescence antibody assay</td>
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<td>IgG</td>
<td>Immunoglobulin G</td>
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<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
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<td>IOL</td>
<td>Intraocular lens</td>
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<tr>
<td>IOP</td>
<td>Intraocular pressure</td>
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<td>kg</td>
<td>Kilogram</td>
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</table>
km/h  Kilometre per hour
MHC  Major histocompatibility complex
MHz  Megahertz
ml   Millilitre
mm   Millimetre
mmHg Millimetre mercury
mm/min Millimetre per minute
MEV  Mink enteritis virus
nm   Nanometre
ng/ml Nanogram per millilitre
NCCF-SA National Cheetah Conservation Forum of South Africa
ONH  Optic nerve head
PHPV Persistent hyperplastic primary vitreous
PHTVL Persistent hyperplastic tunica vasculosa lentis
PPM  Persistent pupillary membranes
PCR  Polymerase chain reaction
PSD  Posterior segment depth
RPE  Retinal pigment epithelium
STT  Schirmer tear test
SD   Standard deviation
TBUT Tear film break up time
yr   Year
CHAPTER 1. INTRODUCTION

In 1900 more than 100 000 cheetahs were estimated to be present in the world. Today, the known cheetah population is approximately 6 700 adult animals (Durant et al. 2015). The cheetah is currently classified as ‘vulnerable’ by the International Union for the Conservation of Nature (IUCN) and it is listed in Appendix 1 (Felidae) of the Convention of International Trade in Endangered Species of wild Fauna and Flora (CITES) (Durant et al. 2015). Cheetahs still occur widely, although sparsely throughout Africa and in a small pocketed area in Iran. Southern Africa has the highest number of cheetahs amounting to an estimated 4190 adults (Durant et al. 2015). The Red Data Book of Mammals of South Africa (Friedman & Daly 2004) classifies the cheetah as vulnerable, but the cheetah is close to being re-listed as endangered (Buk & Marnewick 2010). According to the National Cheetah Conservation Forum of South Africa (NCCF-SA), most of South Africa’s cheetahs are found outside conservation areas on privately owned land (Marnewick et al. 2007). The decline in cheetah numbers is due to habitat loss, illegal trade, non-regulated captive breeding as well as direct persecution of them and their prey (Buk & Marnewick 2010).

At the end of the last ice age, approximately 10 000 years ago, an extinction of large vertebrates occurred on several continents. This extreme climate change event also caused a reduction in the cheetah populations. This became known as ‘the bottleneck’ and resulted in inbreeding amongst close relatives which led to a reduction in overall genetic variability among the cheetah subspecies (Menotti-Raymond & O’Brien 1993). Krausman & Morales (2005), list five cheetah subspecies: 1) North Africa to central India (Acinonyx jubatus venaticus), 2) Northwest and Western Africa (Acinonyx jubatus hecki), 3) Eastern Africa (Acinonyx jubatus fearsoni), 4) Southern Africa (Acinonyx jubatus jubatus) and 5) Northeast Africa (Acinonyx jubatus soemmeringii). Cheetahs have a significantly reduced genomic variation compared to any other felid or mammal species (O’Brien et al. 1983). They are homogenic for the major histocompatibility complex (MHC) (Brower et al. 2013), which is the group of genes that is responsible for the immune response in vertebrates to adapt and respond to pathogens (Castro-Prieto, Wachter & Sommer 2011).
This loss of polymorphism could potentially cause congenital defects, infertility, susceptibility to disease and failure to adapt to environmental changes (Buk & Marnewick 2010).

Cheetahs mostly live a solitary lifestyle, avoiding contact with humans, other carnivores and unrelated cheetahs except during mating. Forced exposure in captivity could lead to chronic stress. The vulnerability to disease increases in captive situations due to closer contact of animals, restricted space, lack of exercise and chronic stress (Munson et al. 2005). The Ann van Dyk Cheetah Centre is one of the most successful cheetah breeding facilities in the world. They started breeding in 1971 and supply zoos, other breeding facilities and South African game reserves. An increase in the incidence of cataracts was noted in the cheetahs of the Ann van Dyk Cheetah Centre by their regular veterinarian. This is a concern because of the future implications that a genetic predisposition to cataracts could have on their breeding programme. This prompted the current investigation into the prevalence of cataracts as well as any other ocular pathology in captive bred cheetahs.
CHAPTER 2. LITERATURE REVIEW

The cheetah’s speed and vision are very important for both hunting and survival. The cheetah, *Acinonyx jubatus*, is best known as the world’s fastest land animal. They can increase their speed from 0–80 km/h in three seconds and can easily reach 103 km/h (Sharp 1997). They are diurnal hunters that normally hunt early in the morning or late afternoon when it is cooler, but there is still enough light (Schaller 1968). The large forward-facing, exposed eyes with binocular vision, allow a cheetah to accurately judge distance when stalking and chasing prey. This makes sight a very important sense for its survival. Their extraordinary eyesight helps to locate prey on open grasslands or plains. The cheetah’s visual organisation is unique among felids and confirms the species specialisation as an open-terrain diurnal speed hunter. The cheetah’s visual organisation has the highest cone number in the retinal visual streak compared to other felids (Ahnelt et al. 2005). Cones are very important for visual acuity and to distinguish colour. In the cheetah, the M-cone (medium wave length) density is 20 000/mm² along the visual streak and peaks in the temporal periphery at about 30000/mm². The domestic cat has about 26000/mm² M-cones in the area centralis (Linberg et al. 2001). The S-cone (short wave length) topography of the domestic cat increases from the superior hemisphere (10%) to the inferior hemisphere of the retina (18%) (Ahnelt et al. 2005). The cheetah’s S-cone concentrations increase from the horizontal meridian (10%) towards both the inferior and superior periphery (25%) (Ahnelt et al. 2006). Its overall S-cone proportion is 14%. The domestic cat and African lion’s (*Panthera leo*) S-cone proportion is 10% and 8% in tigers (*Panthera tigra*) (Ahnelt et al. 2005).

2.1 Ophthalmic Examination

A complete ocular examination is of great importance in accessing ocular pathology for early and correct diagnosis of ocular disorders.

2.1.1 Schirmer Tear Test

The tear film plays an important role in the health of the conjunctiva and cornea as well as the maintenance of corneal clarity. Tears provide nutrients to the corneal surface and contain immunoglobulins, lysosomes and other important proteins to
help with the defences of the eye (Gum & Mackay 2013). Deficiency in the aqueous tear production is a frequent cause of corneal and conjunctival lesions in animals (Featherstone & Heinrich 2013). Standard values for the Schirmer tear test (STT) in domestic species are published and clinically useful for the evaluation and identification of quantitative tear film deficiencies. The STT measures the production of the aqueous component of the tear film. In this test, a standardised strip of Whatman no. 41 filter paper, with dimensions of 5 mm x 35 mm, is impregnated with blue dye and marked with 1 mm gradations. The strip is first bent at a notch 5 mm below the rounded tip. This step is done within the packaging to avoid contamination of the strip by oil from the examiner’s hands. The strip’s rounded tip is then placed in the lower conjunctival fornix of the eyelid and in contact with the cornea. The test strip is kept in the eye for one minute and tear production is seen as the dye migrates down the strip. This is recorded as mm wetting per minute. The test strips should be read immediately after removal from the eye, as fluid may continue to migrate over time and falsely elevate the measurements. Alternatively, strips can dry out after removal and lead to a false low production of tears. The STT can be performed concurrently or sequentially on each eye. Two STT readings have been described in the literature. The STT I measures reflex as well as basal tear secretion (Mould 2002). The mean value for the STT I in the domestic cat is 14.3 ±4.7 mm/min (Cullen, Lim & Sykes 2005). The STT II measures only the basal tear production. This is the amount of tears that is usually produced to lubricate the corneal surface (Featherstone & Heinrich 2013). It is measured in the same way as the STT I with the difference that the test is performed after the instillation of topical anaesthetic. The STT II value in the normal cat is 13.2 ± 3.4 mm/min (McLaughlin et al. 1988). Waters (1994), found the inter-individual variation among cats to be very large with the STT II values differing by 1–3 mm/min when the left and right eyes were compared. STT values in the cat should therefore be interpreted very carefully and in combination with clinical signs. The STT II is not routinely used in animals in clinical settings, but is much more commonly used in humans where a low basal tear production might be masked by a high reflex tear production (Featherstone & Heinrich 2013). Although the STT has been reported to be inconsistent, it still remains the standard method to quantify aqueous tear production in veterinary ophthalmology (Hawkins & Murphy 1986).
A variety of species specific values for the STT have been published (Featherstone & Heinrich 2013), but to the author’s knowledge, no current data on the normal STT values in cheetahs are available.

It is known that sedation and/or general anaesthesia cause a reduction in tear production. The following mechanisms of action have been suggested with the administration of these drugs: vasoconstriction of the vasculature or the tear gland itself, altered automatic regulation of tear production and an altered metabolism at the gland’s cellular level (Dodam, Branson & Martin 1998). In a study from Arnett, Brightman & Musselman (1984), domestic cats that underwent anaesthesia with ketamine and acepromazine, showed a reduction in the tear production. Sanchez, Mellor & Mould (2006), described how the STT values in dogs fall below 15 mm/min after sedation with medetomidine, but return to normal levels once the medetomidine component of the sedation had been reversed. It has also been shown that general anaesthesia cause a significant decrease in tear production in dogs (Herring et al. 2000), horses (Brightman et al. 1983), and koalas (Phascolarctus cineureus) (Grundon et al. 2011). Tropicamide is a topical short-acting anticholinergic drug, used to facilitate visualisation during ophthalmic examination. It is a rapid-acting drug which causes mydriasis within 15 minutes after topical instillation in domestic cats and begins to decline within 4 hours (Herring 2013). Margadant et al. (2003) showed that tropicamide caused a significant reduction of the STT readings in cats, but not in dogs.

Featherstone & Heinrich (2013) reported that tear production is normally lower in younger animals. Similarly, it was found that in cats less than a year, the STT II values were significantly lower than cats older than one year (Waters 1994). Juvenile pigs (Trbolova & Ghaffari 2012) and juvenile dogs (Broadwater et al. 2010), showed an increase in STT values as the animals aged and gained body weight.

2.1.2 Intraocular Pressure

Tonometry is the measurement or estimation of intraocular pressure (IOP) in the eye. The assessment of IOP can assist in the diagnosis of ocular diseases like glaucoma and uveitis. Glaucoma is defined as an increase of intraocular pressure that results from inadequate drainage of aqueous humour. This is destructive to the health of the eye and may lead to loss of vision (Plummer, Regnier & Gelatt 2013).
Disrupted axoplasmic flow in the optic nerve head and death of retinal ganglion cells and their axons, inevitably lead to progressive loss of retinal sensitivity and function, reduction in the visual field and eventually blindness (Miller 2013).

Aetiologically, glaucoma can be classified as primary, secondary and congenital. Primary glaucomas have a breed predisposition and are believed to have a genetic basis (Miller 2013). These glaucomas are not associated with any ocular or systemic disorder. Primary glaucomas are divided into two forms: the open angle, in which the drainage angle appears gonioscopically normal, and the closed angle, where the drainage angle appears gonioscopically narrowed or closed. This is mostly caused by goniodygenesis which is an abnormal development of the pectinate ligaments (Miller 2013). Secondary glaucomas are a much more common clinical finding when compared to primary glaucomas. These glaucomas are associated with other ocular or systemic disorders which disrupt the aqueous humour flow (Plummer et al. 2013). The most common causes for secondary glaucoma in cats are anterior uveitis with peripheral anterior synechia, or posterior synechia with pupillary obstruction, lens luxation due to trauma or cataracts, intumescent cataracts, phacolytic or phacoclastic uveitis, hyphema, intraocular neoplasia and malignant glaucoma as a result of aqueous misdirection (Stiles 2013). Congenital glaucomas are normally the result of extensive goniodygenesis or trabecular maldevelopment and are diagnosed in the first few months of an animal's life (Plummer et al. 2013).

Uveitis can reduce the IOP. This inflammatory process leads to a reduction in the active secretion of aqueous humour because of the impinging on the active transport mechanisms. Prostaglandin release during inflammation increases aqueous humour outflow through the uveoscleral route and may contribute to the lower IOP. The IOP may vary depending on the severity and duration of the uveitis (Gabert & Kaufman 2003).

The most accurate method of assessing IOP is via direct tonometry with a manometer. This method is however invasive and impractical for clinical use. Indirect tonometry, the measurement of corneal tension, is a quick, non-invasive procedure and can be measured by four different methods: digital tonometry,
indentation tonometry, applanation tonometry and rebound tonometry (Featherstone & Heinrich 2013).

Digital tonometry is performed by placing the index or middle finger on the patient’s closed upper eyelids and applying slight pressure to the eyeball. The difference between globes can give an indication of a ‘soft’ or ‘hard’ eye. This is a very subjective method of assessing IOP and varies considerably between clinicians and should only be used when no other method is possible (Featherstone & Heinrich 2013).

Indentation tonometry can be performed with a Schiotz Tonometer. A specially designed scale with a specific weight and foot plate is placed on an anaesthetised cornea to measure corneal indentation produced by the given weight. The scale readings are converted to mmHg using the “1955 Friedenwald Nomogram” table. For accurate readings, the patient must be restrained with its head and eyes directed upwards. The footplate of the Schiotz Tonometer was designed for human corneal curvature and therefore its accuracy may vary in veterinary patients. Eye, eyelid movement and protrusion of the third eyelid may affect the results. It is not recommended to use the Schiotz Tonometer in diseased or weakened corneas because of inaccurate measurements and the chance of damaging the cornea further (Featherstone & Heinrich 2013). The average IOP reading of clinically normal domestic cats was greater than or equal to 30 mmHg when measured with a Schiotz Tonometer (Miller & Pickett 1992).

Applanation tonometry estimates the intraocular pressure by measuring the force needed to flatten an area of the cornea. Different applanation tonometers are available, but the Tono-Pen is commonly used. Local anaesthesia is needed before the instrument can be used on the cornea. The Tono-Pen is held perpendicular to the cornea and the pen is used to let the probe tip make gentle contact with the central cornea without indenting it. The mean IOP is then displayed on the Tono-Pen (Featherstone & Heinrich 2013). Rusanen et al. (2010) showed the Tono-Pen compares well with direct manometry and an average of 18.4 mmHg was obtained in normal domestic cat eyes. Kroll, Miller & Rodan (2001), reported that the mean IOP measured with applanation tonometry in domestic cats older than 7 years, was 12.3 mmHg but can range from 3-31 mmHg in domestic cats with normal eyes.
Rebound tonometry is used by induction-impact tonometers. Studies have shown that its accuracy is comparable to that of direct manometry but that the IOP was 2–3 mmHg higher than measurements with the Tono-Pen (Rusanen et al. 2010). Rebound tonometry is performed without topical anaesthesia and is the most popular method of accessing IOP in the veterinary field because of ease of use and portability. It can also be used on any size eye. The rebound tonometer probe is electromagnetically activated to come into contact with the cornea and then rebounds from it. The characteristics of the rebound are used to estimate the intraocular pressure. This technique is affected by ocular surface tension and should be performed before application of any topical medications (Maggs 2013).

