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Investigation of the prevalence and causes of chronic foot problems in greater one-horned rhinoceroses (*Rhinoceros unicornis*)

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1. Abstract

Greater one-horned rhinoceroses (*Rhinoceros unicornis*) are an endangered species and an average number of 128 animals live in zoological collections in the world.

The investigations carried out in this project show that these animals often suffer from chronic foot problems, a clinical picture showing a separation of the tissue between the sole of the central digit from the adjacent pad. This mainly occurs in the hind feet.

It was possible to demonstrate - with the help of light-microscopical examinations - that the structures of this particular area resemble a 'locus of minor resistance'.

The prevalence is high in this otherwise rather healthy species in captivity, showing different degrees of lameness and infection once the lesions become apparent.

The greater one-horned rhinoceros is also the only species of the family *Rhinocerotidae* with this particular problem and males seem to suffer more often from it than females.

Unfortunatelly the definite causes are difficult to pinpoint at, mainly due to a lack of more detailed information than that obtained through this survey. However, from the received information and by comparing the facilities in captivity with the natural surroundings of these creatures in the wild, hard floor surfaces and a lack of access to a pond or wallow seem to be decisive causes.

Additionally, some animals seem to be more prone to it than others and a conjectural genetic predisposition is worth further research.

As treatment proves to be difficult and success is not always guaranteed, due to the location of the lesion on the one hand and the nature of the animal on the other, it seems to be worth putting as much emphasis on preventive medicine as possible in order to maintain a healthy breeding population of greater one-horned rhinoceroses in captivity.

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2. Contents

For the latest family tree, please contact Bristol Zoo, the studbook coordinator

2.1 List of photographs

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4. Introduction

Since 1982, when the first report on chronic foot problems in captive greater one-horned rhinoceros (*Rhinoceros unicornis*) was published, this problem has received little attention. The long-term occurrence of this clinical problem in the two animals kept at Whipsnade Wild Animal Park, UK, led to an interest in finding possible causes for it and to do a more detailed study, not only to understand why it occurs but also to prevent it and to treat it properly.

Thus this project is meant to serve serveral purposes.

First it wants to evaluate the scope of this problem in the captive greater one-horned rhinoceros population between 1. 1. 1980 and 30. 6. 1996. Secondly it will concentrate on possible reasons leading to this problem. Because the cure turns out to be very difficult and often unsuccessful, resulting in a chronic patient, this project will try to provide different aspects of treatment schemes which might give additional help to those who are facing this problem in their animals.

For this purpose questionnaires were sent out to all zoological collections keeping this species. An attempt was made to gain precise information about each captive animal and of the way each individual collection keeps their animals and possibly treats them once affected.

Since many intensively managed species are prone to foot problems, especially horses, cattle and pigs, a comparative study with regard to the anatomical and histological structures was initiated. The objectives are to be able to compare the pathological lesions and to draw a conclusion from the results for possible pathogenetic factors. Feet of greater one-horned rhinos, which died of other reasons, were used for a thorough histological examination.

As mentioned above, no proper investigation has been done to evaluate the foot problem, confined to this species. The main reason for this project is to attempt not only to evaluate the nature of this problem but also to show that the prevalence of this problem is higher than has been realized and that it needs to receive more attention in the future. This is especially important with regrad to the endangered nature of this species and the potential need for a good healthy breeding population.

5. Review of literature

5.1 Status of the wild population

The Asian greater one-horned rhinoceros (*Rhinoceros unicornis*) has often been quoted as one of the success stories of wildlife conservation (Martin 1985, Penny 1987, Fosse and van Strien 1997). Highly protected in a few reserves in north-eastern India and southern Nepal, the greater one-horned rhinoceros survived until now a severe bottleneck situation.

The original range extended up to the great South Asian floodplains, before being hunted almost to extinction by sportsmen and poachers. They were also driven away by the pressure of a growing human population and fragmantation of their habitat at the beginning and middle of this century. Their original range extended from the Indus river in the west, to the Ganges in the south and the Brahmaputra in the northeast (Emanoil 1994).

Approximately 2.000 species of the third largest land animal thrive in and around riverine floodplains and tall swampy grassland (Foose et al.1997). Occasionally - depending on the onset of the monsoon - they can be seen on open grassland, bush, savannah, hilly country and forests (Guggisberg 1966) but they seem to favour edges of rivers or pools, not only for taking a bath to '...prevent overheating, the attack of insect and sunburns..., but also for grazing...' (Penny 1987).

Of its kind, it is the most common Asian rhinoceros. The estimated wild population size of the Javan rhinoceros (*Rhinoceros sondaicus*) is below 100 and around 400 individuals still exist of the Sumatran rhinoceros (*Dicerorhinus sumatrensis*) (Foose et al. 1997).

Compared to the world population of the five species of rhinoceros - which is estimated to range around 12.800 animals, the 'Africans' - the black rhinoceros (*Diceros bicornis)* and the white rhinoceros (*Ceratotherium simum)* - come up to approximatelly 9.900 and the Asian rhinos to about 2.900 wild individuals (Foose et al. 1997).

5.2 Captive Status

Reports of the existence of greater one-horned rhinoceroses in captivity go as far back as the time of the Roman Empire. It was at that time - and even still at the beginning of this century - the most commonly exhibited rhinoceros species (Reynolds 1960). Since the 16th century more and more greater one-horned rhinoceros were

brought from India via ships to the European continent, where the animals were exhibited by being toured around.

In 1834, London Zoo received the first greater one-horned rhinoceros, followed in 1872 by Berlin Zoo (Lang 1975).
But it was not until 1956 that the first calf was successfully born in captivity at Basel zoo, followed by Whipsnade Wild Animal Park in 1957 (Lang 1960).

Nowadays it is not only the wild population that has grown but also the captive one and in the studbook of 1997 - written by Basel Zoo - 51 institutions are listed as holding 129 individuals (Wirz-Hlavacek, Studer and Steck 1997).This can be compared to the status of 1975 when Lang (1975) reports in the first international studbook that 25 zoos were listed to keep 24 males and 20 females.

5.3 Health status of rhinoceroses in captivity

All five species of the family *Rhinocerotidae* are listed in appendix I of the Convention on International Trade in Endangered Species (CITES) as being highly endangered (Emanoil 1994).

The main aim of keeping these large species in zoological collections is to' ...maintain a captive population capable of long-term viability to guard against any unforeseen extinction of the population...' (Foose 1997). To be able to do so, Fouraker and Wagener (1996) write that the above mentioned aim will only be successful if '...captive stewards of the rhino know how to provide improved and proper husbandry during the period of intensive management...'.
In this regard the accomodation as well as the diet and preventive medicine, as already mentioned by Lang (1975) seem to be of exceeding importance in order to maintain a healthy breeding pair or population.
With regard to the health status of the greater one-horned rhinoceros and the commonly kept white rhinoceros, they seem to be less affected by diseases than the black rhinoceros.

Parasites are a common finding in newly imported, wild caught rhinos and are generally easily taken care of, once diagnosed (Göltenboth 1995).

Under certain circumstances bacterial infections, such as salmonellosis, tuberculosis and others can be fatal (Silbermann & Fulton 1979, Wallach & Boever 1983, Char et al. 1984).

Until now only a few viral diseases have been recorded to affect *Rhinocerotidae*, but don't seem to play a major role in the health status, as proper precautions such as vaccinations are available for some of them (Mayr & Mahnel 1970).

As rhinoceroses share similar anatomical features with the *Equidae*, gastrointestinal torsions and impactions have been described in all captive species by several authors (Jones 1979, Rüedi 1983, Kock & Garnier 1993).

Musculoskeletal problems such as capture myopathy or myoglobinuria have been observed in free-ranging African species after capture (Mc Cullock & Achard 1969). Reports by Jaroffke and Klös (1979) describe the occurrence in captivity.