The TonoVet tonometer has been calibrated to measure IOP in cats and dogs (“d”) and horses (“h”) and has been used in other species (Rusanen et al. 2010). The TonoVet is firstly activated and then held horizontally at a range of about 4-8 mm from the axial cornea and at an angle of 90° to the cornea. Six consecutive readings must be taken from the centre of the cornea. After each successful reading is there a short beep. After six readings there is a longer beep and the average intra-ocular pressure is shown on the TonoVet and displayed in mmHg. The display also indicates the variance between readings. A blinking display with a line at the bottom means the variance is acceptable whereas a blinking display with a line at the top or in the middle means an unacceptable variance. The tonometer displays an error message if there is a problem with the probe motion, misalignment with the central portion of the cornea or excessive difference between measurements (Knollinger et al. 2005). Rusanen et al. (2010) showed an average IOP reading of 20.7 mmHg in clinically normal domestic cats with the rebound tonometer. The highest IOP has been documented in the rhinoceros (Rhinocerotidae) (32.1 ± 10.4 mmHg) (Ofri et al. 2002), and the lowest in the chinchilla (2.9 ± 1.8 mmHg) (Müller, Mauler & Eule 2010). Because of the large variation between species, it is important to establish a reference interval for IOP in each species. Anatomical and physiological differences of the corneas, the ciliary body and the drainage pathways of aqueous humour, are thought to be reasons for species differences in IOP readings (Ofri et al. 2002). To the author’s knowledge there is no current information available on normal IOP values for cheetahs.
A variety of factors can affect the IOP. Pressure by the fingers of the examiner on the globe or eyelids (Klein et al. 2011) or excessive restraint with pressure on the jugular (Klein et al. 2011, Pauli et al. 2006), can falsely elevate the IOP reading. Body position has been documented to cause a difference in IOP (Broadwater et al. 2008). It was reported that the mean IOP of horses increased significantly when the head was below the level of the heart compared to above the level of the heart (Komáromy et al. 2006). An increased IOP has also been described in mice in a head-down position (Aihara, Lindsey & Weinreb 2003). Human IOP also showed an increase in the supine position compared to the sitting or the standing position (Galin, McIvor & Magruder 1963). The suggested mechanisms that could contribute to such an increase in IOP are compressive forces on the globe by congested orbital contents, increases in episcleral venous pressure and when congestion of the uveal tract causes increases in the ocular blood volume (Weinreb, Cook & Friberg 1984).

Circadian rhythms have been documented to influence the IOP readings (Del Sole et al. 2007, Martin-Suarez et al. 2014). In nocturnal species such as cats and rabbits, IOP increases during the night (Del Sole et al. 2007, Rowland, Potter & Reiter 1981), whereas in diurnal species such as dogs, IOP peaks during the day (Giannetto, Piccione & Giudice 2009). It is hypothesized that the activity phase of each species, correlates with the higher values of IOP (Del Sole et al. 2007).

Age also affects the IOP. Kroll et al. (2001), showed a lower IOP reading in young kittens when compared to adolescent cats, a higher IOP reading in adolescent cats versus adult cats and a lower IOP reading in geriatric cats compared to cats. A lower IOP was reported in lions younger than 1 year of age (12.8 mmHg) compared to lions older than 1 year of age (23.9 mmHg) (Ofri et al. 2008). IOP reading in dromedary camels (Camelus dromedarius) proved the opposite, with the mean IOP for immature camels higher than that of mature camels (Marzok & El-khodery 2015). Ofri et al. (1998) also showed differences in IOP between genders of lions. A significantly higher IOP was reported in the male lion (24.9 mmHg) when compared to the female (20.9 mmHg). Ferrets (Mustela putorius furo) showed a similar pattern with a higher IOP in males (15 mmHg) compared to the females (13.4 mmHg) (Hernández-Guerra, Rodilla & López-Murcia 2007). In humans, females have been documented to have higher IOP levels than males (Wu et al. 2006).
The reproductive status in cats has been shown to cause a difference in IOP. The IOP for females in estrus and for those that were pregnant with a high progesterone concentration, was documented to be significantly higher than the females that were not in estrus or non-pregnant. No differences were found between male IOP and the female group that were not in estrus (Ofri et al. 2002). When comparing lionesses in different stages of their estrus cycle, it was shown that the IOP for lionesses in the luteal phase (progesterone concentration > 5 ng/ml) were significantly higher (27.1 mmHg) than females not in the luteal phase (progesterone concentration < 5 ng/ml) (21.0 mmHg) (Ofri et al. 1999).

Various medications, including anaesthetic premedication, induction, and maintenance drugs, can alter IOP by changing the rate of aqueous production or outflow, or by changing the extraocular muscle tone and relaxation of eyelid muscles (Cunningham & Barry 1986). All agents which are commonly used to induce general anaesthesia, lower the IOP (Murphy 1985). In contrast however, ketamine may increase extraocular muscle tone which can lead to an increase of IOP (Ofri et al. 1998). A significant increase was seen in the IOP of dogs (Hofmeister et al. 2006, Kovalcuka et al. 2013), and cats (Hahnenberger 1976), sedated with ketamine. Contradictory to these studies, no significant effect on IOP were seen where ketamine was combined with diazepam in lions (Ofri et al. 1998), or xylazine in cats (Ofri et al. 2002), and monkeys (Erickson-Lamy et al. 1984).

Topical administration of medetomidine caused a significant reduction in the IOP of rabbits and cats (Jinet et al. 1991), whereas sedation of dogs with intravenous medetomidine had no significant effect on the IOP (Verbruggen et al. 2000, Wallin-Håkanson & Wallin-Håkanson 2001). Dexmedetomidine however, showed a significant decrease of the IOP after 20 minutes (Artigas, Redondo & López-Murcia 2012). Tiletamine-zolazepam (Zoletil) showed no significant effect on the IOP of dogs (Jang et al. 2014), or cats (Hahnenberger 1976). Tiletamine alone caused no change in IOP although Zolazepam on its own resulted in a 10% reduction in the IOP (Hahnenberger 1976). Tiletamine is a dissociative agent and its pharmacodynamics is similar to those of ketamine. It is more potent and has longer duration of action (Jang et al. 2014), but unlike ketamine, has minimal effect on the contraction of the extraocular muscles (Hahnenberger 1976).
A possible explanation for this finding is that zolezapam reduce IOP slightly and may lessen the increase in IOP induced by tiletamine (Hahnenberger 1976).

Mydriatic agents like tropicamide, cause dilatation of the pupil and cause a rise in IOP of about 3 mmHg in domestic cats (Stadtbäumer, Köstlin & Zahn 2002).

Ocular pathology may influence the IOP reading and it is therefore advised that measurements should be taken from the most normal part of the cornea (Featherstone & Heinrich 2013). An increase of 100 µm in corneal thickness can increase the IOP reading by 2 mmHg for the TonoVet (Park et al. 2011).

### 2.1.3 Slit-lamp Biomicroscopy

The slit-lamp biomicroscope is the instrument of choice for the examination of the ocular anterior segment. It improves visualisation of the eyelids, third eyelid, conjunctiva, sclera, cornea, anterior chamber, iris, lens and anterior vitreous. The slit-lamp biomicroscope combines magnification with bright focused light and provides a choice of full or slit beams. Full diffuse light is helpful with the examination of a large area of the eye. It gives the examiner an initial overview and is useful to assess gross pathology. The slit beams create an optical section of the tissues, by projecting a narrow, sharply focused light onto the eye. A slit beam provides information about the relationship of ocular tissues with each other as well as the topography of tissues examined. For example, the anterior lens capsule is visible as a convex bright line of illumination and the posterior lens capsule will be a concave, less bright line of illumination. Cataracts will be visible as bright opacities in the lens section and their position can be correctly identified and recorded (Featherstone & Heinrich 2013). The long slit beam can be reduced to a small pinpoint to allow visualisation of the Tyndall effect, as in the case of uveitis. The light beam is angled at 20 to 45 degrees from the axis of the microscope and the oculars are rested against the examiner’s brow. When using the Keeler slit-lamp biomicroscope, the magnification can be adjusted between 10 and 16 times. The focal distance of the instrument is 7 to 10 cm. Fine focus can be achieved by moving either slightly closer or away from the eye. Both direct illumination and retro-illumination are used during ocular slit-lamp biomicroscopy.
During direct illumination, the structure to be examined is illuminated by the light source itself. When using retro-illumination, the structure of interest is illuminated by light reflected from neighbouring tissues (Featherstone & Heinrich 2013).

### 2.1.4 Ophthalmoscopy

Examination of the fundus is best performed on dilated pupils using direct or indirect ophthalmoscopy. Distant direct ophthalmoscopy gives a good and rapid assessment of the degree and distribution of an opacity in the visual axis. When an ophthalmoscope is set to ‘0’ or zero, it is used with the light source directed at the patient’s eye and the beam is parallel with the examiner’s line of sight. The patient is viewed from an arm’s length distance to observe the tapetal reflex. Any opacity in the path of the tapetal reflex will appear black. This evaluation also helps to distinguish nuclear sclerosis from cataracts. Nuclear sclerosis shows a refractive ring at the nuclear cortical interface, which is normally positioned just inside the pupillary margin. In cases of nuclear sclerosis, light is normally transmitted through the centre of the lens, whereas cataracts appear black and will block the tapetal reflex.

When using direct ophthalmoscopy, the examiner’s eye should be 2-3 cm from the patient’s cornea. The image of the fundus is upright and highly magnified, but the field of view is very narrow. The magnification depends on the species being evaluated (Featherstone & Heinrich 2013).

Indirect ophthalmoscopy is performed with a light source and a biconvex lens. A 20 dioptre (D) lens or a 2.2 panretinal lens is normally used for domestic animals and gives a 4 x magnification in dogs and 5 x magnification in cats. A binocular ophthalmoscope on the head of the examiner allows stereoscopic vision and an intensified image. The examiner’s head must be 0.50–0.75 m or an arm’s length from the animal’s eye, in the same axis as the lens. The lens is positioned between the index finger and the thumb, while the other fingers rest on the frontal sinus area of the dog’s head for stability. The axis of the lens must lie in the same axis as the pupil and parallel to the iris. This gives the examiner a larger view, but inverted image of the fundus (Mould 2002).
2.1.5 Fluorescein Dye Test

The fluorescein dye test can be used to diagnose corneal and conjunctival defects, aqueous humour leakage, nasolacrimal duct patency and qualitative tear film abnormalities with the tear film break up time (TBUT) (Mould 2002). Fluorescein is a water soluble weak acid. Its absorption peaks at 490 nm and then converts the absorbed light to a peak wave length of 520 nm, which shows as fluorescent light. Fluorescein is an orange dye that changes to green in alkaline conditions. It is highly lipophobic and hydrophilic. Fluorescein is available as an impregnated paper strip or as a 2% alkaline solution. One drop of fluorescein solution is applied to each eye, or the strip can be moistened and the dorsal bulbar conjunctiva must be touched gently. When it is applied to the eye, it does not adhere to the lipid-containing cell membranes of the epithelium, but gets absorbed by any exposed corneal stroma. The stained area should be examined in a dark environment with magnification and a blue light source from a cobalt filter. Defects will appear as bright green areas. Fluorescein is very accurate in detecting corneal ulcers where the epithelium is absent and stroma is exposed. Fluorescein also stains inter-cellular spaces and can assist in detecting corneal abrasions. While it stains conjunctival ulcers and abrasions, the Descemet’s membrane will not stain. The Seidel test assesses the leakage of aqueous humour through deep corneal ulcers, lacerations, puncture wounds and suture sites. Aqueous humour can be seen as a bright green colour when it is runs through and dilutes the fluorescein on the cornea (Mould 2002).

The fluorescein drainage test, which assesses tear drainage, is called the Jones test. Fluorescein is applied to the eye and the time taken for the fluorescein to pass through the nasolacrimal system to the ipsilateral nares is recorded (Jones 1961). The time required for the fluorescein to appear at the nostril is highly variable and depends on the species, snout length, skull formation and the way in which the test is performed (Maggs 2013). A time interval of 15 seconds to 1 minute has been reported in cats (Martin 2005).

The stability of the tear film can be evaluated by measuring the TBUT. It indirectly evaluates the lipid and/or mucin layers of the tear film. Fluorescein is applied to the eye, the animal is allowed to blink, and then the eyelids are manually held open until the tear film 'breaks up' as dark spots start appearing on the cornea.
The mean value for the TBUT in the juvenile cat is 16.7 seconds and 21 seconds in the adult cat (Cullen et al. 2005). TBUT is reduced in cats with conjunctivitis, ulcerative keratitis and FHV-1 (Cullen et al. 2005).

2.1.6 Ultrasonography

Ultrasound has become an important diagnostic tool in ophthalmic examinations to evaluate the soft tissues of the eye and orbit (Kassab 2012). Ultrasonography is a non-invasive imaging technique which is safe and rapid to use. It is used for the qualitative and quantitative evaluation of orbital and intraocular structures. Ultrasonography is indicated in suspected orbital diseases, ocular trauma, intraocular haemorrhage, intraocular or orbital foreign bodies or masses, lens luxations, retinal detachment and in cases when an ophthalmic examination cannot be performed in opaque eyes (Rubin & Koch 1968, Williams & Wilkie 1996). It is also helpful to determine any variation in size, form, or position of the eye (Toni et al. 2010). A thorough knowledge of the normal appearance, dimensions and anatomy is important in the assessment of ocular pathological changes. To date and to the author’s knowledge, there are no reference ranges currently available for the cheetah species. Biometrics are used to determine changes in the ocular dimensions during diseases, such as buphthalmic globes in glaucoma, microphthalmos or phthisis bulbi (Hernández-Guerra, Rodilla & López-Murcia 2007). Biometry can also be used to calculate the intraocular lens (IOL) power, to determine artificial IOL implant size, and to estimate prosthetic globe size after an enucleation (Gonzalez, Rodriguez & Garcia 2001). Values for normal eyes have been established in many animals such as dogs (Cottrill, Banks & Pechman 1989, Ekesten & Torrang 1995, Schiffer et al. 1982), cats (Gilger, Davidson & Howard 1998), rabbits (Toni et al. 2010), horses (Rogers et al. 1986), bovine (Potter, Hallowell & Bowen 2008), Saanen goats (Capra aegagrus hircus) (Ribeiro et al. 2009), camels (Kassab 2012, Hamidzada & Osuobeni 1999), Asian elephants (Elephas maximus) (Bapodra et al. 2010), and ferrets (Hernández-Guerra, Rodilla & López-Murcia 2007).

Animals are examined following the application of topical anaesthetic. The probe is placed directly on the cornea or sclera while the eyelids are held open manually.
Scanning through closed eyelids is also possible, but the eyelids reduce the sound waves and quality of the image which generally makes this method less desirable. However, in cases of corneal injury, ocular trauma or after intraocular surgery, this is the recommended examination technique to avoid further damage to the cornea. Large amounts of coupling gel are used on the cornea to decrease near-field reverberation artifacts. A transverse and sagittal plane in the axial direction, are normally used to evaluate the eye during ultrasound examination (Dietrich 2013).

Ultrasound works on the basis of the reflection of sound waves from the border between two tissues of different acoustic impedance. The boundaries that reflect sound in the eye are the anterior and posterior corneal surfaces, the anterior and posterior lens surfaces and the retina. These echoes, from the reflections, are used in different ultrasound techniques such as A (amplitude) -mode, B (brightness) -mode, M (motion) -mode and Doppler scanning (Osuobeni & Hamidzada 1999).

B-mode ultrasonography is most commonly used in veterinary ophthalmology with a standard 10-14 MHz transducer and a focal range of 3-4 cm. This allows visualisation of anterior and posterior segment abnormalities as well as orbital lesions (Dietrich 2013).

A low frequency 7.5 MHz ultrasound transducer gives poor near-field visualisation but better tissue penetration for deeper structures like the retrobulbar area. High frequency ultrasound waves (20-50 MHz) and ultrasound biomicroscopy (50-100 MHz), penetrate only a few millimetres into tissue and are ideal for imaging structures such as the cornea, sclera, anterior chamber, iris, iridocorneal angle, ciliary body and anterior lens capsule (Pavlin & Foster 1995, Ye et al. 1995). A-mode ultrasonography is when a fixed, single beam of ultrasound is projected through the eye. The returning echoes are seen as vertical spikes on a horizontal line. The height of the spike reflects the intensity of the echo. The distance between the spikes is the time required for the ultrasound waves to reach a certain acoustic interface and to return to the transducer. The distance between the spikes indicates the measurements of the various intraocular distances. Biometric A-scan is commonly used for axial eye length measurements in both veterinary and human ophthalmology and requires a special biometric A-mode transducer. 

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B-mode is when multiple sound beams are projected through the eye and the returning echoes are seen as reflective lines or dots (Dietrich 2013).

Although A-mode ultrasound has been considered to be the most accurate and preferred modality to measure structures in the eye, B-mode ultrasound is an accessible and practical method, allowing the simultaneous evaluation of intraocular anatomy and measurement of intraocular distance (Ruiz et al. 2015). Although some studies have shown differences in ocular measurements between A-mode and B-mode ultrasound (Hamidzada & Osuobeni 1999), others have proved that there are no significant differences in the ocular measurements of veterinary patients when these modalities are compared (Boroffka et al. 2006, Cottrill et al. 1989, Grinninger, Skalicky & Nell 2010). According to Hamidzada & Osuobeni (1999), the B-mode measurements are significantly smaller in axial globe length, lens thickness and vitreous chamber depth than the A-mode technique, but overestimate the corneal thickness and anterior chamber.

Gender differences were observed in the axial globe length of dromedary camels, where the female globe was shown to be larger than the male globe (Yadegari et al. 2013). In dogs, the globe length was documented to be larger in males than females (Schiffer et al. 1982). In contrast, no significant gender differences were found in dogs (Cottrill et al. 1989), goats (Ribeiro et al. 2009), and ferrets (Hernández-Guerra et al. 2007).

The lens thickness was also shown to be affected by gender in dromedary camels (Yadegari et al. 2013), and in ferrets (Hernández-Guerra et al. 2007). The lens thickness of males appeared larger than the females in both species.

It has also been documented that ocular dimensions increase with age in miniature horses (Plummer, Ramsey & Hauptman 2003), Saanen goats (Ribeiro et al. 2009), Asian elephants (Bapodra et al. 2010), buffalo (Bos bubalis) (Kassab 2012), lions (Ofri et al. 2008), and one-humped camel (Kassab 2012). In dogs the axial globe length increases until 52 weeks of age (Tuntivanich et al. 2007).

In humans, the eye continues to develop, with an increase in ocular dimension until approximately 13 years of age (Larsen 1971, Tuntivanich et al. 2007).
2.2 Ocular Infectious Diseases

Severe inflammatory reactions to common infectious agents have been reported in captive cheetahs throughout the world (Munson et al. 2005). Several domestic cat viruses are known to infect non-domestic felids and could potentially affect their eyesight (Evermann et al. 1993). The cheetah’s genetic uniformity and the chronic stress of a captive environment, could potentially increase disease development by changing normal physiological homeostasis and immunity (Munson et al. 2005).

The following diseases not only cause ocular problems, but can also have devastating consequences in the conservation of cheetahs.

2.2.1 Feline Coronavirus

Feline coronavirus (FCoV) is a contagious and serious pathogen of domestic and non-domestic felids. The FCoV in domestic cats may lead to be asymptomatic, or an enteric disease or Feline infectious peritonitis (FIP). Feline infectious peritonitis is a fatal arthus-type immune reaction of cats to the viral infection (Foley et al. 1998). Large multicat, indoor environments are known to be predisposed to FCoV infection and FIP (Pedersen 2009). Sexually intact and purebred cats are more likely to develop FIP (Pesteanu-Somogyi, Radzai & Pressler 2006). Feline infectious peritonitis occurs most commonly in young cats and it may present as a dry, non-effusive form or a wet, effusive form of the disease. Neural and ocular lesions are more likely to be seen with the non-effusive form (Andrew 2000). Bilateral granulomatous anterior uveitis with fibrinous exudate in the anterior chamber and keratitic precipitates, are the most common ocular lesions in domestic cats. Chorioretinitis with pyogranulomatous exudate around the retinal vessels may be present. Retinal haemorrhages, detachments and optic neuritis can be additional findings (Campbell & Reed 1975).

Feline infectious peritonitis has also been reported in wild felids kept in zoos, namely lion, leopard (Panthera pardus), black leopard (Panthera pardus), jaquar (Panthera onca), caracal (Caracal caracal), lynx (Lynx lynx), serval (Leptailurus serval), puma (Puma concolor), tiger and cheetah (Van Rensburg & Silkstone 1984). Feline infectious peritonitis’ morbidity and mortality were devastating in cheetah populations during 1982 – 1983 (Evermann, Roelke & Briggs 1986). Evermann et al. (1986)
noted that captive cheetahs are highly vulnerable to infection and disease from FCoV. Outbreaks in captive cheetahs have been documented by Brown et al. (1993), Heeney et al. (1990) and Peiffer & Gelatt (1975). Post mortem findings confirmed the diagnosis, however, no specific ocular lesions were recorded. Serology and examination of faecal contents can help to identify the majority of infected and carrier cheetahs who are shedding the virus. The inconsistent correlation between seropositive and faecal viral shedding make the diagnostic testing very challenging, unreliable and difficult to interpret (Gaffney et al. 2012, Kennedy et al. 2002).

2.2.2 Feline Herpesvirus1

Feline herpesvirus1 (FHV-1) is common and widespread among domestic cat populations. It is estimated that over 90% of domestic cats world-wide are seropositive to this virus (Maggs, Lappin & Nasisse 1999). Of these infected cats 80% remain latently infected and of these 45% will have spontaneous viral reactivations. This will manifest either as asymptomatic virus shedding or as clinical disease (Townsend et al. 2004). The virus is spread from cat to cat by aerosol transmission, fomites or by direct contact. The FHV-1 infects the epithelial surfaces of the corneal epithelium, conjunctiva and respiratory tract. When the virus replicates and invades nearby cells, it causes necrosis of these tissues (Hoover & Griesemer 1971). The virus travels via the neuronal axons to the trigeminal ganglion where it becomes latent (Maggs et al. 1999). FHV-1 is associated with the following lesions in domestic cats: serous to mucopurulent ocular and nasal discharge, conjunctivitis, ulcerative keratitis and non-ulcerative stromal keratitis, keratoconjunctivitis sicca, ophthalmia neonatorium, symblepharon, corneal sequestrum, eosinophilic keratitis and anterior uveitis (Cullen & Webb 2013). The identification of FHV-positive carrier animals is difficult because of the nonspecific clinical signs and the limitations of diagnostic tests. Many of the diagnostic tests, including Polymerase chain reaction (PCR) assay, Immunofluorescence antibody assay (IFA) techniques, viral isolation and histopathology, have false negative results. This is likely because these tests are dependent on the stage of infection, amount of viral shedding, sampling techniques and sample handling (Witte et al. 2013). Swabs from the conjunctiva, cornea or oropharynx are used for virus isolation and can help in the diagnosis and identification of carrier animals.
These areas should be swabbed aggressively to obtain cells because the FHV-1 is an intracellular organism. Vaccination does not protect against FHV-1 infection, however, it reduces the severity of clinical signs, reduces the active viral shedding and potentially prevents its reactivation later in life (Maggs 2005).

FHV-1 has been described in leopards, cheetahs, jaguars and lions (Junge et al. 1991). FHV-1 is an endemic and benign disease in free-ranging felids (Van Vuuren, Goosen & Rogers 1999). In captive situations some cheetahs acquire a self-limiting rhinitis and chronic epiphora, while others appear to be especially vulnerable to severe disease and can experience persistent or recurrent clinical signs or conditions. This might include keratitis, corneal ulcers, conjunctivitis, uveitis and even blindness (Munson et al. 2004, Witte et al. 2013). Persistent cutaneous ulcers, as a result of FHV, are unique to the cheetah and very rarely occur in FHV-1 infected domestic cats or other exotic species (Junge et al. 1991). Ulceration, crusting, purulent discharge and necrosis with eosinophilic inflammation are seen in lesions affecting the periocular, perinasal and periorbital regions (Flacke, Schmidt-Küntzel & Marker 2015, Hargis & Ginn 1999). Lesions occasionally also occur on the extremities (Flacke et al. 2015, Munson et al. 2004). Ulcerative herpes dermatitis is mostly diagnosed in young animals, but has been reported in a cheetah of nine years of age (Flacke et al. 2015). Recognising the clinical signs and syndromes of FHV could lead to earlier diagnosis and treatment of this condition (Witte et al. 2013).

### 2.2.3 Feline Leukaemia Virus

Feline leukaemia virus (FeLV) causes severe illness and death in domestic cats. It has, however, rarely been reported in non-domestic felids (Briggs & Ott 1986). The FeLV is a retrovirus that replicates in epithelial tissues and results in malignant transformation of specific lymphocytic/haematopoietic cells.

Transmission of FeLV is via saliva and blood while grooming or fighting. The FeLV infections cause few ocular problems in domestic cats, except for FeLV-associated ocular lymphosarcoma (Townsend 2008). Intrauterine or early neonatal infection cases can cause retinal dysplasia (Glaze 2005). The uveal tract is a common site for hematogenous metastasis of neoplastic lymphocytes. Ocular lymphosarcoma may initially present as uveitis.
The iris gradually becomes more involved and distorted and may lead to glaucoma. Marker et al. (2003), reported on a wild born-captive cheetah which died of multicentric T-cell lymphoma associated with FeLV, but no ocular lesions were noted. This cheetah was in a cage next to a FeLV infected cheetah which was in contact with domestic cats. The affected cheetah, which was previously FeLV negative, tested positive when diseased. Marker et al. (2003), tested captive cheetahs in Namibia and found FeLV not to be endemic to cheetahs. They are however very susceptible to FeLV. It is therefore advisable to be cautious about contact with FeLV positive domestic or wild felids. The enzyme-linked immunosorbant assay (ELISA) test can be used on serum samples to detect the FeLV antigen (Townsend 2008).

2.2.4 Feline Immunodeficiency Virus

Feline immunodeficiency virus (FIV) is a lentivirus which is most likely transmitted between animals via saliva and bite wounds (Pedersen et al. 1989). The FIV causes T-cell lymphocyte depletion and thereby compromises the animal’s immune system. These animals are therefore susceptible to diseases like toxoplasmosis (Brown et al. 1993). Anterior uveitis is the most frequent ocular disease in domestic cats with FIV (English et al. 1990). Infection with FIV has been demonstrated serologically in several species of non-domestic felids, in captive and free-ranging populations including lions, pumas (Puma concolor), bobcats (Lynx rufus), snow leopards (Panthera uncia) and cheetahs (Barr et al. 1989). There is, however, little evidence of FIV pathology in wild felids (Brown et al. 1993). The ELISA test is specific in detecting FIV antibodies and can be done on serum samples (Pedersen et al. 1989).

2.2.5 Feline Panleukopenia

Feline panleukopenia virus (FPLV) is classified under the family Parvovoridae and related to Mink enteritis virus (MEV) and Canine parvovirus (CPV) (Nakamura et al. 2001, Truyen et al. 2009). It is highly contagious and is transmitted by direct and indirect contact with infected animals and their secretions, especially faeces. Fleas may also transmit the virus and/or the virus may spread by food bowls, bedding or cages (Cullen & Webb 2013). In utero transmission may also occur (Truyen et al. 2009).
Cats are easily exposed to the virus because it is extremely resistant and can survive for a long time in the environment (Nakamura et al. 2001). The FPLV infects rapidly dividing cells such as lymphoid tissue, bone marrow, and intestinal mucosal cells. It can cause a wide range of diseases and clinical signs including acute onset fever, depression, leukopenia, vomiting, haemorrhagic diarrhoea and secondary infections (Gould & Papasouliotis 2013). The severity of the infection may be influenced by the pathogenicity of secondary bacterial infections (Lane et al. 2016). Queens that are infected or vaccinated just before or during pregnancy, normally do not show clinical illness, but infertility or abortion are common signs. Central nervous system (CNS) involvement, cerebellar hypoplasia, ataxia, intention tremors and a hypermetric gait have been noticed in kittens with late fetal or early neonatal infection.

Retinal dysplasia is the main ocular manifestation of FPLV during in utero or postnatal infection. Retinal thinning, degeneration and optic nerve hypoplasia have also been described (Percy, Scott & Albert 1975). Retinal dysplasia is defined as the abnormal retinal development and is clinically suspected by visualising rosettes or folds in the retina. Rosettes are microscopic folds of the retina which look like circular lesions of foci (Stiles 2014). Retinal dysplasia can have different appearances on the fundus examination. Multiple gray foci can be located in the tapetum or non-tapetum. Affected areas can be visualised as hyperreflective or hyporeflective lesions in the tapetum while lesions in the non-tapetal fundus will appear depigmented or pale (Stiles 2014). Lesions can be geographic or local (Stiles 2013). Less severe cases will show bilateral retinal folds and severe cases will also show areas of retinal degeneration and scarring (Narfstrom 1999). Diagnosis of FPLV can be confirmed by histological examination, electronmicroscopy and identification of the virus. Serological testing is of limited value (Gould & Papasouliotis 2013, Johnson 1964).