The skin seems to be a very sensitive organ in all rhinoceros species. Jones (1979) mentiones not only dietary factors to be associated with skin problems but also the fact that the animals need a facility 'to bath and to wallow' in order to maintain a soft and moist skin, thus preventing cracks to form and infections to settle.

The feet of these animals have never received much attention. The first report ever to describe foot problems was written by Boever in 1976, which describes a case of interdigital corns in a black rhinoceros. These granulomas/papillomas were also observed by Jones (1979) to occur in all three captive species. Boever (1976) assumes that traumatic insults are possibible causes for this problem, which seems to impair the animals gait due to the room-taking interdigital mass. In additon to that, Jones (1979) mentions the occurrence of laminitis in all rhinoceros species kept in captivity, and relates it to a high protein diet, as it has been described for horses (see under 5.5.1). Fissures of the sole due to sharp objects in the enclosure are another possible cause for a lame animal as well as abrasive and urine stained floors which are likely to cause damage and necrosis to the feet (Jones 1979).

As mentioned above, the black rhinoceros is an exceptional common patient, suffering from lethal diseases which only occur in this species. Current research projects have been set up to investigate the causes of their susceptibilty to haemolytic anaemia, mucocutaneus ulcers and fungal pneumonia (Fouraker and Wagener 1996).

5.4 Chronic foot problems in captive greater one-horned rhinoceroces

It was in 1982 that Strauss and Seidel reported for the first time a clinical case of chronic foot problems in their greater one-horned rhinoceros male.They give a detailed description of cracks and ulcers forming between the sole of the central toe (phalanx III) of both hind feet and the adjacent pad. The central toe nails were overgrown. As a possible primary cause they suggested either excessive growth or an insufficient rub-down of the nails, leading to an increase of tension in the area just behind the sole and the pad. If the tension increases to a certain point the connective tissue will tear, resulting in cracks and an entry for bacteria. Their treatment consisted of trimming all three nails regularly in each hind foot. Debridement of the wounds, disinfection and application of antiseptic powder which supports the granulation process,were also helpful.

In addition, they also mentioned the possible danger of the location of the infection site, as the nearby joints of the third digit might easily become infected if the infection is neglected.

In 1986 another report was published by Göltenboth, which describes exactly the same appearance of cracks between the sole of the central toe and the pad of the hind feet in a female rhino from Berlin Zoo. He holds the often very dry surface in the outdoor enclosure responsible as well as long toe nails and the heavy weight which these animals have to bear. The latter seemed to be of importance in this case as the female became lame after being mounted by her mate.

Rüedi and Tobler (1991) also mention a further case in one of their greater one-hornerd rhinos at Basel Zoo.

According to Strauss and Wisser (1995) the male rhino, whose case was described in 1982, suffered from a recurrence of these cracks, despite a successful treatment at the onset. In addition to above mentioned causes, they refer to a lack of moisture in the sole as also being a possible cause. They support this theory by the fact that the more time the animal spends in the mud wallow, the less extreme the problem seems to become.

Like Strauss et al., Göltenboth (1991) explains that once these cracks became apparent they seem to become very persistent with different degrees of severity and never seem to disappear completely, despite constant foot care.

Until today the prevalence of foot problems in greater one-horned rhinoceroses has not been evaluated and publications about the occurrence are still rare. Furthermore, no definite answer has yet been found concerning the possible primary causes of this problem. Interestingly enough these specific cracks have never been noticed in any species other than the greater one-horned rhinoceros.

5.5 Foot problems in intensively managed animals

5.5.1 Laminitis

Laminitis can occur in all hoofed species but particularly affects horses and intensively farmed cattle. Extensive studies, including light-microscopy as well as electron-microscopy show that laminites is refering to degenerative and inflammatory changes in the laminae of the hoof wall. The degree of severity varies from acute to chronic and can affect all four feet (Jubb, Kennedy & Palmer 1985).

Possible etiologies, which are most commonly encountered in the horse are :

- excessive intake of carbohydrates (metabolic laminitis),
- traumatic laminitis due to hard/fast work on hard surface, also leading to bruising of the sole
- toxaemic laminites due to endometritis or severe systemic infection,

- massive ingestion of grass (clover or alfalfa) in already overweight animals (with ponies being very susceptible),
- drug therapy, especially corticosteroids, (Stashak 1987).

In cattle, additional predisposing factors are metritis, mastitis, ketosis and genetic factors, as some breeds are more often affected than others (Vermunt and Greenough 1994).

The term chronic is used for horses, if a period of 48 hours of continual pain occurs or a rotation of the distal phalanx (Stashak 1987).

5.5.2 Footrot

Footrot is a disease of ruminants, caused by a synergistic infection of anaerobic bacteria. *Bacteroides nodosus* and *Fusobacterium necrophorum*, are the most commonly encountered bacteria. *B.nodosus* is the chief pathogen.

Depending on the degree of virulence of *B. nodosus* the clinical picture is called benign or virulent. Sheep are more prone to infection especially if kept on damp pastures.

Porcine footrot occurs due to abrasive wearing of the horn usually on the lateral aspect of the lateral digit and is a mixed infection leading to abscesses at the coronet, lameness and deformations of the hooves (Jubb et al. 1985).

5.5.3 Lameness in pigs

Geyer (1979) describes the occurrence of lameness in pigs under intensive management. Cracks, predominantly in the hind feet, become visible, especially in those areas where the hard horn of the sole connects to the soft horn of the pad. He holds as primary causes the high weight as well as the surface upon which most intensively managed pigs are kept. A genetic factor might also play an important part in the occurrence of these cracks.

5.5.4 Necrobacillosis

Necrobacillosis of the bovine foot (also called panaritium, fouls and foul-in-the-foot) is a noncontagious bacterial infection of the interdigital skin and possibly of the tissue underlying the horn, due to *Fusobacterium necrophorum* and *Bacteroides melaningenicus*. It can occur in animals which are kept on wet, rough ground, causing skin lesions between the digits as well as between the sole and the pad, followed by inflammation and necrosis. Acute or chronic trauma can also be a cause (Weiss 1986). Besides the feet, internal organs as well as the upper digestive tract are often affected. Necrobacillosis is a common finding in many species of the order *Artiodactya* and *Perissodactyla*, in the wild as well as in captivity (Rosen 1970).

5.5.5 Elephants

Intensively managed animals like the elephant (*Loxodonta africana, Elephas maximus*) need good foot care when kept in captivity as their feet/nails are prone to cracks, overgrowth and infection if not properly taken care

of. Lack of movement as well as poor floor surface in the enclosures are also predisposing factors which cause foot problems in this species (Fowler 1993).

5.5.6 Overgrowth of horn

Overgrowth of the horn, and sometimes of the sole (often in the elephant) and cracks are commonly encountered in hoofed animals, kept in captivity. Trimming of the hooves, or the provision of an appropriate ground surface is important. Each species has its own requirements due to the differences in the quality of horn. This has to be taken into account when keeping these animals in captivity (Göltenboth 1995).

With the help of light- and electron-microscopy, several authors (Geyer 1980; Marks & Budras 1987; Pollitt & Molyneux 1990; Mülling, Bragulla, Budras & Reese 1994; Pellmann 1995) were able to locate areas within the hoof structure, which can be looked upon as „*loci minores resistentiae*" and are prone to degenerative changes under certain circumstances. Besides nutrition, weight, the floor surfaces, upon which animals are kept, and genetic predisposing factors, might also play an important role in the occurrence of foot problems in many intensively managed animals.