FPLV has been reported in many captive wild felids like leopards (Johnson 1964), lions (Chandran et al. 1993, Studdert, Kelly & Harrigan 1973), tigers (Povey&Davis 1977), cheetahs (Van Vuuren et al. 2000), European wild cat (Felis sylvestris) (Wasieri et al. 2009), African wild cat (Felis lybica), ocelot (Leopardus pardalis), puma, Siberian tiger (Panthera tigris altaica) and the spotted cat (Prionailurus rubiginosus). No ocular lesions were documented (Filoni et al. 2006).
Eighty four percent of the free ranging lions in the Kruger National Park (Spencer 1991) and 48% of the cheetahs in Namibia (Munson et al. 2004), also tested positive for FPLV antibodies. These animals were free of any clinical signs at the time of testing.

An outbreak of FPLV has been documented in young vaccinated cheetah cubs in 2012 at a breeding centre in South Africa. Eleven, 6-8 month old captive bred cheetah cubs were presented with lethargy, inappetence, vomiting and diarrhoea. Five of the cubs died, despite aggressive treatment. No ocular lesions were identified, clinically or on necropsy. Gross pathology, electron microscopy and PCR were used to diagnose FPLV (Lane et al. 2016). After this outbreak, 12 more cases of FPLV have been diagnosed in captive, unvaccinated African black-footed cats (*Felis nigripes*), caracal, cheetah, lion, ocelot and serval, throughout South Africa (Lane et al. 2016). Intensive farming conditions, a lack of vaccination, poor hygiene and the unsuccessful exclusion of domestic carnivores from enclosures have been suggested to cause the increasing incidence of FPLV in captive carnivores (Lane et al. 2016).

### 2.2.6 Bartonellosis

*Bartonella* is a vector-borne, gram negative bacterium that infects mammalian erythrocytes and endothelial cells. It causes long-lasting bacteraemia in its reservoir host (Cullen & Webb 2013). *Bartonella henselae* is common in domestic cats with 55-81% of cats being seropositive. Many infected cats, however, do not show any clinical signs (Lappin & Black 1999), and only 5-10% of infected patients have ocular signs (Cunningham Jr & Koehler 2000). Bartonellosis most commonly causes uveitis, but ocular pathology like blepharitis, conjunctivitis, keratitis and chorioretinitis has also been reported (Cullen & Webb 2013). Fleas, ticks and biting flies can carry the bacteria and act as vectors in the transmission of *Bartonella* from cat to cat. Chomel et al. (2006) isolated *B. henselae* in non-domestic felids from the *Panthera* genus (lions, tigers, leopards and jaguars), cheetahs and various small wild cats of the genus *Felis*, in zoological parks in California. He also diagnosed bartonellosis in captured lions and cheetahs in Africa between 1982 and 2002. No ocular lesions were noted.
Moila et al. (2016) isolated *B. Henselae* and *B. Koehlerae* in free-ranging lions from the Kruger National Park, a cheetah from Namibia and in semi-captive cheetahs from North America. PCR can be used on EDTA samples to detect *Bartonella* DNA. IFA can detect the presence of *Bartonella* antibodies in serum (Chomel et al. 2006).

### 2.2.7 Toxoplasmosis

*Toxoplasma* is an intracellular protozoal parasite with a worldwide distribution (Dubey et al. 2004). Cats are intermediate and definitive hosts of *Toxoplasma gondii* and are the only species that can shed oocysts which are infective to other species. Oocysts are resistant to environmental conditions and they may remain infectious for months to years (Dubey et al. 2004). Toxoplasmosis can cause multi-systemic disease. Ocular pathology typically is chorioretinitis with or without concurrent uveitis. Optic neuritis has also been reported in affected domestic cats (Davidson & English 1998). Associations have been made between toxoplasmosis and FIV. Positive serum antibody titres for toxoplasmosis have been found more often in FIV-positive domestic cats than in FIV-negative domestic cats (O'Neil et al. 1991). A number of reports identified *Toxoplasma gondii* exposure in cheetahs in zoological parks (Sedlák & Bártová 2006, Spencer, Higginbotham & Blagburn 2003) as well as in free-ranging populations (Cheadle, Spencer & Blagburn 1999). Although infection is prevalent in domestic and non-domestic felids, clinical disease is rare (Dubey et al. 2004) and no ocular lesions have been documented in clinically diseased captive cheetahs (Lloyd & Stidworthy 2007, Van Rensburg & Silkstone 1984). Cheadle et al. (1999) showed that captive and free-ranging non-domestic felids in Southern Africa have been exposed to, and are likely to be infected with *Toxoplasma gondii* and *Neospora caninum*. Serological tests are validated for use in domestic cats, but not in the cheetah (Lloyd & Stidworthy 2007). Although immunoglobulin G (IgG) titres are frequently raised in exposed non-domestic felids, single samples do not help in the diagnosis of active infection. This is because IgG levels may be elevated for months or years after exposure. Demonstration of a rising IgG titre over 2-3 weeks may indicate recent or active infection (Lappin & Powell 1991).
2.2.8 Cryptococcosis

Cryptococcus is an opportunistic, non-contagious organism and is the most prevalent systemic mycoses in mammals and humans (Cullen & Webb 2013). Cryptococcus neoformans is the most commonly reported feline mycotic infection. It is normally associated with high nitrogen-containing environments like soil enriched with avian faeces. Birds can therefore be vectors of Cryptococcus spp. (O’Brien et al. 2004). Inhalation of infective material is the most common route followed as it spreads systemically to sites like the nasal passages, skin and CNS. Ocular lesions such as chorioretinitis with granulomatous inflammation and retinal detachments, optic neuritis and anterior uveitis have been reported in domestic cats (Gerds-Grogan & Dayrell-Hart 1997). Millward & Williams (2005) reported a free-ranging cheetah with Cryptococcus neoformans, while all the previous reported cases have been in captive cheetahs (Bernstein 1979, Berry, Jardine & Espie 1997, Bolton et al. 1999). No ocular lesions were reported. Lateral flow antigen testing and CSF analysis can help in the diagnosis of cryptococcosis. Serological tests on serum for cryptococcal antibodies are also available (Berry et al. 1997).

2.3 Cataracts

A cataract is an opacity of the lens and/or its capsule. An important differential diagnosis is nuclear sclerosis. New lens cells are produced at the equator of the lens, throughout an animal’s life. The new transformed lens fibres force the old lens fibres towards the centre called the lens nucleus. Nuclear sclerosis is the hardening of the nucleus of the lens due to compression of the central portion of the lens. Clinically it appears as an obvious but transparent sphere within the lens. Cataracts can be caused by several events and diseases such as embryological maldevelopment, heritability, diet, trauma, metabolic and infectious diseases.

The position of the cataract in the lens and the appearance of the opacity, can help to classify the cataract and determine a possible cause. The position of the opacity in the lens may be capsular, subcapsular, nuclear or cortical. It may lie at the anterior or posterior poles of the lens, or involve the equatorial region of the lens (Ofri 2013). Cataracts can also be classified by the stage of development. Incipient cataracts are very early lens changes and may involve just a few lens fibres.
Immature cataracts do not involve the entire lens and a fundic reflex can still be seen. Mature cataracts involve the entire lens and no tapetal reflex is visible. In advanced or hypermature cataracts, degradative enzymes from degenerative and ruptured lens fibres cause further proteolysis of areas in the lens. Lens proteins may liquefy and leak through the lens capsule and cause uveitis. Morgagnian cataracts have liquefied lens proteins and a dense nucleus which sinks ventrally in the lens capsular bag (Petersen-Jones 2002). Whether an animal is affected clinically by cataracts, depends on the lenticular opacifications. Minor changes may cause minimal to no visual problems while complete cataracts cause blindness in the affected eye (Narfstrom 1999).

Congenital cataracts are often associated with other ocular abnormalities such as microphthalmia, persistent pupillary membranes (PPM), persistent hyperplastic primary vitreous/persistent hyperplastic tunica vasculosa lentis (PHPV/PHTVL), and retinal dysplasia. Hereditary cataracts usually have characteristic anatomic localisation and appearance of the lens opacity in the initial stages. The age at the start, the progression, bilateral nature, and absence of other ocular disorders that might cause cataract formation, can indicate that these cataracts are likely to have a heritable basis (ACVO Genetics Committee, 2010). Hereditary cataracts most commonly involve the nucleus or the posterior cortex and progression is variable. Hereditary cataracts in domestic cats are rare (Williams & Heath 2006). Congenital cataracts have been described in Persian (Peiffer & Gelatt 1975), British shorthaired breeds (Irby 1983), Birman (Schwink 1986), Himalayan (Rubin 1986) and domestic short haired cats (Stiles 2013). Inherited cataracts have been shown to be caused by developmental disturbances during lenticular differentiation in the already-formed lens vesicle (Graw 1996). Williams and Heath (2006) reported that the prevalence of cataracts in the domestic cat population, increases with age and that by 17 years of age, all cats are affected to some extent by lens opacity.

Apart from the above mentioned congenital and hereditary types of cataracts, most feline cataracts are secondary to other ocular diseases such as uveitis, glaucoma, ocular neoplasia, nutrition or trauma (Narfstrom 1999).
Conditions such as anterior uveitis and glaucoma change the composition and characteristics of the aqueous humour. Aqueous humour is important for the nutrition and removal of waste products for the lens. Both of these disease processes can therefore induce cataract formation (Petersen-Jones 2002). Direct trauma to the lens or trauma-induced uveitis may result in cataract formation. These cataracts tend to be in the region of the incident, and are often associated with posterior synechia (Davidson & Nelms 2013).

Metabolic cataracts due to diabetes mellitus are very common in dogs and progress very quickly to mature cataracts. The increase of glucose in the blood levels leads to the increase of glucose in aqueous humour and in the lens. The normal hexokinase pathway for glucose in the lens becomes saturated. Glucose then enters the sorbital pathway where aldose reductase converts glucose to sorbitol. Sorbitol is a larger molecule than glucose and cannot diffuse out of the lens fibres. This creates an osmotic gradient, which causes fluid uptake in the lens and leads to the disruption of the lens fibres, vacuolation and cataract formation (Petersen-Jones 2002). Diabetic cataracts are rare in felines because of the low activity of the aldose reductase in lenses of older cats compared to canines (Stiles 2013). Contrary to other findings, Williams and Heath (2006) found cataracts to be present in almost all of the diabetic domestic cats in their study. These feline cataracts were small linear opacities, posterior cortical opacities or posterior polar plaques.

Poor nutrition, like inappropriate milk substitute, can cause cataract formation. A study by Remillard et al. (1993) showed that milk replacements, with inadequate levels of arginine, can cause anterior and posterior lens opacification in kittens. Quam, Morris & Rogers (1987) also proved that histidine is an important requirement in kitten diets for normal lens fibre growth. The majority of the opacities faded to a perinuclear halo or incipient cortical opacities as the kittens matured and the milk replacement was substituted by a balanced growth diet (Remillard et al. 1993). The pathogenesis of these diet related opacities can be, according to Remillard et al. (1993), be more complex than just a single amino acid, protein or glucose deficiency or imbalance.
Electric shock, like biting through an electric cord (Brightman et al. 1984), electric fencing or a lightning strike can result in anterior subcapsular cataract formation (Davidson & Nelms 2013). Radiating energy, which is used for treatment of neoplasms of the head or nasal area, is reported to affect the newly formed lens fibres. This can result in equatorial and anterior and posterior subcapsular cataract changes (Roberts et al. 1987).

Cataracts in various stages of development were found in a group of closely related Angolan lions (African leo bleyenberghi) in two German zoos. Inherited and congenital cataracts were suspected in these cases (Steinmetz et al. 2006).

Unpublished reports from AfriCat in Namibia, showed that 75% of the cheetahs had ocular lesions and that the incidence of cataracts was 27.47%. A very high incidence of corneal lesions was also noted and both lesions were probably related to trauma from an overgrazed, bush encroached environment (Bauer n.d.).

### 2.4 Retina

Non-infectious ocular diseases, which have been documented in cheetahs, include feline central retinal degeneration (FCRD) associated with dietary taurine deficiency (Ofri et al. 1996). Taurine is an important amino acid in felines and is essential for vision, cardiac function, muscle function and proper function of the nervous, reproductive and immune system. Felines lack the enzyme cysteine sulfenic acid decarboxylase, which is needed to synthesize taurine (Lombardini 1991). Although dietary intake is the most important source of taurine in cats, their taurine homeostasis depends on many factors like endogenous synthesis, microbial degradation in the lower gut, turnover in the enterohepatic circulation and urinary and faecal losses (Morris, Rogers & Pacioretty 1990). Retinal changes can take several weeks to months to occur on a taurine deficient diet (Markwell & Earle 1995). Typical ocular lesions of taurine deficient retinopathy are the granular appearance of the tapetum which progresses to a hyperreflective horizontal streak in the region of the area centralis, dorsolateral to the optic disc (Cullen & Webb 2013). A second horizontal band of hyperreflectivity can appear on the medial side, which extends until the two sides coalesce superior to the optic disc.
Advanced cases can even show retinal degeneration with attenuation of retinal blood vessels and visual deficits. The degenerative process is more advanced in the outer retinal layers, where disorganisation and disorientation of the photoreceptors occur. Electroretinogram (ERG) abnormalities can be observed after several months (Barnett & Burger 1980). Partial vision loss might be reversible following taurine supplements, but the ophthalmic lesions are permanent (Berson et al. 1981).

Taurine levels can be measured by whole blood concentration or plasma levels to indicate insufficiency or to monitor supplementation. Whole blood concentration is a better indication (Hedberg, Dierenfeld & Rogers 2007), because plasma levels are influenced by dietary intake (Markwell & Earle 1995). Taurine blood levels of above 200 µmol/L and plasma levels above 50 µmol/L, would indicate a satisfactory taurine status in the domestic cat (Morris et al. 1990). Dietary taurine levels of 1200 mg taurine/kg dry matter in dry extruded diets and 2500 mg taurine/kg dry matter in canned diets have been suggested to prevent retinal disease in felids (Earle & Smith 1991, Morris et al. 1990).

Taurine deficiency in captive leopard cats (*Felis bengalensis*) has also been described (Howard et al. 1987). Ophthalmic examination revealed bilateral mydriatic pupils with tapetal hyperreflectivity. Retinal blood vessels varied from being attenuated to complete avascularisation (Howard et al. 1987, Morris et al. 1990).

Docosahexaenoic acid (DHA) deficiency has been reported to cause decreases in ERG amplitudes and affects the phototransduction (Narfström & Peterson-Jones 2013). DHA is part of the omega-3 fatty acids and is concentrated in various cells of the retina and brain (Bazan 2006). The highest concentration of DHA is found in the outer segments of the photoreceptors. Retinal pigment epithelium (RPE) cells play an important role in the maintenance of the photoreceptors. During outer segment renewal, the RPE cells recycle DHA back to the inner segments of the photoreceptors (Bazan 2006). It has been reported that infant formulas supplemented with DHA, enhanced retinal function maturity, visual acuity and overall neurological performance in infants (Birch 1998, Uauy 1990). Essential fatty acid (FA) deficiencies have been suspected in captive cheetahs (Davidson, Cantrill & Varday 1986).
Tordiffe (2016) reported a marked difference in the serum FA profiles between captive and free-ranging cheetahs. These serum profiles indicated that free ranging cheetahs consumed significantly more saturated fat and less unsaturated fat when compared to captive cheetahs. It has been suggested that dietary FA composition can have a potential impact on the health of cheetahs in captivity.

2.5 Miscellaneous

Less common ocular pathology described in cheetahs are bilateral optic nerve hypoplasia or optic nerve atrophy (Walser-Reinhardt et al. 2010), and corneal squamous cell carcinoma (Caligiuri et al. 1988).
CHAPTER 3.OBJECTIVES, BENEFITS AND HYPOTHESIS

3.1 Objectives

The objective of this research programme is to describe the abnormalities and to provide an indication of the prevalence of the abnormalities that can be observed by routine ophthalmic examination of two populations of immobilised captive adult cheetahs.

3.2 Benefits

Knowledge about the prevalence of ocular diseases can help with the breeding selection, management and treatment of cheetahs in captivity.

To the author’s knowledge, no data is currently available for the average STT, IOP and ocular ultrasonic appearance and biometry of the cheetah species. Reference values specifically for cheetahs can aid in the diagnosis and treatment of ocular disease in cheetahs.

3.3 Hypothesis

The prevalence of the ophthalmic observed abnormalities in immobilised captive adult cheetahs will be higher and of a different nature to that which is described for the domestic cat population.
CHAPTER 4. MATERIALS AND METHODS

4.1 Model System

The populations of adult cheetahs within the Ann van Dyk Cheetah Centre and AfriCat Foundation were used for this research project.

The Ann van Dyk Cheetah Centre is a breeding centre for cheetahs and other endangered animals. It was founded in 1971 by the conservationist Ann van Dyk. She has bred over 600 cheetahs since establishing the Centre (www.dewildt.co.za). Cheetahs owned by Ann van Dyk were examined during the period of June 2014 – June 2016. They were housed at the Ann van Dyk Cheetah Centre (Figure 1) and the Shingwedzi Centre (Figure 2) in camps with an average size of 1.5 hectares and 1-4 cheetahs per camp (Appendix no 1). The Ann van Dyk Cheetah Centre is situated in the foothills on the northern side of the Magaliesberg Mountain Range, to the northwest of Pretoria. GPS coordinates of the Centre are 25° 40’ 25.1” S, 27° 55’ 25.4” E. The farm is located in the savanna biodiversity region at 1118m above sea level. The average temperature is 23.4°C with January being the hottest month of the year with average temperatures of up to 30°C. June is normally the coldest month of the year when temperatures can fall to around 2°C. The annual rainfall is 620mm.

The Shingwedzi Centre is close to Bela-Bela in the Waterberg Mountains with coordinates of 24°40’12.4” S, 28° 02’ 00.7” E. Shingwedzi is about 1151 m above sea level and is also located in the savannah biodiversity region. The average temperature is the same as at the Ann van Dyk Cheetah Centre and with an annual rainfall of 625mm.

Both of these two groups of cheetahs formed part of Ann van Dyk breeding programme. The management, diet, camp size and environment are similar. For the purposes of this study, these two groups will be treated as a single entity. The cheetah’s diet consists of 1.2 kg mixed food once a day, six days a week. The mixed food consisted of 250 g Ultra Feline pellets (Scientific Veterinary Diets, South Africa), 600 g cooked chicken mince and 350 g horse mince. Once a week they received 1.5 kg bone, mixed with the meat.
Powdered supplements with calcium, multivitamins and minerals (Predator supplement; V-Tech, Centurion, South Africa) are given on alternative days.

The AfriCat Foundation (Figure 3) is situated on the Okonjima Farm, 50km southwest of Otjiwarango in central Namibia (Figure 4) (www.okonjima.com/ www.africat.org). GPS coordinates are 20°49’ 19.36”S, 16°38’ 21.25”E. The Okonjima Farm is located at an average altitude of 1532 m and is surrounded by the Omboroko Mountains. The vegetation is described as savanna veld with woody trees and scrubs. The annual average temperature is 20.3°C, with December being the warmest month of the year (up to 30°C). June is the coldest month, with temperatures as low as 1°C. The annual rainfall at the AfriCat Foundation averages approximately 450 mm.

The AfriCat Foundation is a 22 000 hectare sanctuary dedicated to research and in particular in the rehabilitation of Namibia’s carnivores, particularly cheetah and leopard as well as wild dogs and brown hyena. AfriCat rescues felids that are casualties of human and wildlife conflict on Namibia’s farmlands and return more than 85% to the wild. All cheetahs are kept in captivity in large enclosures. The camp sizes vary from 3.5-25 hectare camps with 2-5 cheetahs per camp (Appendix no 2). All the females are treated yearly with contraceptive implants, as it is prohibited by law to breed with large carnivores in captivity in Namibia. Their diet consisted of 1.2–1.5 kg of donkey or horse meat and bones for 6 days of the week. The diet is supplemented with a powdered multivitamin and mineral supplement (Predator Powder®; Healthtech, South Africa).
Figure 1. The Ann van Dyk Cheetah Centre.

Figure 2. Cheetah at the Shingwedzi Centre.

Figure 3. The AfriCat Foundation’s logo.
4.2 Study Design

A prospective descriptive study design was used to determine the prevalence of ocular pathology in captive adult cheetahs.

4.3 Patient Selection

During the current study, a complete ocular examination was performed, during the period from June 2014 to July 2016, on immobilised adult cheetahs between 1 to 14 years old of age. These animals were undergoing routine health examinations which were performed as part of their health programme undertaken by the Ann van Dyk Cheetah Centre and the AfriCat Foundation.

The study design and cheetah immobilisation programme of the Ann van Dyk Cheetah Centre, was set up according to their breeding protocol, which did not allow for any study-specific immobilisation for research purposes. Twenty six females and 21 males were examined and formed part of Group 1.
In the case of the AfriCat Foundation cheetahs, eight females and 18 males were examined and formed part of Group 2.

4.4 Study Procedures

This study formed part of the cheetah’s health examination while they were immobilised. The immobilisation was performed by wildlife veterinarians, experienced in cheetah anaesthesia. They immobilised and monitored the animals for the duration of the procedures. The health examination performed, included a combination of the following procedures: dental checks, abdominal ultrasound, gastric biopsies, blood collection, sperm collection and vaccinations. The concomitant ocular tests and examinations were solely performed by the author and included the following procedures: STT, IOP, slit-lamp biomicroscopy, indirect ophthalmoscopy, fluorescein testing and ocular ultrasound examination and measurements. The examination and measurements were taken between 08h00 and 16h00. The identification, microchip, sex, weight, ocular measurements and examination were recorded on an examination record sheet (Appendix no 3) for each cheetah.

Group 1:

1) The cheetahs were enticed with food to move into a small cage for immobilisation. The drug combination of 0.05-0.08 mg/kg medetomidine hydrochloride (Medetomidine 10mg/ml, Kyron Laboratories Pty Ltd, South Africa) and 3 mg/kg ketamine (Anaket V, Bayer (Pty) Ltd, Isando, 1601, South Africa) was used for immobilisation. This drug combination was administered intramuscular using a pole syringe. The dose was adapted to suit age, physical condition of the animal, excitement, stress and time of the day.

2) After immobilisation (7–15 minutes after administering of the injection), the cheetah was immediately removed from the cage onto a carry mat or stretcher (Figure 5). The cheetah was transported on the back of a vehicle to the hospital or examination area. It was weighed as soon as the cheetah was removed from the vehicle and before it was moved into the examination area (Figure 6).
3) The cheetah was placed on its left side. Blood samples were taken from the medial saphenous vein in labelled EDTA, serum (SST) and heparin vacuum containers (Figures 7 & 8). These blood samples were kept in a cooler bag with ice during examination. The blood in the serum container was centrifuged within six hours from collection and the serum was separated as soon as possible. The serum, EDTA and heparin were divided into aliquots of 1.2 ml, labelled and stored in the virology lab. Serum samples were stored at –20°C and the EDTA and heparin samples were stored at –80°C until needed for further testing. Potentially, this blood can be used for future DNA genetic testing, serum chemistry analyses, serology and virus isolation.

4) An intravenous catheter was placed in the saphenous vein and one litre Ringer’s lactate drip was infused for the duration of the immobilisation.

5) The STT (Schirmer Tear Test, Merck Animal Health, 117 16th Road, Halfway House, Midrand, 1685, South Africa) (Figure 9) was measured and recorded on the data sheet.

6) Tonometry was done with the rebound TonoVet tonometer (Icare, Äyritie 22, FI-01510 Vantaa, Finland), using the ‘d’ setting. Care was taken to avoid excessive manipulation of the eyelids or pressure on the neck.

7) A conjunctival swab was taken for virus isolation. It was placed into transport medium, kept cold and stored at -80°C as soon as possible.

8) A drop of 1% Tropicamide (Mydriacil, Alcon Laboratories (Pty) Ltd., 65 Peter Place, Bryanston Extension 13, South Africa) was applied to each eye to cause temporary mydriasis and assist in the evaluation of the lens and retina.

9) The examination area was darkened for the rest of the ocular examination.

10) Slit-lamp biomicroscopy (Keeler PSL Classic, Keeler Ltd, ClewerHill Road, Windsor, SL4 4AA, UK) was performed to assess the extraocular structures as well as the cornea, anterior chamber, iris, lens and anterior vitreous (Figure 10).

11) Other procedures including a health examination, dental examination, gastric biopsies and semen collection were also performed.

12) After these procedures the pupil was dilated sufficiently to perform the rest of the ocular examination. Another slit-lamp biomicroscopy examination was performed to evaluate the peripheral lens.
13) The fundus was examined with a binocular indirect ophthalmoscope (Neitz 10-α binocular indirect ophthalmoscope Neitz Co, Ltd, Tokyo, Japan) and a 20 dioptre biconvex lens (Heine Germany) (Figure 11).

14) Fundus images were taken (Volk PictorPlus Ophthalmic camera, Volk Optical, Inc. 7893 Enterprise Drive, Mentor, OH 44060) (Figure 12).

15) Fluorescein sodium 2% (Minis® Fluorescein Sodium 2% w/v, Bausch & Lomb, Chauvin Pharmaceuticals Ltd, UK) was applied and examined with a cobalt blue light.

16) A drop of Oxybuprocaine (Novesin Wander 0.4%, Novartis, Adcock Ingram Limited, Bryanston, 2021, South Africa) was installed in both eyes to provide local anaesthesia for the ocular ultrasound examination.

17) Ultrasonography was performed after application of acoustic ultrasonic coupling gel on the cornea (Figure 13). A portable ultrasound machine with B-mode transducer of 12 MHz and linear array probe was placed directly on the cornea (Sonoscape S2, SonoScape Medical Corporation from Axim, Midrand South Africa). Transverse and sagittal views were used to assess the globe. The following measurements: axial globe length (AGL), axial lens thickness (ALT), anterior chamber depth (ACD) and posterior segment depth (PSD) were taken in transverse view, using the electronic built-in calliper of the ultrasound unit (Figure 14).

18) Ultrasonic gel was removed by careful irrigation of the eyes with sterile eyewash after completion of the ultrasound examination.

19) Following full ophthalmological examination, the eyes were treated with an ocular lubricant containing sodium carboxymethyl cellulose (OptivePlus™, Allergan Pharmaceuticals (Pty) Ltd, 30 New Road, Randjespark Ext 11, Midrand 1685, South Africa), to prevent desiccation of the cornea.

20) After examination, 0.03-0.06 mg/kg atipamazole (Antisedan, Pfizer Animal Health, Sandton, 2196, South Africa) was given intramuscularly to reverse the sedation.

21) The cheetah was placed into a cheetah crate, in a shady area for 30-60 minutes to ensure good recovery under supervision (Figure 15).

22) Once the wildlife veterinarian was satisfied with the cheetah’s recovery, the cheetah was taken back to its normal enclosure.
Group 2.

1) To facilitate capture, the cheetahs were called from their large ‘home’ camps into adjacent smaller management camps prior to darting. Each cheetah was darted intramuscularly with a dart gun (Dartinject, Denmark) (2 ml air-pressured dart delivered by a carbon dioxide powered dart gun) with a combination of 0.94–1.4 mg/kg tiletamine/zolazepam (Zoletil®, Virbac, Halfway House, South Africa) and 0.033–0.045 mg/kg medetomidine hydrochloride (Medetomidine 10mg/ml, Kyron Laboratories Pty Ltd, South Africa). This was based on last known weight and visual assessment of each cheetah.

2) STT and IOP, in that order, were evaluated as soon as the animal could be safely approached, approximately 12-20 minutes after the animal had been darted. These measurements were taken as described in Group 1.

3) Topical Tropicamide (Mydriacil, Alcon Laboratories (Pty) Ltd., 65 Peter Place, Bryanston Extension 13, South Africa) was administered to each eye.

4) Once the wildlife veterinarian was satisfied that the cheetah was stable under immobilisation, the cheetah was carried on a stretcher to a vehicle and transported to the clinic (5–10 minutes drive).

5) The cheetah was weighed and placed in left lateral recumbency. Blood samples were taken for storage and an intravenous catheter was placed in the saphenous vein to infuse intravenous Ringer’s lactate.

6) The cheetah was intubated with an endotracheal tube and general anaesthetic was maintained with either isofluorane in oxygen (Isofor, Safeline Pharmaceuticals, Johannesburg, South Africa) or a continuous rate infusion of intravenous propofol (Fresenius Propofol, Fresenius Kabi, Johannesburg, South Africa) with supplemental oxygen. The anaesthesia protocol was part of a research study and cheetahs were chosen randomly for isofluorane or propofol anaesthesia.

7) A number of other procedures were also performed on the immobilised cheetahs as part of concurrent studies, for example blood tests, gastric endoscopy with biopsies, dental assessment and treatment, sperm evaluation and abdominal ultrasonography.

8) The examination area was darkened to perform the ocular examinations.

9) Slit-lamp biomicroscopy was performed as described above for Group 1.
10) The fundic examination and photography were performed as previously described.