5.6 Anatomy of the equine and rhinoceros foot

Many detailed light-microscopic descriptions exist of the equine foot (Banks 1986; Stashak 1987; Budras, Hullinger & Sack 1989; Dellmann 1993; Budras & Röck 1994; Pellmann 1995; Dyce, Sack & Wensing 1996) and have been used as references for the following text.

The foot is defined as the hoof, the dermis and the structures contained therein. The hoof itself is the epidermis and its cornified derivates (Dellmann 1993).

In this review, special attention will be given only to those parts which seem to be of clinical relevance to cases associated with hoof problems. The horse will serve as the main reference due to the amount of research which has been conducted on this species. The hoof of the horse can be divided into the following parts: periople, coronary band, wall, sole and the frog.

5.6.1 The wall

The wall is made up of three layers:

1. The stratum externum consists of soft whitish-shiny horn, which originates from the perioplic corium. This highly vascularized papillated tissue is located distad to the skin.
2. The str.medium, makes up the main part of the hard wall structures and consists of tubular and intertubular horn. This horn is produced by the str.germinativum of the coronary epidermis (str.basale and str.spinosum) and covers the coronary dermis with its fairly long papillae.

3. The str.internum (lamellatum) is continously connected with the str.medium. It is made up of vertically keratinized primary laminae and secondary laminae. The latter consist of a str.basale and str.spinosum. Both interdigitate with the primary and secondary papillae of the dermis and thus form the 'suspensory apparatus' of the hoof.

5.6.2 The sole

The sole is made up of tubular and intertubular horn. The dermis consists of vertically orientated papillae. The horn is produced by the str.germinativum, which covers the dermal papillae.

5.6.3 The frog

The horn of the frog is softer and the papillae of the dermis slightly longer than the ones in the sole. The dermis is connected with the digital cushion via elastic fibric tissue.

5.6.4 Ruminant and pig hooves

Although the ruminant and pig hooves seem obviously quite different, they are in fact quite similar to those of the horse, with of course a few exceptions. The hooves of these species consist of a wall, sole and a well-developed bulb or pad. Main histological differences exist in that the str.internum and the laminar corium have no secondary laminae or papillae, respectively. Furthermore they have no frog but a bulb of rather soft skin, making up the major part of the plantar/palmar surface. The sole consists only of a small rim next to the wall and in the case of the *Suidae* there is a marked boundary line between the sole and the pad. The consistency of the pad-horn is soft compared to that arising from the str.germinativum of the sole and the coronary region (Geyer 1979).

5.6.5 The rhinoceros foot/hooves

; for the ruminants and pigs, similarities and differences exist when comparing the equine and the rhinoceros feet. The rhinoceros belongs to the group of odd-toed ungulates (*Perissodactylae*) and the first report which ever described a thorough anatomical study of the foot of a greater one-horned rhinoceros dates back as far as 1895 and was written by Eber.

The foot is made up of the II (medial), III (central) and IV (lateral) digit (Grasse' 1955), their adjacent tendons and ligaments, vessels, nerves and elastic fibric tissue as well as the epidermal modifications, the hooves. Regarding the hooves, the central one is the largest of the three. They form with their inner margin a square-like structure into which the large pad perfectly fits. The area between the middle toe and the pad is marked by a relatively deep fold (Ebers 1895). The pad is made of relatively soft horn compared to the adjacent sole. Without using the aid of a light-microscope, Eber describes the fine structures of the dermis, after having separated the hooves from the dermal structures. These structures generally seem to resemble the anatomy of the horse, with a

few exceptions: the dermal laminae are two- sometimes even three-folded. A frogis non-existent. The sole is relatively small, comparable to the ones of ruminants and pigs. The pad takes up most the space of the ventral surface forming a circular area. This is the main part on which the animal bears its weight and due to its elasticity the foot can expand and retract according to the movement of the animal. This 'cushion' helps the animal to spread the weight on a larger surface when footing.

5.7 Genetic studies in greater one-horned rhinoceroses

Small populations in the wild as well as in captivity have been focused upon because of their extent of inbreeding. Inbreeding, the mating between close relatives, can lead to inbreeding depression, a term used to describe the production of inherited deleterious traits in progeny. This deleterious trait can show up in a reduction of the so called fitness character, the individuals' probability to reproduce and to survive (Bruford 1996).

Ralls and Ballou (1983) documented that inbreeding in zoo animals can often lead to a reduction in viability and fertility.

Bauer and Studer (1995) looked upon the extent of inbreeding and inbreeding depression in captive greater one-horned rhinoceroses, a species which has been bred predominantly in only a few zoos.[1] . They found out that animals in zoos, which have been successful in breeding this species in the past and present, have a higher level of inbreeding than other zoos. The offspring of inbred females, tend to be higher in number, concerning juvenile mortality, than those from non-inbred dams. Due to the fact that many other factors attribute to juvenile mortality, which are not associated with inbreeding, Bauer and Studer concluded that inbreeding so far has not led to any significant deleterious effects in the captive population. This is based on the fact that there were no further associations between juvenile mortality, survival and inbreeding. Nevertheless, the authors suggest that prevention of future inbreeding with possible deleterious effects is better than to wait for negative results.

6. Materials and Methods

6.1 Questionnaire

For this study it was thought important to receive information about the husbandry and mangement of each individual animal and the zoological collection itself. For this reason a 5-page questionnaire - see appendix- was

[1] The studbook of 1997, written by Basel Zoo, gives the inbreeding coeficient and mean kinship for all inbred greater one-horned rhinoceroses

sent out at the end of last year (1996) to all zoological collections, keeping greater one-horned rhinoceroses [2]. Questions were asked about the health status with regard to foot problems, possible treatment schemes, primary causes, indoor and outdoor housing facilities and the climate.
Furthermore, the people were asked to send pictures of affected feet and to state if any histological, bacteriological or other diagnostic procedures were undertaken. The investigation period took place between the 1. 1. 1980 and the 30. 6. 1996. [3]

6.2 Case Studies

Whipsnade Wild Animal Park, UK keeps two one-horned rhinos with foot problems. These animals serve as 'live examples' for this study in order to demonstate the course of the disease as well as its severity and the difficulties of treatment. The male ('Kumar', 25 years of age) and the female ('Roopa', 26 years of age) had seven offspring together. One of them, a male ('Bardia, born in Oct. 1989, died in Sept. 1995') suffered from the same foot problems as his parents.

6.3 Histological examination of rhinoceros feet

To understand the nature of the lesions and to find a possible answer to the question why the foot problems occur mainly between the central sole and pad, a histological examination was performed on the hind and front hooves of clinically affected and healthy feet. The samples were obtained from Bardia's (see under 6.2) affected left hind and clinically normal appearing right front foot. He died under general anaesthesia, while beeing treated for his chronic foot problems. A further left hind foot was obtained from a male (studbook # 0042, age 28) which died last year in Berlin Tierpark, Germany of unknown reason.
A cooperation work was initiated with the anatomy department of the Freie University of Berlin, Germany, a place which has specialised over many years in anatomical structures of healthy and unhealthy feet of many different species.
The clinically affected left hind foot and the healthy right front foot of the Whipsnade animal were cut in half and preserved in 10% formalin immediately after post-mortem. Samples for a histological examination were taken from different places - see picture 1 and 2, preserved in 10% formalin and were sent off to La Grange Vet. Lab. (West Yorkshire, UK). In addition, a slice about 1 cm thick was cut from the sagitall-cut feet, preserved in tissue paper soaked in formal saline, cleared by CITES and posted to the University of Berlin [2]. The methods for further processing were only available from the Institute in Berlin and will briefly be described here:

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[2] Further information can be obtained from the international studbook 1997, from Basel Zoo.
[3] It includes all animals, disregarding their age, origin or the time they were present in this survey.
[2] The samples were send away at the beginning of this year.