11) Fluorescein was applied topically as described above.

12) Ultrasound and biometry was performed after topical anaesthesia as described previously. A portable ultrasound machine was used with a 5-10 MHz linear array transducer set at 10 MHz (Mindray Model M7, Shenzhen Mindray Biomedical from Lomaen, Johannesburg, South Africa).

13) Ultrasonic gel was removed by careful irrigation of the eyes with sterile eyewash after completion of the ultrasound examination.

14) Following full ophthalmological examination, the eyes were being treated with an ocular lubricant containing sodium carboxymethyl cellulose (OptivePlus™, Allergan Pharmaceuticals (Pty) Ltd, 30 New Road, Randjespark Ext 11, Midrand 1685, South Africa), to prevent desiccation of the cornea.

15) After all the examinations were completed, the cheetahs were placed in a cheetah crate and given 0.08 – 0.12 mg/kg atipamazole (Antisedan, Pfizer Animal Health, Sandton, 2196, South Africa) intramuscularly, to antagonise the medetomidine.

16) The cheetahs were released once the wildlife veterinarian was satisfied with their recovery.
Figure 5. The cheetah being carried on a stretcher from the vehicle.

Figure 6. Weighing the cheetah at the Shingwedzi Centre.

Figure 7. Blood being collected from the medial saphenous vein of the cheetah.
Figure 8. Close up of blood being collected from the medial saphenous vein.

Figure 9. The Schirmer tear test is being taken in both eyes of this cheetah.

Figure 10. Slit-lamp biomicroscopy of the cheetah eye.
Figure 11. Indirect ophthalmoscopy examination of a cheetah.

Figure 12. Fundus imaging of a cheetah with a Volk PictorPlus Ophthalmic camera.

Figure 13. Ocular ultrasonography of the left eye of the cheetah.
**Figure 14.** Biometry of an adult cheetah eye with B-mode ultrasonography. 1- Axial globe length. 2- axial lens thickness. 3- anterior chamber depth. 4- posterior segment depth.

**Figure 15.** Cheetah recovering in a cheetah crate after immobilisation and examination.
4.5 Data Analysis

Data from the examination sheets were entered into a spreadsheet (Microsoft Office Excel 2007). Age was categorised into three equal sized groups (1-4 yr / 5-6 yr / ≥7 yr). Statistical significance was assessed at $P \leq 0.05$. Analyses were performed using Stata 14 (StataCorp, College Station, TX, U.S.A.).

For continuous outcome measurements (STT, IOP, AGL, ALT, ACD, PSD), the left and right eye were compared using paired $t$-tests. The values for left and right eyes of each animal were averaged and then considered as a single value for further analyses. The mean, standard deviation and range were calculated for each outcome. Means were compared between groups, age groups and genders using one-way ANOVA with Bonferroni adjustment. Multiple linear regression analyses were performed to investigate the simultaneous association of group, age group and gender with each of the continuous ocular variables and to adjust for potential confounding.

For binary outcome variables (presence of specific lesions), the prevalence of each lesion was calculated with a 95% confidence interval. These lesions were then compared between different groups, age groups and genders using cross tabulation and two-tailed Fisher’s exact test. Multivariable analysis was not performed for the binary outcomes due to the very low numbers of positive outcomes for most lesions.

4.6 Ethical Consideration

This study was approved by the Animal Ethics Committee according to the South African National Standards (SANS 10386-2008). This project falls in the research category B where the procedures on the animals produced stress, but no pain was inflicted on any animal. No animal was specifically anaesthetised for the sole purpose of this study. The University of Pretoria Animal Ethics Committee authorised the Ann van Dyk Cheetah Centre project (Project no. V038-14). This research project also formed part of the African Foundation long-term health and immune–competence study of captive cheetahs and was approved by the University’s Animal Use and Care Committee and Research Committee (Project no. V044-16).
CHAPTER 5. RESULTS

A total number of 73 cheetahs were examined. A summary of the total number of cheetahs examined, the different genders and the distribution of different age groups are reported in Tables 1, 2 & 3.

Table 1. Group and gender distribution of cheetahs examined.

<table>
<thead>
<tr>
<th>Group</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AvDCC</td>
<td>26</td>
<td>21</td>
<td>47</td>
</tr>
<tr>
<td>AfriCat</td>
<td>8</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>39</td>
<td>73</td>
</tr>
</tbody>
</table>

AvDCC = Ann van Dyk Cheetah Centre

Table 2. Group and age group distribution of cheetahs examined.

<table>
<thead>
<tr>
<th>Group</th>
<th>1–4 yr</th>
<th>5–6 yr</th>
<th>≥7yr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AvDCC</td>
<td>25</td>
<td>11</td>
<td>11</td>
<td>47</td>
</tr>
<tr>
<td>AfriCat</td>
<td>2</td>
<td>12</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>23</td>
<td>23</td>
<td>73</td>
</tr>
</tbody>
</table>

AvDCC = Ann van Dyk Cheetah Centre

Table 3. Gender and age group distribution of cheetahs examined.

<table>
<thead>
<tr>
<th>Group</th>
<th>1–4 yr</th>
<th>5–6 yr</th>
<th>≥7yr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females*</td>
<td>14</td>
<td>10</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>Males</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>23</td>
<td>23</td>
<td>73</td>
</tr>
</tbody>
</table>

Measurements of the left and right eyes are reported in Table 4.
The STT measurements for the left and the right eye differed significantly ($P=0.03$).
The anterior chamber depth also showed a significant difference between the left and right eye (\( P=0.04 \)), but the mean difference was only 0.25 mm. No other measurements showed a statistical difference between the left and right eyes.

Table 4. Average measurements of the left and right eye of cheetahs examined.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Right eye</th>
<th>Left eye</th>
<th>( P )- value</th>
</tr>
</thead>
<tbody>
<tr>
<td>STT (mm/min)</td>
<td>11.79</td>
<td>13.61</td>
<td>0.03</td>
</tr>
<tr>
<td>IOP (mmHg)</td>
<td>30.69</td>
<td>30.21</td>
<td>0.40</td>
</tr>
<tr>
<td>AGL (mm)</td>
<td>32.55</td>
<td>32.53</td>
<td>0.94</td>
</tr>
<tr>
<td>ALT (mm)</td>
<td>6.85</td>
<td>6.83</td>
<td>0.89</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>8.66</td>
<td>8.91</td>
<td>0.04</td>
</tr>
<tr>
<td>PSD (mm)</td>
<td>16.25</td>
<td>16.03</td>
<td>0.31</td>
</tr>
</tbody>
</table>

\( STT = \) Schirmer tear test. \( IOP = \) Intraocular pressure \( AGL = \) anterior globe length. \( ALT = \) axial lens thickness, \( ACD = \) anterior chamber depth. \( PSD = \) posterior segment depth.

All the measurements between the eyes of each animal were averaged and each animal was considered as an individual for further calculations (Table 5).

Table 5. Average ocular measurements of total eyes of cheetahs examined.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>STT (mm/min)</td>
<td>12.7</td>
<td>5.49</td>
<td>4 - 30</td>
</tr>
<tr>
<td>IOP (mmHg)</td>
<td>30.5</td>
<td>4.29</td>
<td>17 - 39.5</td>
</tr>
<tr>
<td>AGL (mm)</td>
<td>32.5</td>
<td>1.96</td>
<td>27.9 - 36.5</td>
</tr>
<tr>
<td>ALT (mm)</td>
<td>6.9</td>
<td>0.85</td>
<td>4.7 - 9.7</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>8.7</td>
<td>1.00</td>
<td>6.5 - 12</td>
</tr>
<tr>
<td>PSD (mm)</td>
<td>16.1</td>
<td>2.00</td>
<td>11.5 - 20.45</td>
</tr>
</tbody>
</table>

\( STT = \) Schirmer tear test. \( IOP = \) Intraocular pressure \( AGL = \) anterior globe length. \( ALT = \) axial lens thickness, \( ACD = \) anterior chamber depth. \( PSD = \) posterior segment depth. \( SD = \) standard deviation.

When ocular measurements were compared, no significant difference in STT values between the two groups of animals examined or between their genders were noted (Tables 6 & 8). The younger age group (1-4 yr) however, showed significantly lower STT readings when compared to the older cheetahs (\( P=0.02 \)) (Table 7).
No significant difference in the IOP was found between the two groups, the age groups or genders (Tables 6, 7 & 8). There was however a tendency for higher IOP in the AvDCC group \((P=0.07)\) (Table 6). Although not significant, the young cheetah group (1-4 yr) had higher IOP values and showed a tendency for these values to decrease with age (Table 7).

The axial globe length showed a significant difference between the two groups, the age groups and genders \((P<0.001)\) (Tables 6, 7 & 8). A significant difference between groups and age groups were also reported in the posterior segment depth \((P<0.001)\) (Tables 6 & 7).

Table 6. Ocular measurements between AvDCC and AfriCat cheetah groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>AvDCC</th>
<th>AfriCat</th>
<th>(P) – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>STT (mm/min)</td>
<td>12.1</td>
<td>13.8</td>
<td>0.201</td>
</tr>
<tr>
<td>IOP (mmHg)</td>
<td>31.1</td>
<td>29.3</td>
<td>0.073</td>
</tr>
<tr>
<td>AGL (mm)</td>
<td>31.8</td>
<td>33.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ALT (mm)</td>
<td>7.0</td>
<td>6.7</td>
<td>0.099</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>8.5</td>
<td>9.2</td>
<td>0.003</td>
</tr>
<tr>
<td>PSD (mm)</td>
<td>15.2</td>
<td>17.8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(AvDCC = \)Ann van Dyk Cheetah Centre. \(STT = \)Schirmer tear test. \(IOP = \)Intraocular pressure. \(AGL = \)anterior globe length. \(ALT = \)axial lens thickness, \(ACD = \)anterior chamber depth. \(PSD = \)posterior segment depth.

Table 7. Ocular measurements between age groups of cheetahs examined.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1–4 yr</th>
<th>5–6 yr</th>
<th>≥7yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>STT mm/min</td>
<td>10.5\textsuperscript{a}</td>
<td>13.0\textsuperscript{ab}</td>
<td>14.8\textsuperscript{b}</td>
</tr>
<tr>
<td>IOP mmHg</td>
<td>31.2\textsuperscript{a}</td>
<td>29.6\textsuperscript{a}</td>
<td>30.4\textsuperscript{a}</td>
</tr>
<tr>
<td>AGL mm</td>
<td>30.8\textsuperscript{a}</td>
<td>33.5\textsuperscript{b}</td>
<td>33.2\textsuperscript{b}</td>
</tr>
<tr>
<td>ALT mm</td>
<td>6.9\textsuperscript{a}</td>
<td>6.9\textsuperscript{a}</td>
<td>6.7\textsuperscript{a}</td>
</tr>
<tr>
<td>ACD mm</td>
<td>8.4\textsuperscript{a}</td>
<td>9.0\textsuperscript{a}</td>
<td>8.8\textsuperscript{a}</td>
</tr>
<tr>
<td>PSD mm</td>
<td>14.4\textsuperscript{a}</td>
<td>17.1\textsuperscript{b}</td>
<td>16.9\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\(\)Within rows, values with no superscript in common, differ significantly.  
\(STT = \)Schirmer tear test. \(IOP = \)Intraocular pressure \(AGL = \)anterior globe length. \(ALT = \)axial lens thickness, \(ACD = \)anterior chamber depth. \(PSD = \)posterior segment depth.
Table 8. Ocular measurements between genders of cheetahs examined.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Female</th>
<th>Male</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>STT (mm/min)</td>
<td>12.6</td>
<td>12.8</td>
<td>0.843</td>
</tr>
<tr>
<td>IOP (mm/Hg)</td>
<td>30.2</td>
<td>30.6</td>
<td>0.661</td>
</tr>
<tr>
<td>AGL (mm)</td>
<td>31.9</td>
<td>32.9</td>
<td>0.030</td>
</tr>
<tr>
<td>ALT (mm)</td>
<td>6.9</td>
<td>6.9</td>
<td>0.874</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>8.6</td>
<td>8.9</td>
<td>0.236</td>
</tr>
<tr>
<td>PSD (mm)</td>
<td>15.7</td>
<td>16.4</td>
<td>0.140</td>
</tr>
</tbody>
</table>

STT = Schirmer tear test. IOP = Intraocular pressure. AGL = Anterior globe length. ALT = Axial lens thickness. ACD = Anterior chamber depth. PSD = Posterior segment depth.

Multivariable analyses, where the association of group, age group and gender with ocular measurements, are reported in Tables 9–14. A significant difference ($P=0.02$) in the STT values was seen in older cheetahs ($\geq 7$ yr) compared to the young cheetah group (1-4 yr) (Table 9).

Table 9. Association of group, age and gender with STT values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$b$</th>
<th>95% Confidence interval</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>0.281</td>
<td>-2.71, 3.28</td>
<td>0.852</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>2.379</td>
<td>-0.94, 5.70</td>
<td>0.158</td>
</tr>
<tr>
<td>$\geq 7$ yrs</td>
<td>4.140</td>
<td>0.82, 7.46</td>
<td>0.015</td>
</tr>
<tr>
<td>Male vs Female</td>
<td>0.001</td>
<td>-2.59, 2.60</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*reference level.

AvDCC = Ann van Dyk Cheetah Centre. $b$ = regression coefficient.
No significant differences were reported when the IOP values were compared with the different groups, age and gender (Table 10).

**Table 10.** Association of group, age and gender with IOP values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$b$</th>
<th>95% Confidence interval</th>
<th>$P$ - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>-1.954</td>
<td>-4.35, 0.45</td>
<td>0.109</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>-0.716</td>
<td>-3.36, 1.92</td>
<td>0.590</td>
</tr>
<tr>
<td>≥7 yrs</td>
<td>0.066</td>
<td>-2.57, 2.71</td>
<td>0.960</td>
</tr>
<tr>
<td>Male vs female</td>
<td>0.914</td>
<td>-1.15, 2.98</td>
<td>0.380</td>
</tr>
</tbody>
</table>

*reference level

AvDCC = Ann van Dyk Cheetah Centre. $b$ = regression coefficient.

Significant differences were detected when the axial globe length of the age groups ($P<0.0001$) and genders ($P=0.05$) were compared (Table 11). The young cheetahs and the females showed a smaller globe length compared to the older cheetahs and to the males (Table 11).

**Table 11.** Association of group, age and gender with axial globe length values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$b$</th>
<th>95% Confidence interval</th>
<th>$P$ - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>0.669</td>
<td>-0.23, 1.57</td>
<td>0.143</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>2.302</td>
<td>1.32, 3.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>≥7 yrs</td>
<td>2.050</td>
<td>1.07, 3.03</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male vs female</td>
<td>0.732</td>
<td>-0.001, 1.47</td>
<td>0.051</td>
</tr>
</tbody>
</table>

*reference value

AvDCC = Ann van Dyk Cheetah Centre. $b$ = regression coefficient.
No statistically significant differences were reported on the axial lens length (Table 12).