The samples were dehydrated by using a rising concentration-solution of alcohol. Afterward, they were embedded in paraffin (Paraplast®) or hydroxyethylmethacryl (Technovit ®, co.: Kulzer, Friedrichsdorf, Germany). Of these embedded samples, horizontal cuts being the size of 5,5µm to 7.5µm were made, using a microtom (sledge microtom, co.: Reichert-Junge, Heidlberg, Germany). Following this the samples were stained with hematoxylin and eosin (HE) and with periodic acid-schiff stain(PAS). Both stains are commonly used in histological examinations and are well described by Romeis (1989). The sample sites are illustrated in the following pictures:

Picture 1:
Sample sites F1 - F6, right front foot (sagittal cut), Whipsnade Wild Animal Park, UK
Sample F3 (junction sole/pad) was taken for histology (see under 7.4).

Picture 2:
Sample sites H1 - H6, left hind foot (sagittal cut), Whipsnade (nail and sole are facing to the left).
Sample H3A (affected sole area) and H3B (affected pad area) were used for histology (see under 7.4)

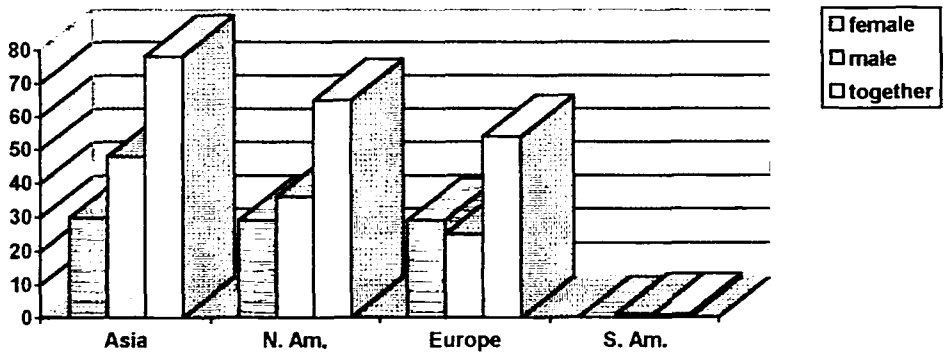
7. Results

7.1 Evaluation of the questionnaire

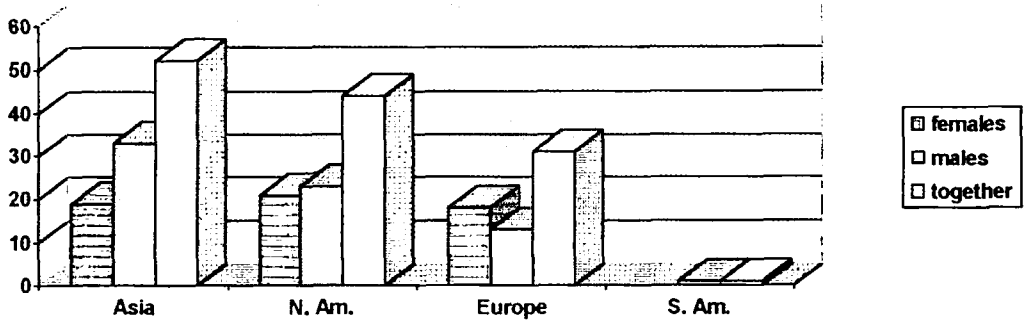
7.1.1 Distribution of greater one-horned rhinos and participitation in the study

Between the study period of 1.1.1980 and 30.6.1996, 198 greater one-horned rhinoceroses were kept in zoological gardens on four continents. Of these, 25 animals were stillborn. Thus 173 animals fall under the study period, of which 127 were still alive at the end of the study. (Included are animals of all age, either taken from the wild or born in captivity.)

The following graphs show the distribution of these animals according to continents and sex:



Graph 1: Distribution of greater one-horned rhinoceros from 1. 1. 1980 until 30. 6. 1996



Graph 2: Number of animals present at the end of the study period (30. 6. 1996)

During this study period, 57 zoological collections kept greater one-horned rhinoceroses, of which 34 replied to the questionnaire. Table 1 gives an overview of the distribution of the zoos worldwide and shows the number of

zoos participating in this study:

Table 1:

Distribution of greater one-horned rhinoceroses worldwide during the time of 1.1.1980 to 30.6.1996

Zoos In:	Nr. of zoos	Nr. of animals in zoos between study period (males/females)	Nr. of animals living at the end of study period (male/fem.)	Nr. of dead birth (DB)	Nr. of zoos replying to questionnaire (Nr. of animals)
Asia	24	78 (48/30)	52 (33/19)	2 (1/1)	5 (17)
North America	17	65 (36/29)	44 (23/21)	14 (8/6)	14 (38)
Europe	15	54 (25/29)	31 (13/18)	9 (3/6)	14 (43)
South America	1	1 (1/0)	1 (1/0)	0	1 (1)
Total:	57	198 (109/89)	127 (69/58)	25 (12/13)	34 (99)

7.1.2 Evaluation of the cover sheet

The cover sheet of the questionnaire deals with the evaluation of the prevalence of chronic foot problems in greater one-horned rhinos. Each above listed zoo was asked to state if any animal in their collection had ever suffered from foot problems during the study period (no matter what clinical picture) and to list if the animals are still present, died or have been moved to another place.

Out of the 34 zoos which replied to the questionnaire 21 zoos had at least one animal with chronic foot problems. Altogether information about 99 animals was returned and of these, 25 suffered from foot problems. The following table shows the participation and the number of affected animals in each continent, compared to the total number of animals in captivity:

Table 2:

Number of animals in continents (stillborns are excluded) and number of replicants to questionnaire, including the number of animals (males/females) with and without foot problems (FP):

	Nr. of zoos and animals	Nr. of zoos replied	incl. Nr. of animals	zoos with FP	animals with FP
Asia	24 - 76(47/29)	5	17 (11/6)	3	3 (1/2)
N. America	17 - 51(28/23)	14	38 (21/17)	8	8 (7/1)
Europe	15 - 45(22/23)	14	43 (20/23)	9	13 (8/5)
S. America	1 - 1(1/0)	1	1 (1/0)	1	1 (1/0)
Total:	57-173(**98/75**)	34	**99** (***53/46***)	21	**25** (**17/8**)

From this table the following facts result:

1. Asia and especially India, with 16 zoos and a total of 55 animals (numbers were taken from the studbook of 1996), hold most of the rhinos in captivity and participated least in answering the questionnaire. Due to this fact the results of this study reveal more the general situation of N.America and Europe.
2. When looking at the number of affected animals with foot problems (FP) compared to either the whole captive population or to the ones which replied, it becomes evident that the percentage of animals with this problem lies at 14,5% (25 out of 173) for the whole population and at 25,3% (25 out of 99)for the ones which were recorded whithin the questionnaire.
3. The next result which can be drawn from the table is that males are more affected than females. Of all captive males (17 out of 98) 17,3% suffer from FP and with regard to the ones recorded through the study (17out of 53) 32% are affected.
4. Furthermore, table 2 shows that in the case of Europe, 60% (9 out of 15) of all zoos and in the case of North America 47% (8 out of 17) have at least one animal with this problem. (Assuming that those who did not reply don't have animals with FP.

7.1.3 Evaluation of sheet 1

Sheet 1 contains questions about indoor and outdoor housing facilities. Each zoo was asked to give as precise information as possible about the size of the enclosures, floor/ground surfaces, pond/wallow availabilties and the approximate time animals made use of them.

The results are:

1. 60% of zoos with and without FP keep their animals on a 100% concrete surface indoors. Some zoos provide straw, hay or woodchips as bedding. Rubber has been used in one zoo as matting. The size of the indoor enclosures vary in both groups, being on average 88 - 59m². When comparing zoos with and without FP there seem to be no significant differences with regard to how the rhinos are kept indoors.