**Table 12.** Association of group, age and gender with axial lens length values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( b )</th>
<th>95% Confidence interval</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>-0.385</td>
<td>-0.90, 0.13</td>
<td>0.141</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>0.138</td>
<td>-0.42, 0.70</td>
<td>0.624</td>
</tr>
<tr>
<td>( \geq )7 yrs</td>
<td>-0.061</td>
<td>-0.62, 0.50</td>
<td>0.827</td>
</tr>
<tr>
<td>Male vs female</td>
<td>0.053</td>
<td>-0.37, 0.47</td>
<td>0.801</td>
</tr>
</tbody>
</table>

*reference value

AvDCC = Ann van Dyk Cheetah Centre. \( b \) = regression coefficient.

The different cheetah groups showed a statistically significant difference of the anterior chamber depth (\( P=0.05 \)) (Table 13). AvDCC showed a smaller ACD compared to AfriCat.

**Table 13.** Association of group, age and gender with anterior chamber depth values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( b )</th>
<th>95% Confidence interval</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>0.576</td>
<td>-0.06, 1.16</td>
<td>0.052</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>0.355</td>
<td>-0.28, 0.99</td>
<td>0.266</td>
</tr>
<tr>
<td>( \geq )7 yrs</td>
<td>0.094</td>
<td>-0.54, 0.73</td>
<td>0.767</td>
</tr>
<tr>
<td>Male vs female</td>
<td>0.142</td>
<td>-0.33, 0.62</td>
<td>0.553</td>
</tr>
</tbody>
</table>

*reference value

AvDCC = Ann van Dyk Cheetah Centre. \( b \) = regression coefficient.
The different cheetah groups and age groups, showed a significant difference in the posterior segment depth \( (P<0.0001) \) (Table 14). The AfriCat and older cheetahs had a larger posterior segment.

**Table 14.** Association of group, age and gender with posterior depth values in cheetahs: outcome of multiple linear regression analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( b )</th>
<th>95% Confidence interval</th>
<th>( P ) - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AfriCat vs AvDCC</td>
<td>1.61</td>
<td>0.75, 2.48</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Age: 1-4 yrs</td>
<td>0*</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5-6 yrs</td>
<td>1.84</td>
<td>0.91, 2.78</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>≥7 yrs</td>
<td>1.77</td>
<td>0.83, 2.71</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Male vs female</td>
<td>0.24</td>
<td>-0.47, 0.94</td>
<td>0.51</td>
</tr>
</tbody>
</table>

\(*_{\text{reference value}}\)

\( AvDCC = \text{Ann van Dyk Cheetah Centre.} \ b = \text{regression coefficient.} \)
The eyes of all the animals appeared ultrasonographically similar. The cornea was seen as hyperechoic and slightly curvilinear. The anterior chamber, vitreous and lens were anechoic. The anterior and posterior lens capsules were observed as echogenic points, which gave the appearance of an ovoid lens. The entire surface was not visible in one scan plane. The iris and ciliary body appeared as echogenic structures. The iris was anterior to the anterior lens capsule, and the ciliary body was a thicker, more irregular structure peripheral to the lens. The posterior wall of the globes was seen as a concave echogenic line. The three layers, retina, choroid and sclera, could not be differentiated from each other ultrasonographically. The retrobulbar area appeared as a heterogeneous echogenicity and the intra- and extracranal spaces could not be determined in the retrobulbar space (Figure 16).

![B-mode ultrasound of an adult cheetah eye.](image)

**Figure 16.** B-mode ultrasound of an adult cheetah eye.

Prevalence of ocular lesions and comparisons between different groups, age groups and genders are summarised in Tables 15-18.

Lens lesions were the most prevalent pathological finding in the cheetahs (Table 15) and revealed a significant difference between the age groups (Table 17). The young cheetah group (1-4 years) had the most lens lesions (Table 17). Other lesions were not statistically significant between the different groups, age groups or genders. Retinal pigment was highly prevalent (Table 15) in both of the cheetah groups, in all age groups and in all genders (Tables 16-18).
Table 15. Prevalence and confidence intervals for ocular lesions in the cheetahs examined.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Prevalence</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraocular</td>
<td>73</td>
<td>6.8%</td>
<td>2.3, 15.3</td>
</tr>
<tr>
<td>Cornea</td>
<td>73</td>
<td>5.4%</td>
<td>1.5, 13.4</td>
</tr>
<tr>
<td>Anterior chamber</td>
<td>73</td>
<td>2.7%</td>
<td>3.3, 9.5</td>
</tr>
<tr>
<td>Lens</td>
<td>73</td>
<td>10.0%</td>
<td>4.9, 20.4</td>
</tr>
<tr>
<td>Vitreous</td>
<td>71</td>
<td>0.00</td>
<td>0.0, 4.9</td>
</tr>
<tr>
<td>Fundus</td>
<td>71</td>
<td>4.2%</td>
<td>8.8, 11.9</td>
</tr>
<tr>
<td>Retinal pigment</td>
<td>71</td>
<td>71.8%</td>
<td>59.9, 82.9</td>
</tr>
</tbody>
</table>

Table 16. Number of lesions in different groups of cheetahs examined.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>AvDCC</th>
<th>AfriCat</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraocular</td>
<td>4 (5.5%)</td>
<td>1 (1.4%)</td>
<td>0.649</td>
</tr>
<tr>
<td>Cornea</td>
<td>2 (2.7%)</td>
<td>2 (2.7%)</td>
<td>0.613</td>
</tr>
<tr>
<td>Anterior chamber</td>
<td>2 (2.7%)</td>
<td>0</td>
<td>0.535</td>
</tr>
<tr>
<td>Lens</td>
<td>7 (9.5%)</td>
<td>1 (1.4%)</td>
<td>0.245</td>
</tr>
<tr>
<td>Vitreous</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fundus</td>
<td>3 (4.1%)</td>
<td>0</td>
<td>0.294</td>
</tr>
<tr>
<td>Retinal pigment</td>
<td>34 (46.6%)</td>
<td>17 (23.3%)</td>
<td>0.417</td>
</tr>
</tbody>
</table>

*AvDCC = Ann van Dyk Cheetah Centre*

Table 17. Number of lesions in different age groups of cheetahs examined.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>1–4 yr</th>
<th>5–6 yr</th>
<th>≥7 yr</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraocular</td>
<td>2 (2.7%)</td>
<td>0</td>
<td>3 (4.1%)</td>
<td>0.265</td>
</tr>
<tr>
<td>Cornea</td>
<td>1 (1.4%)</td>
<td>1 (1.4%)</td>
<td>2 (2.7%)</td>
<td>0.829</td>
</tr>
<tr>
<td>Anterior chamber</td>
<td>2 (2.7%)</td>
<td>0</td>
<td>0</td>
<td>0.326</td>
</tr>
<tr>
<td>Lens</td>
<td>6 (8.2%)</td>
<td>2 (2.7%)</td>
<td>0</td>
<td>0.044</td>
</tr>
<tr>
<td>Vitreous</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Fundus</td>
<td>3 (4.1%)</td>
<td>0</td>
<td>0</td>
<td>0.103</td>
</tr>
<tr>
<td>Retinal pigment</td>
<td>19 (26.0%)</td>
<td>18 (24.7%)</td>
<td>14 (19.2%)</td>
<td>0.308</td>
</tr>
</tbody>
</table>
Table 18. Number of lesions in different genders of cheetahs examined.

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Female</th>
<th>Male</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraocular</td>
<td>4 (5.5%)</td>
<td>1 (1.4%)</td>
<td>0.177</td>
</tr>
<tr>
<td>Cornea</td>
<td>2 (2.7%)</td>
<td>2 (2.7%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Anterior chamber</td>
<td>1 (1.14)</td>
<td>1 (1.4%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Lens</td>
<td>3 (4.1%)</td>
<td>5 (6.8%)</td>
<td>0.716</td>
</tr>
<tr>
<td>Vitreous</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Fundus</td>
<td>1 (1.4%)</td>
<td>2 (2.7%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Retinal pigment</td>
<td>26 (35.6%)</td>
<td>25 (34.2%)</td>
<td>0.293</td>
</tr>
</tbody>
</table>

Extraocular lesions included an old lesion of a unilateral third eyelid laceration in an 11-year-old cheetah from the AfriCat group (Figure 18). Bilateral hyperaemic conjunctiva with and without a mucoid discharge, were noticed in 3 cheetahs from AvDCC. One of these had bilateral prolapsed third eyelids. A young one-year-old cheetah from AvDCC was noted to have unilateral symblepharon with mild clear ocular discharge. The third eyelid was prominent and adhered to the palpebral conjunctiva and medial cornea (Figure 19).

One 14-year-old cheetah from AvDCC had an active small superficial ulcer at the time of examination. The rest of the corneal lesions were corneal scars. The most extensive lesion was an old stable corneal lesion from a previous perforation in a four year old female from AvDCC. The dorsolateral cornea adjacent to the limbus had prominent oedema with anterior synechia from the iris towards the corneal lesion. The eye was stable, comfortable and without an aqueous flare at the time of examination (Figure 19).

Persistent pupillary membranes (PPM) were detected in two cheetahs from AvDCC. A four-year-old female cheetah showed bilateral multiple small iris-iris PPM's. Another four-year-old male also had a unilateral PPM. The PPM extended from the collarette region into the direction of the lens. It was not attached to the lens and no lesions were seen on the lens capsule.
Three litter mates from the young cheetah group (1-4 yr) of the AvDCC, had bilateral posterior cortical immature cataracts. These cataracts all had a similar appearance and were limited to the posterior extremity of the lens, while the remainder of the nucleus and lens cortex was found to be normal. The left and right lenses had similar lesions in each individual (Figures 20 & 29). Another young, two-year-old cheetah had similar bilateral posterior immature cataracts. The lens lesions were however more extensive (Figure 30).

Two, four-year-old cheetahs from AvDCC had each a unilateral posterior cortical immature cataract. An older, five-year-old cheetah had bilateral immature nuclear cataracts (Figures 21 & 31). Only one, five-year-old cheetah from AfriCat, had a unilateral immature anterior and posterior subcapsular cataract (Figures 22 & 32).

Retinal lesions were seen in three, four-year-old cheetahs from the AvDCC. Multiple ‘streaks’ and ‘lines’ of retinal hyperpigmentation were seen in the tapetal area. These lesions were dorsal to the optic nerve head (ONH) and on the border of the tapetum and non-tapetum (Figures 24 & 25). One of the males had obvious visual deficits and was observed to have mydriatic pupils. Apart from the areas of multiple retinal hyperpigmentation, a focal oval area of hypopigmentation was also visible dorsolateral to the ONH (Figure 25). These three cheetahs were the same three siblings which also had the bilateral posterior subcapsular immature cataracts as described above.

Retinal pigment was observed in 71% of the cheetahs. This pigment appeared as an increased density in the area centralis, dorsal to the ONH in a horizontal line. The pigment area did not appear to be raised or swollen. It varied from a small mild thin area or line of ‘pigment’ (Figure 26) to a thick discrete horizontal line from medial to lateral, in the visual streak (Figures 27 & 28).
Figure 17. An old laceration in the leading edge of the third eyelid membrane of the cheetah.

Figure 18. Symblepharon between the third eyelid, the palpebral conjunctiva and medial cornea of the cheetah.

Figure 19. An old lesion in the dorso-lateral cornea of the right eye of the cheetah. Note the corneal oedema, anterior synechia and the dyscoric pupil.
Figure 20. An immature posterior subcapsular cataract in the right eye of the cheetah.

Figure 21. Immature focal nuclear cataract in the left eye of the cheetah.

Figure 22. An immature, anterior subcapsular cataract in the right eye of the cheetah.
Figure 23. Normal fundus image of a cheetah.

Figure 24. Multiple retinal hyperpigmentation areas in the tapetum of the cheetah.

Figure 25. Multiple areas of hypo- and hyperreflectivity in the tapetum and on the border line of the tapetum and non-tapetal area are illustrated. An area of depigmentation with possible choroidal hypoplasia dorsolateral to the ONH is also visible. Note the small focal immature cataract which leads to the obscured visualisation of the fundus in the cheetah.
Figure 26. Mild retinal pigmentation in the visual streak of the cheetah.

Figure 27. Marked increased retinal pigment in the medial and lateral area of the visual streak in the cheetah.

Figure 28. Advanced increased retinal pigment in the medial and lateral area of the visual streak. Note the small focal immature cataract, which lead to obscured visualisation of the fundus of the cheetah.
Figure 29. An ultrasound image of a small immature posterior cortical cataract in the cheetah.

Figure 30. An ultrasound image of a focal immature posterior cortical cataract in the cheetah.
Figure 31. An ultrasound image of a small focal immature nuclear cataract in the cheetah.

Figure 32. Ultrasound image of an immature anterior and posterior subcapsular cataract in the cheetah.
CHAPTER 6. DISCUSSION

All the cheetahs examined were immobilised for their examination, and therefore the STT and IOP should be regarded as estimates, rather than true measurements of tear production and intraocular pressure. It is impractical and unsafe to perform these measurements in conscious cheetahs and wildlife practitioners are likely to perform these tests in immobilised animals under similar conditions, making the values highly applicable. The results of the STT, IOP and ocular measurements provide a reference of normal values to which individual animals can be compared.

6.1 STT

A significant difference was recorded between the STT reading of the left and right eye ($P=0.03$) (Table 3). The left eye recorded a higher STT reading of 13.61 mm/min compared to the right eye of 11.79 mm/min. A wide range of STT measurements was also found in the cheetahs examined (4-30 mm/min) (Table 4). As a result of the immobilisation, the STT could only be done 12-20 minutes after injecting or darting the animal, or only once the animal was brought to the clinic. During the interval the animal would be lying down in lateral recumbency as the immobilisation agents took effect. During the period the cheetahs had their eyes open. It can be presumed that wind, dust and humidity might play a role in the tear production measured. A limitation of the current study was that the side on which the cheetahs lay was not well recorded. It was therefore not possible to accurately determine whether lateral recumbency influenced the individual eye STT reading. The examiner measured the STT of the AvDCC cheetahs once they arrived from the camps and most of them were already lying on their left side. The cheetahs were transported from the camps to the examining area and placed in a left lateral recumbency which was ideal for the gastric scoping. The STT of cheetahs from the AF was measured as soon as it was safe to approach the animals, before they were transported to the examination area. These cheetahs were lying randomly on whatever side they went down following the immobilisation.
Most of the cheetahs examined were from the AvDCC and it is suspected that the positioning, together with the environmental factors might have an influence on the variability of the STT readings between the eyes. Therefore it is important to interpret STT measurements in immobilised cheetahs very carefully in conjunction with all other clinical findings.