2. The outdoor enclosures, in 80% of both groups, consist mainly of earth, grass or sand and the enclosures are on average 1400m² large with extremes ranging from a minimum size of 50m² to a maximum size of 300 acres.

   The presence of an outdoor pond does not vary within the groups (70% have one), but zoos without FP seem to provide to a greater extent an additonal place to wallow (79%) than do zoos which have animals with FP (50%). The average time spent in the pond per day is 6 hours and extremes range from 2 -12 hours in each group. In some zoos the animals even spend whole days in the water if constant access is allowed.

7.1.4 Evaluation of sheet 2

On this sheet questions were asked about the climate with regard to indoor and outdoor enclosures.

1. In both groups no constant climate exists outside. Temperatures vary from -25°C to 46°C (-15°F - 115°F). The average humidity ranges around 75%, with extremes from 10% - 100% for both groups.
2. The indoor facilities differ in that zoos with FP provide a more constant climate than the other group. The latter also seems to keep their animals under more extreme conditions with regard to temperature and higher humidity levels (70% compared to 80%). The average temperature is 20°C in zoos with FP compared to 13°C - 30°C in the other group. If these measurements have any effect on the occurrence of FP is difficult to evaluate. They might be important in connection with the softness and elasticity of the skin in these animals.

7.1.5 Evaluation of sheet 3

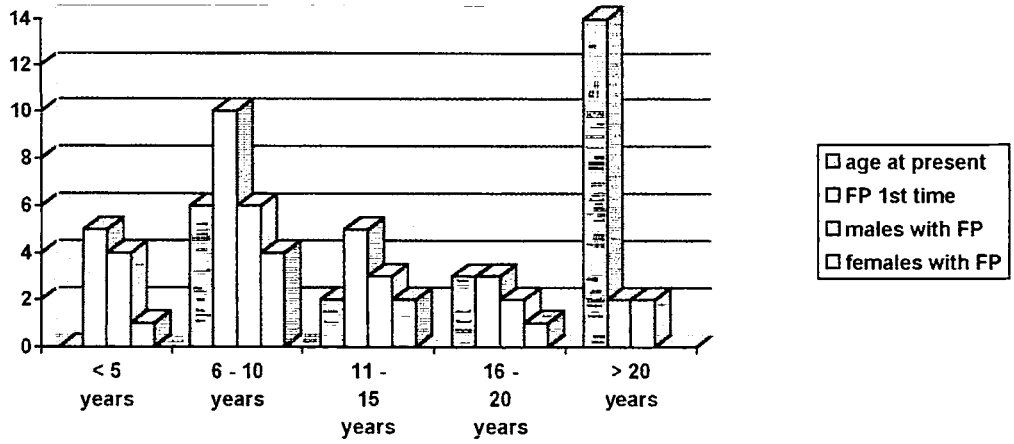
Collections which keep animals with FP were asked to give more detailed information about the location of the lesions, the clinical picture and the degree of severity.

The results are:

1. Chronic foot problems occur mainly in the hind feet (22 out of 25 cases) and to a lesser extent in the front feet (9 out of 25). In some animals all four feet were affected. In each of these 22 cases a separation of the middle toe from the adjacent pad has been recorded with different degrees of severity. The most commonly described picture is of a deep crack (up to 5cm in severely affected animals) along this junction, covering most of the area behind the middle sole (length up to 10 cm).
2. In 15 cases the hind feet also showed an overgrowth of the middle toe nail, leading to unphysiological footing. Less pressure is put on the central part of the pad but more on the hind part and on the tip of the toe nail.
3. Vertical cracks occur mainly in the nails of the front legs, followed in some cases by a severe lameness and abscesses, forming at the coronary band. They were more often encountered than a separation of the sole from the pad (5 out of 9).
4. Additionally, inflammation and granulation tissue formed inbetween the digits of the hind legs. 10 cases were reported where a separation of the sole and pad occurred at the same time as the interdigital problem.

Picture 3:
Separation of the central toe from the adjacent pad; left hind foot, greater one-horned rhinoceros (*Rhinoceros unicornis*), 'Roopa', may 1997.

The zoos were also asked to state the time when FP occurred for the first time in their animals. The following *graph* gives an overview of the age and sex distribution of the occurrence of FP:



Graph 3: Age and sex distribution of greater one-horned rhinos with foot problems:

As this graph shows most zoos reported that the first time they recognized FP in their rhinos was between the age of 5 and 11. The youngest recorded animal was four years old.

7.1.6 Evaluation of sheet 4

This sheet deals with the question of using diagnostic aids, such as histology, bacteriology or any other test of importance as a possible diagnostic aid.

7.1.6.1 Histological evaluation

Three zoos replied to the question of having conducted a histological examination. In one case the diagnose was pappilomatosis. The histological sample was taken from the interdigital granulation tissue of a hind foot. The two other examinations were performed once on an euthanized animal (due to the severely affected hind feet) and the other biopsy was taken from granulation tissue forming between the sole and the pad of an other animal. In both cases the diagnose according to histology revealed a necrotising pododermatitis and granulation tissue. The histological examinations which were performed on the feet of the rhinos from Whipsnade and Germany will be described thoroughly under 7.4.

7.1.6.2 Bacteriological evaluation

Bacteriological examinations were performed on four chronically affected feet. Several samples were taken (from deep reaching cracks) over a period of time and either isolated growth of *Streptococci/Staphylococcus aureus* was present or a mixed growth of *Corynebacteria sp.*, *Streptococcus sp.*, *Klebsiella pneumonia* and *E. coli*. In one case, *Bacteriodes melanogenicus* was detected as well. This is a very important pathogen. It occurrs together with *Fusobacterium necrophorum* in necrobacillosis of the bovine foot. The results seem to match with the fact that once the lesions occurred, ubiquitous bacteria find access to the wound and are difficult to keep away. The lesions are almost impossible to keep clean and covered with aseptical material. There were no reports on any further diagnostic tests.

7.1.7 Evaluation of sheet 5

In this section questions were asked about what each individual collection thought to be a possible primary causes of the occurrence of foot problems. Some zoos stated more than one cause and out of 17, 15 replied to this question.

The other part of the sheet deals with the treatment scheme and its long-term success/affect. Herein will also be included some more detailed information, which was sent additionally with the questionnaire.

7.1.7.1 Possible primary causes

The majority holds hard surfaces, chronic trauma, a lack of moisture/humidity (esp. during the winter time), the lack of free/constant access to water and the overgrowth of the central toe nail responsible.

The latter was associated in most cases with a lack of general exercise and to a lesser extent with non-abrasive surfaces. This overgrowth finally led to an increasing tension of the tissue between the sole and the pad.

One zoo mentioned a conjectural genetic predisposition, one the high weight of the animals (esp. important while mating) and another the nature of the animals, since they seem to make sharp turns when frightened or when chasing a mate. This can possibly lead to a rupture of the connective tissue between the sole and the pad.

7.1.7.2 Treatment scheme

The treatment consisted in the majority of the cases in trimming of the overgrown nails. Thus physiological footing is achieved and the pressure is taken away from the area between the nail and the pad, the main area where the lesions occur. When trimming the nails, it seems of utmost importance not just to cut the nails short as best as possible but also to consider the way the animal puts its feet down. This can become difficult to assess and to perform, if the animal lies in an awkward position when anaesthetised.

The forming of granulation tissue leads to additional pressure in the area between sole and pad and prevents proper healing. This tissue can grow to such an extent that the animal is unable to walk. Therefore many zoos have to anaesthetize their animals on a routine basis (from every 6 weeks to half a year, depending obviously on

the degree of severity).

Good information were passed on by Mark Atkinson from The Wilds, Ohio, USA [4]. Concerning the frequency of treatment, he reports that severe cases need constant aggressive debridement every 6 - 8 weeks, if one wants to control the problem. This fact puts the foot problem in another perspective. Not only is it difficult to treat and that it will take a long time to improve, but several courses of general anaesthesia are needed as well. This can constitute a severe danger to the patient (stress, anaesthetic dosage increases with regard to the frequency of immobilisation, risk of respiratory failure increases,..). The risk of anaesthesia has proved to be lethal in one case. In addition, treatment consists for the most part in cleaning the wounds with several solutions and powders. Some with astringent potencies have proved to be very effective.

Copper sulfate [5] is used as a caustic dressing for debridement and coagulation in wounds and in footbaths for the treatment of footrot in cattle and sheep. Some authors used it successfully, on a daily basis, in their rhinos as a part of their treatment scheme[6].

Copper napthenate [7]is a topical antifungal, antiseptic and astringent, usually used for treating thrush, hoof punctures, cracked hooves, footrot in cattle and sheep. This drug has also been used after operations and for cleaning wounds.

The cooper sulfate foot bath is thought to be safe on wounds when applied for the first time 1 -3 days after aggressive trimming of the exuberant tissue [8] .

The use of oral antibiotics has been mentioned by some zoos and potentiated sulfonamides, such as trimethoprim sulfadiazine [9] seem to be the most frequently used.

Any use of supportive shoes or casts proved to fail their purpose and bandanges seem to work for only a short period of time. When applied after surgery, they serve the purpose of stopping the heavy bleeding after debridement.

In each case the treatment period turned out to be very long (in some cases over years) and difficult. It often demands general anaesthesia of the animal due to the painfull procedures or due to the difficulties of getting proper access to the lesions.

Some zoos were successful in getting the problem under control by incorporating the above mentioned daily foot bath using CuSo4 bath (approx. 10 - 20 min per day). Oxytetracyline is either incorporated in the bath or used as as aerosol [10] after the bath. The best way seems to train the animal right from the beginning to accept its pelleted

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[4] M.Atkinson pers. comm., to be presented at the AAZV 1998
[5] Copper sulphate Powder®, UKASTA, London, UK
[6] Refers to footnote number 3
Kopertox®, Crown Vet. Pharm. Lancashire, UK
[8] Refers to footnote number 3
[9] Tribrissen ® Pilman-Moore, UK
[10] Terramycin ® Acrosol, Pfizer, UK

food in a chute and then to gradually train it to put its feet in the bath while eating [11] . This proved to demand a good deal of work and patience but was successful and easy to perform once the animal got used to it.
Formaldehyd and zinc sulphate solutions are used in farmed animals for the treatment of footrot. The latter is frequently used, being less toxic and less irritant to the tissue. No reports exist if this medication has been used or not for affected rhino feet.
Two cases used a biotin supplementation for a long time (up to 18 month) with the effect that the quality of the horn strengthened. If this prevents the occurrence of FP has not yet been found out.
In 6 cases the zoos reported that the lesions healed much better and faster if the animal had constant access to water. The theory behind this is not only the presence of moisture but the fact that the animal doesn't have to bear any weight and doesn't put any pressure on the affected sole and pad, while 'floating' in the water.
One zoo reported that the lesion disappeared completely after the animal spent five days in a row in the pond.
The success rate of complete healing is low but some zoos managed to keep the problem under control by regular trimming the nails, increase of excercise and access to water (many animals seem to grow old with the problem). In 10 cases no success at all has been recorded so far.

7.2 Evaluation of the 'Whipsnade cases'

Whipsnade Wild Animal Park, UK, was one of the first zoos ever to keep greater one-horned rhinoceroses and had bred them in the past successfully. The animals living at Whipsnade now were both bred in captivity.
'Roopa' was born in Delhi in 1971 and came to Whipsnade in 1973. 'Kumar', the male was born in Berlin Zoo in 1972 and arrived at Whipsnade in 1976. Since then, they had seven offspring of which three were stillborn.
Both animals are still present at Whipsnade and are part of the group of animals suffering from chronic foot problems. These two cases were choosen as they seem to represent the picture of chronic foot problems in every aspect.
The female showed FP first in 1983 (age 12) when vertical cracks appeared on the lateral aspect of the front nails. A swelling along the coronary band indicated that the superfical cracks led to the occurrence of underlying infected tracks. Pus discharged when the abscess burst on the coronary band. Although the cleaning of the tracks and the opening of the outside cracks - to relieve the pressure - as well as the application of systemic and topic antibiotics led to an improvement and initial healing, these cracks recurred over a period of serveral years with varying intervals. As mentioned in the literature above, these sort of 'foot problems' have been observed in all captive rhino species. It is thought that they often develop from acute traumatic insults, from dry, brittle horn and in some cases a high intake of protein has been associated with them.
After an interval of nearly six years without severe foot problems, the cracks recurred in fall 1996. Her left hind

[11] Refers to footnote number 3

leg (lateral aspect of the middle toe nail) was showing a vertical crack, one month later the left fore leg, in the same position. When the necessity for general anaesthesia was indicated, a separation of the sole from the pad was diagnosed in both hind legs (see picture 3). Since that time the animal has shown the typical signs of chronic FP. Treatment causes temporary success and cracks appear in the fore nails now and again. The central toe nails of the hind legs seem to grow very fast, indicating the need to trim the nails nearly every three months. The tracks between the sole and the pad improve when treated but never seem to heal completely.

The male 'Kumar' started to show foot problems one year after he arrived at Whipsnade, in 1977 (5 years old). Interdigital fibroma developed between digits two and three in the hind left leg and less severely between other digits. They seemed to bother the animal when walking, but showed no signs of infection. In 1978 the right hind leg showed a separation of the sole from the pad and in 1979 all feet, except the left front, were severely affected by the same problem. Up until now the problem got sometimes better and sometimes worse. Since 1993 general anaesthesia was performed about every 4 - 5 months. The overgrowing nails of the hind legs were trimmed and any hyperplastic tissue, forming between sole and pad, was cut away. It is interesting to notice that this animal often had problems with the skin, being dry, brittle and infected. In 1996 the animal was first trained by the keepers to voluntarily lay down or to lift its feet. This allowed minor treatment (cleaning, application of disinfectants,...) and trimming of the nails, without general anaeshesia and proved to be very helpful. Although the feet improved tremendously, the separations were still present on both hind feet and occasionally worsened. The animals are now trained to accept a cooper sulfate foot bath and the indoor enclosure has been changed from being 100% concrete to a thick layer of woodchips in the outside den for both animals. Additionally, each animal will have access to a pond, but only for half a day, as they have to 'share' it. They don't get along well with each other (appart from mating seasons), thus alternative 'swim-turns' have to be taken.

Neither animal looks as if they enjoy putting a lot of weight on their hind feet, resting most of the time. Since they lack excercise through this, trimming is needed very frequently. A reduction of protein in their diet was also initiated to avoid a gain in weight which might impair them additionally. So far no solution has been found. Intensive treatment courses are performed, but due to a lack of extra space or the availability of water for each animal they don't really seem to improve. This is unfortunate since other collections reported an improvement - after no success with other treatments - if the animals had the possibility of constant access to water.

7.3 Evaluation of the family tree

A family tree was set up with the help of the current studbook 1997 and 1996 (see appendix).

Within this family tree the animals suffering from chronic foot problems are marked and it is possible to draw the following results from it:

a. Of the 25 animals suffering from chronic foot problems, 6 animals belong to the group of wild founders. None of them have descendants with FP.
b. Three animals, belonging either to the 1st or 2nd generation born in captivity showed FP. None of them had ancestors with FP and only one female (the one from Whipsnade), mated with a male with FP (Kumar, Whipsnade). She gave birth to seven offspring, of which three were stillborn and two developed foot problems at a later age.
c. The rest of the animals with FP (16) are either descendants of the wild sire with the studbook number 0018 or another wild founder with the number 0005. Eight of their descendants carry the genes of them and four of either one.

   Of these sixteen animals seven have an inbreeding coefficient larger or equal to 0.125. According to the studbook of 1997, these seven animals also have a high mean kinship, which is the average relatedness of an individual to all other individuals in the zoo population. Out of the 16 animals, 6 are offspring of rhinos (either sire/dam or both) which suffered from FP themselves.

Due to the fact that most animals (64%) with FP are related to either sire 0018 and/or 0005 it might be possible that there is a predisposition, especially to their descendant. If this is due to inbreeding or due to a deleterious 'special FP gene' in these two founders is difficult, if not impossible to say.

No definite results can be drawn from the family tree but it is interesting to notice that the majoritty of animals with FP accumulate around a group of captive rhinos, including the 1st to the 4th generation (it is important to notice that they are all housed in different collections).

7.4 Histological examination

Several samples, as mentioned under methods and illustrated in pictures 1 and 2, were examined. The light-microscopy results revealed that one particular area (see picture 4) seems of importance, when evaluating foot problems in greater one-horned rhinos. This area is the junction between the sole and the pad, the area which is affected in most cases of this study (see sample sites F3 in picture 1 and H3A and H3B in picture 2). For this reason the sample sites of the other areas will be neglected, as they roughly resemble the structures found in cattle and horse feet, with slight differences (besides that, the description would go beyond the scope of this project).

This study also shows that the wall of the rhinoceros feet was not affected as it happens in most cases of laminitis in horses.Several light-microscopy pictures were taken and are used in this project to facilitate the illustration of the physiological structures as well as the pathological structural changes, in this area.

The following picture gives an overview over the rough anatomy of a half cut hind foot. The area of interest is enlarged. Two things of importance mark this picture:

a. The nail is relatively short, with the sole being about 6 - 7 cm long and the adjacent pad makes up the main area on which the animal bears its weight.
b. The third digit reaches far down to the tip of the toe and only three cm separate the joint from the area of interest. This gives rise to the assumption that an infection of the enlarged area, might possibly lead to an infection of the joints in more severe cases.

Picture 4:Sagittal cut through a left hind foot of a greater one-horned rhino, Tierpark-Berl., Germany

Pictures 5 and 6: (page 34)

Both pictures were taken from the same sample and illustrate the structure of the dermis and epidermis in the junction of the sole and the pad (sample: rhino, Tierpark Berlin).

Picture 5 has been taken from the area orientated more toward the sole. The darker stained structure on the left is the dermis, including fibric tissue, vessels, nerves and the primary dermal papillae, which interdigitate with the surrounding lighter stained horn. The round circles in the middle of the picture still represent the papillae, but

appear as circles, due to the cut. The larger clear white spaces within the papillae are artefacts. The more purple stained structures to the right are the tubular horn masses, surrounded by intertubular horn.
Picture 6 has been made further towards the pad. When comparing these two pictures one can realise that the dermal papillae in the 6th picture are thicker, longer and more in number. Remembering that these two pictures were taken from the same slide, this sudden change in structure leaves an area of minor resistance to any impact. In picture 4 this rapid change in structure is also visible.
Due to the fact that this change in structure is a weak point and probably the weakest point in the whole hoof, more samples were taken to illustrate this better.

Pictures 7 and 8: (page 35)
Pictures 7 and 8 derive from the same area - sole/pad junction - of the right front foot from the Whipsnade animal, which appeared clinically healthy.
Picture 7 (equally to # 5) was taken closer to the sole, showing a few papillae only, which seem short and thin.
Picture 8 in contrast, shows thick papillae (artefacts in the middle ones visible as white areas) which extend further to the right than in picture 7 and are more in number as well. Again both pictures were taken from the same slide, being approx. 1000µm apart.

The last pair of pictures which illustrate this change in structures, derives from the lateral hind left hoof of a two year old cattle.

Pictures 9 and 10: (page 36)

Picture 9: The top of both pictures shows the dermis. Small purple dermal papillae, interdigitate with the epidermal papillae. The lighter structures towards the bottom represent the tubular (red) and intertubular horn. Picture 10 illustrates the pad-area of the junction. The dermal papillae are longer and the str.granulosum is strongly visible as a mid-line. This has not been found in the rhino foot.
In cattle, the area shown in picture 9 and 10 has been diagnosed as being the main place of infection for panaritium/footrot.

Pictures 11, 12, 13, 14: (page 37/38)

In order to demonstrate the dramatic changes not only in the superfical epidermal layer but also in the dermis, four pictures were taken from the affected area of the left hind foot from the Whipsnade animal.
Picture 11 illustrates long small papillae, dysceratotic horn cells surrounding the dermal papillae and an increasing amount of cells arising from the stratum spinosum. Those cells are abnormal in structure and size as they look more blown up than would be normal.

Pictures 12 and 13 show the pathological changes in the area towards the pad.
Number 12 makes possible the recognition of the dermis on the left, forming big dermal papillae which seem to have lost an organised growth and structure. The dermal line is also irregularily arranged giving rise to the diagnose that the traumatic insult reached deep into the dermis.
Picture 13 is the continuum of the right side of picture 12, showing the distortion of horn structures. On the right side an attempt to regenerate horn is visible.
Picture 14 illustrates the facts which have been demonstrated with the pictures above. This picture has also been taken from the hind left foot of the Whipsnade rhino and shows a crack which formed straight through the above described area. Additionally, necrotic papillae and openings of the medulla of the horn are visible.They serve as further entrances for bacteria.

Picture 5:
Hind left foot, greater one-horned rhinoceros, Tierpark, Berlin. Junction sole/pad (here orientated more towards sole), HE stain. Dermis(1), dermal papillae (2), tubular (3) and intertubular (4) horn.

Picture 6:
Same animal/foot/area/stain as in picture 5, this time view is orientated more towards the pad

Picture 7:
Right front foot, Whipsnade, section: sole - pad junction, orientated more towards the sole, HE
Dermis (1), dermal papillae (2), str.spinosum (*), tubular (3) and intertubular (4) horn.

Picture 8:
Same as number 7, view orientated more towards the pad

Picture 9:
Two year old cow, left lateral hind hoof, HE stain, sole/pad junction, orientated more towards sole
Dermis (1) with dermal papillae (2), tubular (3) and intertubular (4) horn.
With courtesy of Dr. C.Mülling, anatomy department , Freie Universität Berlin, Germany.

Picture 10:
Same as 9, orientated more towards the pad. Str.granulosum well visible (*)
With courtesy of Dr. C.Mülling, anatomy department Freie Universität Berlin, Germany

Picture 14:
Left hind foot, Whipsnade, affected area: sole/pad junction. Cut through epidermis into dermis (1), with necrosis of dermal (□) and epidermal structures (*).

Picture 11:
Left hind affected foot, Whipsnade, sole/pad junction, section closer to sole. Shows the pathological changes in the dermal papillae (2) and epidermal structures esp. str. spinosum (*)

Picture 12:
Affected area of left hind foot. Whipsnade, cut taken from pad (distad). Shows pathological changes in dermal papillae (2) and horn (3).

Picture 13:
Adjacent picture to the right part of picture 12, showing deformations in the horn structures (3) and an attempt (*) of regeneration:

8. Discussion

This project's aim is to evaluate the prevalence and the primary causes of chronic foot problems in greater one-horned rhinos. As it became obvious through this study, the prevalence of the problem is high, especially in the male population (twice as many as females).

Of the total male poulation (98), 51 males are living in Europe, N. America and S. America. Of these, the study covered 42 males.

The number of males suffering from chronic foot problems is 17, thus concluding that 33,3% are affected. Since the study included all age groups of animals these figures can possibly mean that there might not be enough potential sires for the near future. This is concluded for the following reasons.

First of all there might not be enough males within the age group of potential sires since sexual maturity of males starts at about 9 years of age. Not all healthy males have yet reached that age.

Secondly, due to the fact that the lesions are often painful, most males will feel very reluctant to mate at all. If they attempt it, this might lead to a worsening of the lesions due to the heavy weight they bear on their hind legs during mating.

Last but not least it is worth considering that there might be a conjectural genetic predisposition to this problem. As Bauer and Studer (1995) have already pointed out in their study, 'rather than wait for significant results, action should be taken to minimize further inbreeding'. Therefore it might be wise not to breed with these animals, and especially not with those descending from the family tree of sire #0018 and sire #0005.

The other important thing which might play an important role is the careful construction of enclosures for this creature which lives mostly in swampy areas. Access to water seems to have proven to minimize not only the risk but also to encourage healing. In a way it seems obvious that the closer one tries to keep an animal to their natural habitat the less problems will occur.

At this stage I would like to refer once again to the words of Fouraker and Wagener (1996) from their Rhinoceros Husbandry Manual: 'Any rhino under intensive management needs to be provided with improved and proper husbandry'. It would certainly be important for each zoo to try and find the reason why their animal has FP and to try actively to find a solution for it.

Although this study does not include any animals from Nepal or India, a recent publication covering the health status of the rhinos in these zoos, mentions no problems concerning the feet of rhinos (Sharma, et al. 1994). This publication also describes the way some of the animals are housed. They do not seem to differ in size but more in

what type of floor surface is used (softer) and in the provision of access to water.
Thus foot problems in the captive population seem to be restricted to animals, kept in Europe and America.

This and the high prevalence of FP in male rhinos in Europe and America, can imply that it might become necessary to transport more animals between continents in order to maintain a breeding population. A procedure which not only imposes a health risk to the animals but also would need a good financial backup.

As the histological examination states clearly, the structure of the area which is most commonly affected, namely the junction between the central toe and the pad of the hind feet, is a 'locus of minor resistance'.
Any traumatic impact, tearing tension or even lack of water to keep that area soft and smooth, will easily crack the tissue and will present a clinical case, like those described above.

Additionally, the problem seems comparable to foot problems in intensively managed animals. Improper husbandry is the most important factor leading to the occurrence of foot problems in these species. With regard to that it might be possible that this is also the case in captive kept greater one-horned rhinoceroses.

Due to the nature of the location of this problem, treatment proves very difficult and often unsuccessful. This can result in a chronic patient or even in death under severe circumstances.

This study did not deal with the role of nutrition in connection with foot problems. It would be worth investigating this matter as foot/hoof diseases are known from other intensively managed animals.

Additionally, the weight of the rhinos might play an important role. To watch the nutritional requirements would therefore serve the well-being of the animals in more than one way.

In any case, preventive medicine would facilitate life, not only of the people who are responsible for them but also for the animals themselves.

With regard to the high prevalence of the discussed matter and when looking at the extensive studies which are carried out on diseases of other rhinoceros species, namely the black rhinoceros (*Diceros bicornis*), it would be interesting to investigate in more detailed studies in the future. To find a solution to this problem would help in keeping a healthy breeding population of this highly endangered species.

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10.1 The questionnaire on chronic foot disease in Asian greater one-horned rhinos

Cover sheet:
Name of collection: Questionnaire completed by
Date:
Name of collection's veterinary surgeon:

A. DETAILS OF ASIAN GREATER ONE-HORNED RHINOS KEPT AT COLLECTION 1.1.1980 - 30.6. 1996

Studbook No.	Local Id No.	Name	Sex M/F	Date of birth	Arrival Date	Arrival from	Still present Y/N	Departure Date	Departure to	Date of death	Cause of death	Did animal suffer from chronic foot problems Y/N	Wheight (if available) kg

1. Please complete Sheets 3 -5 fo each animal affected with chronic foot disease, and photocopy as necessary.
2. It would be of great interest if you would send photogroaphs of the lateral aspect of the fore and hind feet of all animals still in the collection; wheather or not affected and all ages and both sexes.

Sheet 1:
Name of collection:
B. DETAILS OF FLOORINGS & ENCLOSURE SUBSTRATES

1. Indoor Housing enclosure? Approx. size: .....m²

Approx. % of total area

Concrete .....
Sand .....
Wooden boards .....
Matting ..... Type used: .....
Straw .....
Shavings .....
Wood chip .....
Pond .....
Other ..... Describe: .....

If several types of flooring substrates have been used, how are they distribute?

1. If your rhinos have access to a pond/wallow, approximately how much time per day do the individuals with foot problems spend in
   - the pond ..... - the wallow: .....

2. Outdoor enclosur Approx. size:.....m²

Approx. % of total area

Concrete .....
Sand .....
Packed earth .....
Mu/Wallow .....
Grass .....
Wood chip .....
Gravel .....
Pond .....
Other ... Describe: .....

If several types of enclosure substrates have been used, how are they distributed?
If your rhinos have access to a pond/wallow, approximately how much time per day do the individuals with foot problems spend in
- the pond - the wallows

Sheet 2:

C. CLIMATE

How can the climate be described on the outdoor

Constant climate: ☐yes ☐no

minimum temperature: .....
maximum temperature: .....
humidity: .....

How can the climate be described in the indoor housing?
Constant climate: ☐yes ☐no
minimum temperature: .....
maximum temperature: .....
humidity: .....

Sheet 3:
Name of collection:
Animal studbook number

Please copy sheets 3 -5 and complete for each animal which has suffered from chronic foot problems during the period 1980 - 1996

D. DETAILS OF FOOT LESIONS:

Affected feet	Affected Yes/No	Date first recorded	Any period when healed Yes/No	Date completely healed (if ever)
Left fore				
Right fore				
Left hind				
Right hind				

Lesions present	Yes/No/Not recorded	Comments
Overgrowth of middle toe:		
Separation of middle toe from central pad *		
Necrotic/infected tracks under running sole:		
Hypoplasia/papillomatosis of sole, or interdigital area:		

*Degree of separation: (Separation please circle)

Medial/Lateral

Which foot? ..... Under 25% 25-29% 50-74% 75-100%

Other lesions present; please desribe:

Please send photographs of foot lesions if available.

Sheet 4:

HISTOPATHOLOGICAL LESIONS

Date	Biopsy/Postmortem	Findings (describe or send a copy of report)

BACTEROLOGICAL EXAMINATION:

Species of bacteria isolated	Number of times isolated	Site(s) of isolation

No. attempted isolations of aerobic bacteria _____

No. attempted isolations of anaerobic bacteria _____

OTHER DIAGNOSTIC TESTS:	Details	Date	Findings
Cytology of smears/scrapings:	_____	____	_____
Serological tests:	_____	_____	_____
Other (desribe)	_____	_____	_____

Sheet 5:

CAUSES OF CHRONIC FOOT LESIONS:

Do you think that:	Yes/No/ Not sure	Comments
overgrowth of the central toe is a 1° cause of the lesions?		
chronic trauma caused these lesions to start? If so, what are the cause		
a bacterial infection is a 1° cause of the lesions		
What other factors do you think are important?		

TREATMENT:

Do You:	Yes/No	How often ?	With the animal Conscious or Immobilized	Comments
Trim overgrown nails				
Clean out infected tracks				
Cut away hyperplastic tissue				
Apply antibiotics Which				
Apply dressings				
Apply casts				

Have any of these been successful?..