The mean tear production was $12.7 \pm 5.5$ mm/min (Table 4). This was lower than that of the domestic cat ($14.3 \pm 4.7 - 16.92 \pm 5.73$ mm/min) (Arnett et al. 1984, Cullen et al. 2005, Margadant et al. 2003, McLaughlin et al. 1988, Veith, Cure & Gelatt 1970), the dog ($21.0$ mm/min) (Gelatt et al. 1975), and the African lion ($24.4$ mm/min) (Ofri et al. 1997). It is well documented that anaesthetic and pre-anaesthetic agents cause a reduction in tear production. The tear production measurement of the cheetahs in this research project, were taken under the influence of medetomidine and ketamine or medetomidine and Zoletil. As in the previously reported studies (Arnett et al. 1984, Dodam et al. 1998, Sanchez et al. 2006), it can therefore be assumed that the tear production in the conscious animal would most likely be higher than that of the anaesthetised immobilised animal.

A statistically significant difference was noted between the STT of the young cheetahs of 1-4 years ($10.5$ mm/min) compared to the older cheetahs ($14.8$ mm/min) (Table 6). This is in agreement with Featherstone (2013), that tear production is normally lower in younger animals.

### 6.2 Tonometry

IOP is a valuable tool in ophthalmology to diagnose ocular disease and its progression like glaucoma and uveitis. The mean IOP of $30.5 \pm 4.3$ mmHg in the cheetahs examined, is high compared to the domestic cat reading (Rusanen et al. 2010) and of an adult lion of $20.74$ mmHg and $23.9$ mmHg respectively (Ofri et al. 1998). All the measurements taken by the author, were taken while the cheetahs were lying in a lateral position. Body position has been documented to cause a difference in IOP (Aihara et al. 2003, Broadwater et al. 2008), and it is possible that the lateral recumbency of the cheetahs could have contributed to the high IOP measured.
The mean IOP readings of the cheetahs from the AvDCC were slightly higher than the IOP readings of the cheetahs from AfriCat. The only variance between the two groups was the immobilisation drugs that were used. Ketamine was used in the cheetahs of AvDCC compared to Zoletil used in the AfriCat group. Ketamine has been documented to increase IOP readings (Hahnenberger 1976, Hofmeister et al. 2006, Kovalcuka et al. 2013), and could explain the difference in IOP measurements.

Circadian rhythms have been shown to influence the IOP readings (Bertolucci et al. 2009, Del Sole et al. 2007, Giannetto et al. 2009, Martin-Suarez et al. 2014, Rowland et al. 1981). A limitation of this study was that the IOP readings were measured during different times of the year, and different times of the day (8h00 to 16h00).

6.3 Ultrasound

Ultrasonographically, the cheetah eye and its structures are very similar in appearance to those in cats (Gilger et al. 1998, Mirshahi, Shafigh & Azizzadeh 2014), and dogs (Cottrill et al. 1989). Weak echoes of the anterior and posterior lens capsule were identified. This is possibly due to the refraction of the sound beams from the convex lens capsule, which makes the peripheral echoes very difficult to identify. Reverberation artifacts or the result of poor alignment of the axial axis in the lateral recumbency, could also have played a role. Ocular measurements (Tables 11& 14) showed a significant difference between the axial globe length and posterior segment depth of young cheetahs compared to older cheetahs. Similar, age-related ocular dimension increases have been reported in goats (Ribeiro et al. 2009), elephants (Bapodra et al. 2010), buffalo and one-humped camels (Kassab 2012). The globe length in this study was also found to be larger in males compared to females (Table 11). Similar findings were reported by Schiffer et al. (1982) in dogs.
6.4 Cornea

Corneal lesions were observed equally in both groups of captive cheetahs in our study. Old scar lesions were mostly noted, but the incidence was much lower (5.4%) compared to the corneal lesions previously observed at AfriCat Foundation (47.2%) (Bauer n.d.). This higher incidence of corneal lesions was most likely due to poor environmental management at that time, which lead to large areas of overgrazed, bush-encroached vegetation. This in turn led to an increased risk of corneal injuries for the cheetahs that were confined to these areas. This issue was subsequently addressed by rehabilitation of the veld and clearing of the bush encroached areas. This may explain the lower incidence of corneal lesions observed in our study.

Only one potential FHV - 1 infection has been recorded in a one-year-old cheetah from AvDCC. At the time of examination, symblepharon was observed between the third eyelid, the palpebral conjunctiva and medial cornea. This cheetah was part of a litter which was relocated at five weeks of age. The entire litter had clinical signs of conjunctivitis and sneezing after the relocation. Because of the limitations of the diagnostic tests and carrier stage of the virus (Witte et al. 2013), no diagnostic tests have been done and a diagnosis was made based on the history and clinical signs. Symblepharon is a common sequel of FHV – 1. It is a cytopathic virus causing lysis of tissues and large ulcerated areas will form. These ulcerated areas can form adhesions to one another. Symblepharon is a permanent adhesion between tissues like the conjunctiva, third eyelid and cornea. This can distort the eyelid opening and tear film distribution and/or drainage, which is the case in this particular cheetah. Surgery can correct the deformity, but the prognosis is guarded and recurrence is likely (Stiles 2013).

6.5 Cataracts

The age and anatomical distribution of cataracts in the AvDCC cheetah group were suggestive of a hereditary or congenital aetiology. In contrast, the unilateral cataract seen in an AF cheetah is most likely due to previous inflammation or trauma. No breeding is permitted at AF while AvDCC is a breeding facility. These findings could indicate a new problem arising within the genetics and breeding management of the cheetahs. Nutritional cataracts can’t be excluded because remnants of nutritional cataracts could look like incipient cortical opacities.
No cataracts were seen in cheetahs older than seven years, during the research project. It may be possible that very old cheetahs with cataracts, had died and were not available for examination at the time. Cheetahs less than one year of age were also not examined during the research project. Further investigation to confirm a genetic, hereditary or nutritional origin would appear necessary in this cheetah population.

Only one unilateral cataract was recorded at the AfriCat Foundation. This prevalence is much lower than the lesions previously described by Bauer (n.d.) (27.47%). As previously discussed under corneal lesions, this may be due to better environmental management, resulting in less trauma associated ocular pathology.

6.6 Retina

The fundic examination of three cheetah siblings, revealed similar retinal lesions associated with multiple hyperpigmented lines and ‘folds’. These lesions resemble retinal dysplasia. A congenital defect due to abnormal development of the retinal is most likely. An intra-uterine infection or post-natal infections like FPLV (Glaze 2005, Percy et al. 1975), or FeLV (Albert et al. 1977, Glaze 2005) can cause retinal dysplasia. A suspected hereditary multifocal dysplasia has been documented in Somali cats (Narfstrom 1999), and therefore, a hereditary cause cannot be excluded in these cheetahs.

Although FPLV infection was not definitely diagnosed in this population, an outbreak of FPLV, where five cheetah cubs died, was described and confirmed by Lane et al. (2016), in a breeding institution in South Africa. It is possible that the affected cheetah siblings survived the viral infection, but were affected at the stage of retinal development, which caused retinal dysplasia. The source of the initial outbreak in the cheetahs remains uncertain. Lane et al. (2016) proposed the loss of cold chain management during a 2012 transport strike may have led to vaccination failure. Maternal immunity lasts between 2-4.5 months and domestic cats are therefore usually affected at 3-5 months of age. The vaccination of domestic cats prevents disease caused by FPLV (Chalmers et al. 1999). Inactivated (killed) vaccines can be used in kittens younger than four weeks of age, pregnant queens, debilitated and old cats (Parrish 1995).
It has been proven in cheetahs that inactivated vaccines are safe to use and induce persistently high levels of serum antibodies to FPLV (Wack et al. 1993). Modified live FPLV vaccinations in adult domestic cats give lifelong immunity, but the vaccines are not registered for use in other felids. Its efficacy against different variants in non-domestic felids, is not well documented (Risi et al. 2012). According to Munson et al. (2005), a vaccination regime, using a combination of inactive (dams in late pregnancy and cubs at eight and 12 weeks of age) and live vaccines (cubs at 16 weeks of age), has been proven to be safe, effective and reduce cub mortality in captive cheetah populations. Stress, inadequate vaccination and vaccine failure are predisposing factors in the susceptibility to the disease (Lane et al. 2016). Although cataractous lesions were also detected in the same three siblings, cataracts are not commonly associated with FPLV and are more likely to have a hereditary, congenital or nutritional origin.

Retinal pigment was observed in 70% of the cheetahs. This finding has not been described before in any of the literature and is unique to our study. Feline central retinal degeneration (FCRD) is the most obvious differential diagnosis. This nutritional deficiency of taurine, presents in exactly the same anatomical location within the area centralis of the retina. The fundic lesion of FCRD is described as an oval area of tapetal hyperreflectivity which becomes progressively ellipsoid and extends in a band from the temporal fundus across the top of the optic disc to the nasal fundus. At later stages severely affected animals show retinal blood vessel attenuation, retinal degeneration and irreversible blindness. The affected cheetahs in this research study presented with hyperpigmentation and not hyperreflectivity. Although is it very difficult to evaluate vision in animals and even more of a challenge in wild animals, no obvious visual deficits were noted or reported in any of the hyperpigmented cheetahs. There was no history, clinical or ophthalmic evidence of taurine deficiency in this population and hence serum taurine determinations were not considered in their annual health examination.
Another possible nutritional cause that could explain the retinal pigmentation is DHA deficiency. Tordiffe (2016) reported a marked difference in the serum levels of FA between captive and free-ranging cheetahs. It is possible that these nutritional differences may have an impact on the health of captive cheetahs. Further research is indicated to compare the fundic findings and ERG values of free-ranging cheetahs to that of captive cheetahs.

Other differentials for retinal lesions are infectious disease like FIP, FCoV, FELV, FIV or fungal agents (Ofri et al. 1996). Typically, retinal lesions induced by these infectious diseases are characterised by chorioretinitis, which differs significantly from the retinal lesions noted in these two cheetah populations. There was also no evidence of concurrent anterior disease such as uveitis, which is frequently present in these infections.

Because retinal pigmentation was observed in so many cheetahs without any evidence of retinal degeneration, it is possible it could be a normal variant. These hyperpigmentation areas could be a normal variant of a high concentration of RPE cells, or any cell type in a specific sub retinal or retinal layer. Histopathology and electronmicroscopy are the ideal ways to evaluate this pigment. Optical coherence tomography (OCT) is a modern modality which is regularly used in human ophthalmic conditions like macular diseases, glaucoma and optic neuropathies. It compares favourably to histopathology in vivo and would be the ideal next step to evaluate the fundus and in particular the hyperpigmented area centralis of the cheetah species. OCT uses the reflectivity of light waves to produce detailed cross-sectional images of ocular tissues. Light from a source is directed onto a partially reflecting mirror and is split into a reference and a sample beam. The sample beam reflects light from the specimen and consists of multiple echoes. The light from the reference beam reflects from a mirror of known optical distance from the light source. When these two beams combine, an interference pattern occurs and only the non-scattered light is detected. High resolution pictures of the retinal layers parallel at differing depths are achieved (Donaldson & Hartley 2013). It would have been ideal to evaluate the fundus and in particular the pigmented area centralis in the cheetah, but unfortunately a portable OCT device was not available for use during this particular project. This aspect should receive further attentions as it could provide answers as to the role of the hyperpigmented area centralis in the cheetah.
6.7 Limitations

Young cheetahs of less than a year old were not examined in our study. This age group of cheetahs may potentially have more ocular problems, like cataracts and infectious diseases, which could influence the incidence of ocular pathology in captive cheetahs.

Diagnostic studies like serology, virology or further blood analysis were not performed on the cheetah groups. The definitive cause of the lesions recorded in our study was therefore not always determined.

The IOP values were measured during different times of the day and year. The circadian rhythms of the cheetahs may have influenced the readings as described before.

Accuracy and precision of reference values could be improved by having a larger sample size of cheetahs. This would reduce the standard error of the mean, ensuring the mean is a closer estimate of the true population mean.
CHAPTER 7. CONCLUSIONS

Establishing STT, IOP and biometric reference values are important for evaluating the ocular health status of the species. These reference values will assist veterinarians working with the cheetah species to perform a full and informed ophthalmic examination.

The prevalence of ocular pathology in captive adult cheetahs in these two populations is of different nature to those documented in domestic cat populations. Although herpesvirus is widespread among domestic cats, a very low percentage of clinical signs, potentially associated with this virus, were observed in these cheetah populations. A higher incidence of cataracts was recorded in young cheetahs, compared to domestic cats. Fundic lesions were relative rare and compare well with domestic cats. The types of cataracts and fundic lesions found in these cheetahs, could indicate hereditary, congenital or nutritional causes. This is a concern because of the future implications it could have on breeding programmes of captive cheetahs. Regular detailed ophthalmic examination in the cheetah can help with the early diagnosis, management and treatment of ocular lesions.

A unique retinal pigment was observed and further investigation is needed to clarify this lesion. Ongoing research, monitoring and investigation of the eye of the cheetah species can greatly benefit the survival of this special and endangered species.
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APPENDICES

Appendix 1. Ann van Dyk CheetahCentre’s map of cheetah camps
Appendix 2. AfriCat Foundation’s map of cheetah camps
Appendix 3. Examination sheet

Animal: Microchip:
DOB: Place:
Weight: Sex: Date:
Time of sedation:
Schirmer tear test: R _______________ L _____________ Time:
Tonometry: R _______________ L _____________ Time:

Right eye

Left eye

Biometry:
Axial globe length:
Axial lens thickness:
Anterior chamber depth:
Posterior segment depth
Other comments:

Christie Boucher. Veterinary Ophthalmology Tel: 012-5298144

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Appendix 4. Animal Ethics Committee Certificate

<table>
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<tr>
<th>PROJECT TITLE</th>
<th>Prevalence of ocular pathology in captive adult cheetahs (Acinonyx jubatus) in South Africa</th>
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<tr>
<td>RESEARCHER/PRINCIPAL INVESTIGATOR</td>
<td>Dr. CJ Boucher</td>
</tr>
<tr>
<td>STUDENT NUMBER (where applicable)</td>
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<tr>
<td>DISSERTATION/THESIS SUBMITTED FOR</td>
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<tr>
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<td>Approval period to use animals for research/testing purposes</td>
<td>June 2014 – September 2016.</td>
</tr>
<tr>
<td>SUPERVISOR</td>
<td>Dr. I Venter</td>
</tr>
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**KINDLY NOTE:**
Should there be a change in the species or number of animal/s required, or the experimental procedure/s - please submit an amendment form to the UP Animal Ethics Committee for approval before commencing with the experiment.

**APPROVED**

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CHIEF ANALYST: UP Animal Ethics Committee

Signature: