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Foot problems in Indian Rhinoceroses (Rhinoceros unicornis) in zoological gardens: Macroscopic and microscopic anatomy, pathology, and evaluation of the causes

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On ne voie bien c’avec le cœur

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1. Introduction and aim of study

The Indian rhinoceros *(Rhinoceros unicornis, Linné 1758)* is listed on CITES Appendix I, classified as seriously endangered. The current population ranges around 2470 individuals in northern India and southern Nepal. Worldwide, 136 (73 males / 63 females) animals live in zoological gardens, 35 (15 / 20) within European collections (Wirz-Hlavacek et al., 1998). Since the beginning of the 20th century, Indian rhinos have been kept in zoos and were successfully bred.

Compared to other rhinoceros species in zoological gardens, these animals suffer seldom from clinical problems, with one exception. The Indian rhinoceros is the only species that is highly susceptible to foot problems. These problems were generally underestimated until a study evaluated the frequency of this specific problem in zoos worldwide (von Houwald and Flach, 1998). The reason for its occurrence remained until now speculative. The aim of this study is to investigate some causes of foot problems in this rare species and to find a solution how to prevent this problem in the future.

In addition, the study is set up to describe the anatomical macroscopic and microscopic structures of the feet and to compare these findings with the known structures found in domestic species. All pathological alterations are documented, histologically described, and compared with domestic species.

Furthermore, the feet of wild Indian rhinos were compared with the feet of captive animals in order to achieve certain knowledge of the anatomy.

2. Literature

2.1. The wild population

2.1.1. Status

Living in the South Asian floodplains, the Indian rhinoceros or Asian Greater One-horned rhinoceros (*Rhinoceros unicornis,* Linné 1758) was almost hunted to extinction by sportsmen and poachers in the beginning and middle of the 20th century. A growing human population and fragmentation of the habitat are further threats to the remaining population. Despite this pressure, the Indian rhinoceros has often been quoted as one of the success stories of wildlife conservation (Penny, 1987; Foose and van Strien, 1997). Highly protected in a few reserves in northeastern India, Assam, and southern Nepal, the Greater One-horned rhinoceros survived in the 20th century a severe bottleneck situation.
The IUCN/SSC[1] Asian Rhinos Specialist Group counted 1999 a total population of 2.471 animals. The first draft of husbandry guidelines for this species (Guldenschuh et al., 2000) give detailed information of the population range in each remaining area. 1.819 Indian rhinos were counted in India and 652 in the Nepal.
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 are thought to exist of the Sumatran rhinoceros *(Dicerorhinus sumatrensis)* (Foose and van Strien, 1997).
The world population of the five rhinoceros species is estimated to range around 12.800 animals. The African species - including the Black rhinoceros (*Diceros bicornis*) and the White rhinoceros *(Ceratotherium simum)* - come up to approximately 9.900 and the Asian rhinos to about 2.900 wild individuals (Foose and van Strien, 1997).

2.1.2. Habitat

The original habitat of the Indian rhinoceros ranged from the Indus River in the west, to the Ganges in the south, and the Brahmaputra in the Northeast of the Indian subcontinent (Emanoil, 1994). Today, the remaining population is restricted to little areas in southern Nepal, Assam, and northern India. The Chitwan Valley National Park in Nepal and the Kaziranga National Park in India hold the majority of this species.
The Indian rhino is the world’s second largest land mammal and thrives in and around riverine floodplains and tall swampy grassland (Laurie, 1997). Occasionally, depending on the onset of the monsoon, they can be seen on open grassland, bush, savannah, hilly country, and forests (Guggisberg, 1966). They seem to favour riverbanks or pools, not only

[1] IUCN – International Union of Conservation of Nature and Natural Resources
SSC – Species Survival Commitee

for taking a bath to '...prevent overheating, the attack of insects, and sunburns ..., but also for grazing...' (Penny, 1987).

2.1.3. Social life

Social groups consist of mother and calf, which are sometimes accompanied by the previous youngster. A calf is born approximately every three years and stays with the mother at least until the next one is born. Young bulls are driven away by the mothers once they reached a certain age (around 4 - 5 years). The mature males are solitary and distinctly territorial. Young bulls are often found in small groups. This 'alliance' makes them less vulnerable to the attacks of older males.
Indian rhinos select their habitat according to the availability of food. For this reason it is possible to encounter several mother and calf groups on common, fertile land. For the resting periods these groups also join for a common bath in large ponds (Laurie, 1978).

2.1.4. Nutrition

185 different plant species are known to make up the menu for Indian rhinos. They are predominantly grazers, but will also feed on shrubs, trees, and twigs. Various grass species make up the majority of their daily intake. The main food sources are tall grass species (up to 8 metres) that grow well under wet conditions. *Saccharum spontaneum* is the preferred one (Laurie, 1997). Water plants come up to 5 % of the daily intake. Under wet conditions those grass species grow very fast and will produce enough plant material to support the large demand of these animals. This is the main reason why these animals live predominantly in and around water areas. They have well adapted to these water conditions and know also how to feed under water.
During the monsoon most rhinos move towards mountainous areas. At that time, many animals will feed on rice fields causing tremendous problems to local farmers. The animals choose their habitat according to the seasonal availability of the food. They will walk long distances on the search for good feeding places and will share the habitat if enough food is available. They do not migrate as it has been observed in elephants and other ungulate species.

2.2. The Indian rhinoceros in zoological gardens

2.2.1. 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 Indian rhinos have been brought from India via ships to the European continent, where the animals were exhibited on 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 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, as more and more zoos breed successfully and fewer animals are taken from the wild. In the international studbook for the Indian rhino of 1998, 51 institutions are listed holding 136 (73 males / 63 females) individuals (Wirz-Hlavacek et al., 1998). In the first studbook of 1975, Lang (1975) reported of 25 zoos keeping 24 males and 20 females.

2.2.2. Body measurements and weight

The Indian rhinoceros has an armour-plated look, produced by the prominent folds on its skin and its lumpy surface. It is the largest of the three Asian species and similar in size with the White rhino, the larger one of the two African species. It has one horn, which can grow up to 61 cm (Penny, 1987). They have sharp incisors in their lower jaws that can be up to 10 cm long and are used as weapons when fighting.
In zoological gardens the oldest age reported was that of a 40 year-old male (Wirz-Hlavacek et al., 1998).
Different reports exist about the size, length, and weight of this species. According to Emanoil (1994) they can weigh up to 1,800 - 3,600 kg (4,000 - 8,000 lb), have a shoulder height of 1,5 - 1,8 m (5 - 6 ft), and are on average 3,4 - 4 m (11 - 13 ft) long. Other authors state that the length is 2,1 - 4 m, the height at shoulder 1,1 - 2,0 m, and the weight 1,500 - 2,000 kg (Penny, 1987; Wirz-Hlavacek et al., 1998).

2.2.3. Husbandry and nutrition

The Indian rhinoceros requires an indoor and outdoor enclosure. The indoor enclosure is necessary in those climatic zones where the temperature may drop below 15°C (59° F) over a longer period of time.

Except mother and calf, each animal has its own stable. Bulls should not have visual contact with the cows. This can lead to aggressive behaviour and constant unrest in the stables. The indoor house should be equipped with a pool. Each animal needs the possibility to make use of it as often as possible.

The outdoor enclosure should provide the animal with sufficient space, a pool, a mud wallow, trees for grooming, a feeding place, and shadow. Adult bulls are kept solitary, except for mating. Females of any age can be kept together, usually one old dam and one or two young animals. Males and females can also be kept together before they have reached sexual maturity (Guldenschuh et al., 2000).

Indian rhinos are mainly grazers but feed also on shrub and trees. They will eat freshly cut grass, hey, straw, fruits, vegetables, and pellets. Daily mass intake ranges around 1 % of the body weight.

2.2.4. Health status

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 and van Strien,1997). In order to comply with theses requirements, Fouraker and Wagener (1996) state 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...'. As already mentioned by Lang (1975), the husbandry conditions, as well as the diet and preventive medicine, seem to be of exceeding importance in order to maintain a healthy breeding pair or population.

Concerning the health status of the Greater One-horned rhinoceros they seem to be of relatively good health compared to other rhinoceros species.

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

Young and very old animals are susceptible to <u>bacterial</u> infections, such as *Salmonella thyphimurium, S. enteritidis, Mycobacterium bovis, M. tuberculosis, Escherichia coli, and Streptococci equisimilis.* All can be fatal (Silbermann and Fulton, 1979; Wallach and Boever, 1983; Char et al., 1984).

Until now only a few <u>viral</u> diseases have been recorded to affect *Rhinocerotidae*. They don’t seem to play a major role in the health status and proper precautions such as vaccinations are available for some of them (Mayr and Mahnel, 1970). The presence of a Herpes virus in connection with skin problems is still presumptive (Göltenboth, 1995). Indian rhinos seem to be susceptible to lung disorders. Cases of chronic interstitial pneumonia are reported from one zoo and were related to the inferior quality of the hay (Rüedi and Müller, 1975).

Rhinoceroses share similar gastrointestinal anatomic features with the *Equidae*. Gastrointestinal torsions and impactions have been described in all captive species by several authors (Jones, 1979; Rüedi, 1983; Kock and Garnier, 1993). The ingestion of sand and foreign material is the most common problem and can end fatal in severe cases. On the whole they are treated like horses.

The skin seems to be a very sensitive organ in all rhinoceros species. Jones (1979) mentions not only dietary factors 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. This is thought to prevent the formation of cracks and infections.

Cases of pustular and exsudative dermatitis occur occasionally in Indian rhinos (Völlm et al., 2000; Rietschel, 2000; Schaftenaar pers. com., 2000). The skin shows infection with common bacteria such as *Staphylococci* without haemolysis, β - haemolytic *Streptococci,* and possibly *Streptococci dysgalactiae* (Völlm et al., 2000). Clinical signs show as reddening of the skin along the medial surface of the hind legs, the caudal part of the abdomen, between the neck folds, and along the edges of the ears. The pustular dermatitis appears as multiple seropurulent, pisiform- to thumbnail-size pustules that cover most parts of the body.

2.3. Foot problems of Indian rhinos in zoos

2.3.1. Description

In 1982 Strauss and Seidel reported for the first time about a clinical case of chronic foot problems in a male Indian rhinoceros. They give a detailed description of the typical clinical picture: Cracks and granulation tissue developed between the pad and the adjacent sole of the central toe (digit III) of both hind feet. In their animal, the horn walls of the central hooves in the hind feet were overgrown. Due to the depth of the lesion they referred to the possible danger of a spreading infection to the nearby joints of the third digit.

In 1986 another report was published by Göltenboth, who describes exactly the same appearance of cracks between the sole of the central toe and the pad of the hind feet in a female Indian rhino from Berlin Zoo. Rüedi and Tobler (1991) also report about a case in one of their Greater One-horned rhino at Basel Zoo. In most cases the central hooves seemed overgrown with the horn wall bending apically, leading to a reduced angle between horn wall and weight bearing border. In all cases, advanced inflammatory processes led to necrotic tissue bulging next to the cracked horn tissue.

2.3.2. Occurrence

An evaluation of this problem (von Houwald and Flach, 1998) in Indian rhinos worldwide came to the result that 25% of the animals in America and Europe show this particular problem. Data, concerning the occurrence of foot problems in the captive population between the years 1980 – 1996, were collected from worldwide zoos. By means of a questionnaire each zoo was asked to give information on the onset, duration, treatment, success, as well as on the husbandry, and nutritional conditions regarding their animals. Out of 57 zoos, 34 replied, giving information about 99 animals out of 173. Of these 99 animals, 25 suffered from chronic foot problems during the study period.

Table I: Occurrence of foot problems (FP) in captive Indian rhinos worldwide, between 1980 and 1996

	Total Nr. of zoos*	+ animals	Nr. of replies	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)

The numbers in brackets (**M/F**) account for the number of **M**ales and **F**emales.
*****The number of zoos keeping Indian rhions has changed during the last years.

2.3.2.1. Gender and age distribution

The results of the study showed that males are more commonly affected than females. Out of 53 recorded males, 17 had chronic problems and out of 46 females, 8 showed alterations.
Foot problems can occur in Indian rhinos already at the age of 5. Most commonly they start between the age of 7 and 11. The youngest recorded animal with severe foot problems was four years old. The problem tends to become chronic and most animals have to put up with it their lifetime.

2.3.3. Presumptive causes

Opinions concerning the causes of the occurrence of this problem are wide spread and remained until now speculative.
As a common cause the excessive growth of the horn walls of the hind central hooves was mentioned. Lack of exercise as well as not enough abrasive surfaces were held responsible for the overgrown horn wall. This overgrowth leads to an increasing tension between the sole and the pad and predisposes this area to cracks (Strauss and Seidel, 1982). Göltenboth (1986) mentions in addition the very dry surface in the outdoor enclosure as well as the heavy weight of the animals. One female became lame after being mounted by her mate. Hard surfaces, chronic trauma, lack of moisture/humidity (esp. during the wintertime), and the lack of free/constant access to water were regarded as further primary causes. The behaviour of the animals seems to play an important part in the formation of the cracks. Males seem to be more active than females. They tend to make sudden sharp turns. While turning, the pad remains on the ground leading to contrary forces within the pad structure and also inside the transitional area between the pad and the sole. This occurs at play, when frightened, or when chasing a female during courtship.

2.3.4. Therapy and prospect of success

The following data result from the evaluation of the questionnaire. As each zoo has its own remedy for the medication of lesions it is difficult to give general data. In addition it was not possible to assess the progress of each individual. In general it can be stated that treatment schemes are difficult to carry out, not very successful, and no 100 % ‘right’ treatment scheme has been established so far. The following data will give an overview of the different approaches to this problem.
The treatment consisted mainly in trimming of the overgrown horn wall and debridement of the granulation tissue. The hooves are shortened approximately at the weight-bearing

the border and white zone as well as along the entire width of the sole. This shortening is thought to relief the tearing tension from the affected area.
Together with the weight of the animals, the extensive growth of granulation tissue in and around the cracks leads to an additional pressure between sole and pad and prevents hence a physiological healing process. This tissue can grow to such an extent that the animal is almost unable to walk. Most zoos have to anaesthetise their animals on a routine basis (from every 6 weeks to half a year, depending on the severity of the lesions). Under sedation the wounds are thoroughly debrided and disinfected. The application of chemical antiseptics or antibiotics on a long-term basis does not help to prevent the contamination with common bacteria. It is impossible to reach all niches that formed within the crevices on a daily basis.
Any use of supportive shoes or casts failed their purpose and bandages work only for a short period of time. Bandages applied after surgery will stop the bleeding but will merely stay on for a short time.
Various medicaments have been used in the past. None can prevent or heal the wounds. All are applied by means of supportive care.
Copper sulphate [2] is used as a caustic dressing after debridement for coagulation in wounds and in footbaths for the treatment of footrot in cattle and sheep. Copper napthenate [3] is a topical antifungal, antiseptic, and adstringent, usually used for treating thrush, hoof punctures, cracked hooves, and footrot in cattle and sheep. This drug has also been used after operations and for cleaning wounds. The cooper sulphate footbath is thought to be safe on wounds when applied for the first time 1 - 3 days after aggressive trimming of the exuberant tissue. Some zoos have mentioned the use of oral antibiotics and trimethoprim sulfadiazine. The use was restricted to severe cases.
The treatment period is very long (in some cases for the lifetime of the animal) and difficult. It often demands general anaesthesia of the animal due to the painful procedures or due to the difficulties of having a proper access to the lesions.
Some zoos were successful in getting the problem under control by incorporating the above-mentioned daily footbath using a CuSo4 bath (approx. 10 - 20 min per day). Oxytetracyline is either incorporated in the bath or used as aerosol [4] after the bath. The animal needs training to accept this procedure. This demands a good deal of work and patience but was successful and easy to perform once the animal got used to it.
Two cases used a biotin supplementation for a long time (up to 18 month). It was reported that the horn became harder but it did not improve the status quo of the foot lesion. In 6 cases the zoos reported that the lesions healed much better and faster if the animal

[2] Copper sulphate Powder®, UKASTA, London, UK
[3] Kopertox®, Crown Vet. Pharm. Lancashire, UK
[4] Terramycin®, Aerosol, Pfizer, UK

had constant access to water. It is thought that the opportunity to lay/swim in water will moisturize the skin and the horny parts and will also allow the animal to relieve its weight from the feet while ‘floating’.
The success rate of complete healing equals zero. Some zoos manage to keep the problem under control by regular trimming of the lesions.
Like Strauss and Seidel (1982), Göltenboth (1991) explains that once these cracks became apparent they became very persistent with different degrees of severity and never seemed to disappear completely, despite constant foot care.
The status quo improves over the summer time and worsens in the wintertime.

2.4. Foot problems of large mammals in zoos

2.4.1. African Elephant (*Loxodonta africana*)
Asian Elephant (*Elephas maximus*)

The two species belong to the order *Proboscidea* (trunked mammals).
They are large land mammals, can grow up to 3 – 4 m high and can weigh between 4,000 - 7,500 kg. The Africans are larger than the Asians. Females are smaller than bulls. Both species can reach 70 years of age (more than 80 in captivity). Their massive body is carried by elongated limb bones, which rest on fibro-elastic fatty pads (Schmidt, 1986; Altevogt, 1987).

2.4.1.1. Anatomical features

The feet of elephants are specialised for weight bearing. The phalanges are embedded in a soft cushion of elastic fibres, enclosed within a fatty matrix. This anatomical feature helps to spread their weight and acts as a shock-absorbing mechanism (Schmidt, 1986).
The anatomical structures of the elephant foot differ not only with respect to other species but also within its family. The African elephant has 4 nails on its front feet and 3 on its hind. The Asian elephant has 5 nails on its front feet and 4 on its hind (Barnes, 1995). The distal phalanx is attached to the toenail in a similar fashion to that of the human fingernail. Each nail has a cuticle (Fowler, 1993).
The nails are rather thin and short and have a very small sole. There is no interdigital space. Elephants are digitigrades, with the digits on the dorsal, medial, and lateral side of the foot surrounding the extensive fibro-elastic cushion. This cushion expands considerably when the animal places the weight on the limb (Fowler, 1993). The pad is often called the sole, but is histologically related to the pad structures of other animals. Its surface con-

sists of hard but elastic horn.

2.4.1.2. Diseases of the feet

Both species have problems with their feet in zoos, which are mainly related to wrong husbandry conditions such as lack of exercise, neglected hygiene in indoor enclosures (poor sanitation), and lack of foot care of the nails and the pad (Göltenboth, 1995).

Overgrowth

Overgrown nails and cuticles can lead to cracks within the horn wall, to ingrown nails, infection, and lameness. The growth of the horn wall is approximately 1 cm per month and needs under most husbandry conditions regular trimming.

The horn of the footing surface grows also constantly and needs close attention in order to avoid the formation of folds and pockets. Those folds are prime targets for dirt, bacteria, and fungi and can cause severe problems to the animal (Fowler, 1993).

Cracks

Horizontal and vertical cracks, with the latter occurring more often, are also a common finding. They may start from the cuticle or from the bottom. Size, width, and depth can vary considerably and lead therefore to different clinical pictures. If the cracks extend into the sensitive corial structures the animal will show severe signs of discomfort. Reasons for the occurrence of these cracks remain still speculative but are thought to stand in relation with nutritional, genetic, environmental, and/or traumatic factors (Fowler, 1993).

Horn quality

The production of inferior horn quality in the nails is occasionally observed in these animals. This is possibly related to the diet. Mineral supplementation has lead to the production of smeary horn in Asian elephants in one zoo (Rietschel pers. com., 1999). After withdrawing this supplementation from their diet the horn quality improved to normal standards.

Viral infection

Elephant pox as well as foot and mouth disease can impair the health of the feet. In severe cases it can lead to the loss of large horn/skin segments (Kuntze, 1975).

Laminitis

Laminitis, as described in horses due to overfeeding or too hard work, has been described in Asian elephants (Schmidt, 1986). It can be also a complication of foot and mouth disease (Evans, 1910).

2.4.2. Black Rhinoceros (*Diceros bicornis*)
White Rhinoceros (*Ceratotherium simum*)

The Black and White rhinoceroses share the basic anatomical features with the Indian rhinoceros. The Black is the smallest of the three. It can weight up to 1400 kg and may measure up to 1,6 m. Usually they are much smaller, on average 1,4 m. The White rhino is large, with a huge hump on its neck, containing a ligament to support the heavy head. The White rhino weights on average 1,700 kg but can be heavier, especially bulls. Both African species have two horns, with the front one being larger. The horns can grow to enormous length (1,6 m) (Owen-Smith, 1995).

Short stout legs support their massive weight. Each foot has three hooves. The side and central hooves surround the soft pad. Together they enclose the footpad to three-fourth. The typical tracks of Black and White rhinos remind of an ‘ace-of-clubs’ structure.

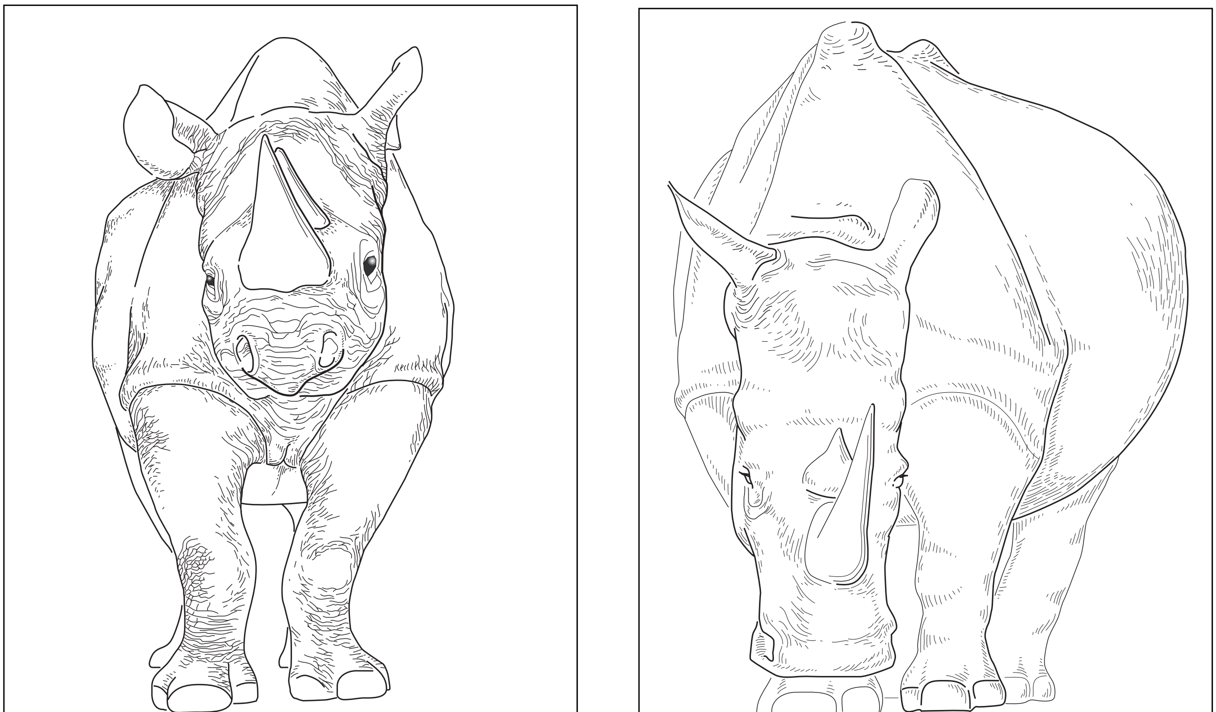


Figure 1: Black rhinoceros White rhinoceros

2.4.2.1. Diseases of the feet

The first report ever to describe foot problems in captive rhinos was written by Boever in 1976 and describes a case of interdigital corns in a Black rhinoceros. These granulomas/papillomas were also observed by Jones (1979) to occur in other captive species. Boever (1976) assumes that traumatic insults are possible causes for this problem. Due to the room-taking interdigital mass the gait of the animals is impaired.

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.

Traumatic injuries due to rocks, stones, or other sharp material lead to injuries on the relatively soft pad (Göltenboth, 1995). These infections can lead to severe discomfort if neglected and infected. Severe laminitis and infection can follow injuries on the sole. Often these lesions are only visible after an abscess has formed along the coronary border. Poor hygiene in indoor enclosures and urine stained floor damage the horn tissue and has led in some cases to infection and necrosis of the foot structures (Jones, 1979).

2.5. Foot problems in intensively managed animals with regard to some selected areas

With the help of light- and electron microscopy, several authors (Geyer, 1980; Marks and Budras, 1987; Pollitt and Molyneux, 1990; Mülling et al., 1994; Pellmann, 1995) were able to locate areas within the hoof structure, which can be looked upon as „ loci minores resistentiae“. These areas are prone to pathological degenerative changes.

Nutritional deficiencies (e.g. biotin), the heavy weight of some breeds, fast growing animals, unhygienic and abrasive floor surfaces, as well as genetic predisposing factors (constitution, claw forms, horn quality) play an important role in the occurrence of foot problems in many intensively managed animals.

2.5.1. Periople/coronary segment

Traumatic impacts on the coronary band can lead to inflammation and infection. This can occur in all domestic species. Depending on the degree of the injuries, the formation and growth of the horn wall can be impaired.

Abscesses occur along the coronary band due to a direct infection, after a traumatic impact, or due to an infection along the weight-bearing border, white zone, sole, or deeper tissue layers. Since there is no drainage, inflammation follows the line of least resistance and drainage occurs at the coronary band (Stashak, 1987).

2.5.2. The wall segment

2.5.2.1. Laminitis

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

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

- Laborious/fast work on hard surface, which can also lead to bruising of the sole (traumatic laminitis).
- Excessive intake of carbohydrates (metabolic laminitis).
- Endometritis, severe systemic infection or ingestion of toxic plants etc.(toxaemic laminitis).
- Massive ingestion of grass (clover or alfalfa) in already overweight animals.
- 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 in horses, if a period of 48 hours of continual pain occurs or a rotation of the distal phalanx has taken place (Stashak, 1987).

2.5.2.2. Cracks

Cracks are defined as a separation of the horn wall and possibly the corial structures (superficial or deep). In general, they do not lead to lameness but their clinical picture can suddenly change in case of a traumatic impact or infection with bacteria (Geyer, 1979). Cracks can appear as horizontal or vertical lesions. They can start at the coronary band and reach to the ground or start from the ground surface (Fessl, 1992).

Horses, cattle, as well as pigs are commonly affected by these alterations of the horn wall (Geyer, 1979; Fessl, 1992; Pollitt, 1999). Predisposing factors are moist and dirty husbandry conditions, which lead to alterations of the horn. The horn becomes less resistant against traumatic impacts (Stashak, 1987). In certain horse breeds this condition is inherited (Pollitt, 1999). Fast growing, heavy pigs are more likely to develop cracks than small, light animals. In this species, the husbandry condition, especially the width of the gaps within the floor surfaces plays a major role in the occurrence of cracks (Geyer, 1986).

2.5.2.3. Deformation of the horn shoe

Many different deformations of the horn wall of horses or cattle are known. These deformation arise (Fessl, 1992) due to neglected foot care, not enough exercise, wrong husbandry condition, or inherited problems (claw form, constitution of the animal). All are regarded as pathological changes and do not only impair the animal's gait but also its performance. If neglected, these deformation can give rise to further problems such as limb deformations, necrosis of the sole/pad, inflammation, infection, and rotation of the phalanges (Fessl, 1992; Pollitt, 1999)

2.5.2.4. Porcine footrot

Porcine footrot is a non-contagious inflammation of the sensitive tissues of the foot, caused by abrasive wearing of the horn usually on the lateral aspect of the lateral digit. It is a mixed infection leading to abscesses at the coronet, lameness, and deformations of the hooves (Jubb et al., 1985).

2.5.3. The transition between the sole and the pad segment

The sole itself shows little problems. Areas, where two different horn qualities are aligned next to each other, are often affected. These areas are called loci of minor resistance and are well known 'problem zones' in domestic species (Mülling et al., 1994).
Geyer (1979) describes the occurrence of lameness in pigs under intensive management conditions. Cracks develop primarily in the hind feet, where the hard horn of the sole connects to the soft horn of the pad. Mechanical influences with regard to the flooring and in particular the width of slatted floors play a major role. Hard, eroded, and wet floors also damage the hooves. All predisposing factors lead to the formation of cracks, ulcers, and further infection. Lesions in the predisposed areas increase with age and weight above 50 kg.

2.5.4. The interdigital segment

Foot rot is defined as a disease of the foot characterized by dermatitis of the interdigital skin and with some underrunning of the horn, especially at the heel. Infection under the horn is common. It is also called pododermatitis (Blood and Studdert, 1996). It is a disease of ruminants, caused by a synergistic infection of anaerobic bacteria. *Bacteroides nodosus*, *Bacteroides melaningenicus* and *Fusobacterium necrophorum* are commonly encountered bacteria. *B. nodosus* is the chief pathogen in ovines. Depending on the degree of virulence of *B. nodosus* the clinical picture is called benign or virulent. Sheep are prone to infection especially if kept on damp pastures (Blood and Studdert, 1996). *F. necrophorum* is an opportunistic bacteria and is commonly found in other species of the order Artiodactyla and Perissodactyla, in the wild as well as in captivity (Rosen, 1970; Abgottspon, 2001). Unsanitary conditions, causing skin lesions, will allow the bacteria to enter the tissue, which is followed by inflammation and necrosis.

2.5.5. Horn quality

Several authors state that biotin has a positive effect on the horn quality of the feet of domestic species (Geyer et al., 1984; Zenker, 1991; Jossek, 1991).
Biotin deficiency alters the horn quality of the feet. Deficient animals have parakeratotic horn. This horn is crumbly and fissures easily. Geyer (1986) reports that pigs show alterations especially in those areas that bend easily, such as the coronary band and the soft heel. Through supplementation with biotin severe lesions as well as the overall horn quality improved.
In horses, Zenker (1991) showed that the horn quality of the white zone improved after supplementation with biotin for 19 months. Josseck (1991) found also an improvement of the horn quality of the horn wall in horses but already after 14 months. The ‘turnover rate’ of the horn wall was measured and ranged between 301 and 378 days (Josseck, 1995). After Budras et al. (1989), the outer part of the horn wall grows faster than the inner part. This is thought to be the reason that the two structures show an improvement in structure at different times (Zenker, 1991).
Some zoos supplement their animals with biotin. In this survey it was not possible to assess whether improvement took place or not.

2.6. Some histological features of the equine foot

Many detailed light-microscopic descriptions exist of the equine foot (Banks, 1986; Stashak, 1987; Budras et al., 1989; Bolliger, 1991; Dellmann, 1993; Pellmann, 1995; Dyce et al., 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 that seem to be of clinical relevance to hoof problems. The horse will serve as the main reference due to the large amount of research that 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.

2.6.1. The periople

The periople is a thin band between the skin and the hoof. The corium consists of long papillae (1 - 2 mm). The epidermis is made up of a Str. basale, spinosum, granulosum, and corneum. The Str. corneum makes up the external layer of the wall. The horn is thin (a few millimetres thick), rubbery, and shiny. In the superficial layer the horn tubules often decay, whereas they are well visible in deeper layers. In some horses the horn can reach to the bottom but is generally filed away by the farrier.

2.6.2. Coronary band

The coronary band continues distally to the periople and is the production site of the coronary horn, the main supportive structure of the hoof. The papillae of the corium are longer (4 - 6 mm) than the ones of the periople and a Str. granulosum is missing. The subcutis underneath the corium is made up of a thick cushion and is highly supplied with blood vessels.

The epidermis consists of intertubular and tubular horn cells, which are arranged in a proximal – distal way. They are capable to bear the weight of the animal by forming the outer hoof capsule. This coronary horn is connected to the corium of the wall through a specialised leaflet formation of the Str. corneum of the epidermis. The formation of these special leaflets starts at the distal edge of the coronary band. Here, the epidermal cells project into the corium and give rise to the formation of leaflets.

The coronary horn is made up of three zones:

The outer zone, which is covered by the perioplic horn, consists of horn tubules that have an oval cross sectional profile (type I tubules) (Bolliger, 1991). The cortex cells of these tubules consist of flat horn cells. Intertubular horn cells connect the tubules.

The middle zone is made up also of type I tubules and intertubular horn cells.

The inner zone consists of type II tubules. They are larger and have a round diameter. The main part of the cortex is made up of spindle-shaped cells. The transition to the intertubular horn is often visible. The arrangement of the intertubular cells is mainly perpendicular to the horn tubules (Bolliger, 1991).

Pigmentation is primarily seen in the outer and middle zone, but can occur to some extent in the inner zone as well.

2.6.3. The wall

The hoof wall is made up of the coronary horn as well as epidermal and corial structures. The formation of papillae in the coronary band changes to the formation of laminae or

leaflets within the wall. This is a specialized interdigitation between corial and epidermal structures. The leaflets adjacent to the coronary band are short and have their maximum length in the middle of the wall (1 - 4 mm long and approx. 0,05 - 0,2 mm thick) (Trautmann, 1931). This length continues to the weight-bearing border.
Only in horses, each primary leaflet consists of secondary leaflets. 100 - 200 secondary leaflets can be found along the rim of a primary leaflet. The Str. germinativum of the leaflets produces constantly cells that modify into horn cells. The coronary horn is attached to these cells through the horny leaflets, which are located between the corial leaflets. Through the continuous production of horn cells the horn wall grows towards the weight-bearing border.

2.6.4. The sole

The sole is slightly concave, approximately 1 cm thick and forms most of the under surface of the hoof (Bolliger, 1991). It is joined to the wall by the white line. The sole is made up of tubular and intertubular horn cells, which run distally in a 45° angle. The superficial cell layers are often brittle and easily removed, a common finding in this area (Zenker, 1991).

2.6.5. The frog

The frog is wedge-shaped and projects into the sole structure, with the opening to the palmar/plantar side. The horn of the frog is softer and the papillae of the dermis slightly longer than the ones in the sole. The tubules have an undulating course of direction. The heel horn, which adjoins the frog on the palmar/plantar side, has in addition a Str. granulosum that is missing in the frog.

2.7. Histopathological changes in some selected areas of the equine hoof

A study on horses proved that macroscopical unaltered hooves show microscopical well visible alterations within the horn structures of various segments (Zenker et al., 1995). The following pathological defects described by Zenker (1991) will serve as references for the pathological alterations of the histological structures observed in the feet of Indian rhinos.

- Minor cracks along the cell membranes. These cracks were predominantly seen between the cortex cells of the tubules and the intertubular horn. They occurred mainly at the transition of the middle to the inner zone of the coronary horn. The extent of the cracks varies in size and can lead to a complete 'opening' of the horn structure.

Minor cracks were also found in the outer zone.

- Enlarged tubules were found as pathological alterations mainly in the outer zone of the coronary horn. In horizontal sections the marrow was enlarged, did not contain any cell material, and appeared ‘empty’.
- Loose connection of the horny leaflets and the terminal horn cells. The terminal horn was in some cases completely detached from the surrounding horny leaflets, leaving a large gap between two leaflets.

2.8. Cattle and pig hooves

Although ruminant and pig hooves appear macroscopically different compared to the equine hoof, they share in fact quite similar structures with the horse. Of course a few exceptions exist. The hooves of these species consist of a wall, sole, and a well-developed bulb or pad.

- In cattle the periople forms a well visible fold. The corium of this fold has long (2 mm) and thick papillae, which project beyond the beginning of the coronary segment (Warzecha, 1993). The horn of the periople does not reach the weight-bearing border.
- The leaflets have no secondary laminae and occur only in the distal half.
- Cap horn is produced in both species but varies with regard to the degree. Cattle produce a lot, pigs less, and horses have only a few cell layers of cap horn.
- Furthermore, cattle and pigs have no frog but a bulb with a rather soft cutis. This structure makes up the major part of the plantar/palmar surface. The sole consists only of a small rim next to the wall. The *Suidae* have a marked boundary line between the sole and the pad. The consistency of the horn of the pad is soft compared to that arising from the Str. germinativum of the sole and the coronary region (Geyer, 1979).

2.9. Genetic studies in the captive population of Greater One-horned rhinoceroses

Small populations in the wild as well as in captivity have been focused upon concerning 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 as a reduction of the so called ‘fitness character’, the individuals probability to reproduce and to survive (Bruford, 1996). Ballou and Ralls (1982) documented that inbreeding in zoo animals can often lead to a reduction in viability and fertility. Baur and Studer (1995) looked upon the extent of inbreeding and inbreeding depression in captive Greater One-horned rhinoceroses, a species that has been bred predominantly in only a few zoos[5]. They found out that zoo animals, which have

5 The studbook of 1997, written by Basel Zoo, gives the inbreeding coeficient and mean kinship for all inbred Greater One-horned rhinoceroses.

successfully breed in the past and present, have a higher inbreeding level than others. Juvenile mortality occurs more often in inbred females. Due to the fact that many other factors contribute to juvenile mortality, which are not associated with inbreeding, Bauer and Studer (1995) concluded that inbreeding so far has not led to any significant deleterious effects in the captive population. This is based upon 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. In how far other health factors such as foot problems are associated with inbreeding or with a genetic predisposition has not been evaluated yet.

3. Material and Methods

In order to assess the health status of horn structures from Indian rhinoceroses under captive conditions a program was initiated to obtain horn material over the period of one year. Husbandry conditions were not changed during this period of time.

Most zoos were visited and the health status of the feet macroscopically assessed. To document the pathological alterations, each foot from each animal was photographed. Additionally, the husbandry conditions and the diet provided were recorded.

Detailed macroscopical and histological studies were carried out on the feet of two Indian rhions, two Black rhinos and two Asian elephants which died during the study period. During the years of 1999 and 2000, Dr. Jacques Flamand, a veterinarian officer from Chitwan National Park in Nepal, photographed the feet of 10 wild animals. Each foot was photographed from underneath and partly from the sides. These photographs were sent to me. I used them to describe the exterior anatomical structures of the feet of wild Indian rhinos and to compare the findings with the feet of captive animals. Of these 10 animals, 8 were adults and 2 subadults. The rhinos were not knowingly related to each other. The pictures were taken on several occasions.

3.1. Zoos and animals within the study group

The study period from 1998 to 2000 includes 35 (15 males / 20 females) Indian rhinos from 12 European zoological gardens. At the end of the study period, two more zoos started to keep this species, but were not added to the study group.

Out of the 12 zoos one zoo was excluded as their animals (2/1) had just arrived at the zoo and came mainly from collections outside of Europe. Besides being of young age those animals have not been long enough in their new enclosures in order to show clinical problems, which might stand in correlation to the new husbandry conditions. All other animals within the study have been under the same husbandry conditions over the last two years.

In 8 zoos it was possible to collect horn material from the feet of some of their animals. The collection of material is only possible if foot care is performed on a routine basis. Out of the 32 (13/19) animals 10 (4/6) served as ‘donators’ for horn samples. These samples were collected every 3 - 5 months. Altogether 19 footpads and 18 hooves were examined.

The following European zoological collections participated:

Table II: Zoos participating in the study

		Animals	Males /		Females
1	Basel Zoo, Switzerland	3	1	/	2
2	Berlin Tierpark, Germany	4	1	/	3
3	Berlin Zoo, Germany	2	1	/	1
4	Dvur Kralové, Czech Republic	3	1	/	2
5	Liberec, Czech Republic	1	1	/	0
6	Munich Tierpark, Germany	3	1	/	2
7	Nürnberg Tiergarten, Germany	2	1	/	1
8	Planckendael Dierenpark, Belgium	5	2	/	3
9	Rotterdam Zoo, The Netherlands	3	2	/	1
10	Stuttgart Zoolog.-bot. Garten, Germany	2	1	/	1
11	Whipsnade Wild Animal Park, UK	4	1	/	3
	Total	**32**	**13**	**/**	**19**

2 (2/0) animals died and their feet - all of one animal and one front and one hind foot of the other animal - were brought to the Anatomy Department of the Veterinary Faculty, University of Zurich for macroscopical and histological anatomic studies. The feet of 2 (1/1) Black rhinos - one front foot of a female one front and hind foot of a male - and two (1/1) Asian elephants - four feet of each animal - were also brought to the University for anatomic research.

3.2. Sampling locations and measurement techniques

With regard to the specific location of the pathological alterations, material of defined areas was collected over a period of one year. The areas were:

- Hard horn of the wall and the sole.
- Soft horn of the transition between the sole and pad.
- Soft horn next to pathological alterations such as cracks, fissures, and granulation tissue.
- Soft horn of macroscopically unaffected footpads.

The horn was collected either during routine foot care or during anaesthesia as some of the animals needed to be sedated in order to work on the clinically altered feet. Using a sharp tong, similar to those used in cattle or horses, the horn of the wall was cut. The soft horn was cut with a scalpel. All large structures of the foot as well as som selected smaler-parts were measured with a tape measure.

3.3. Processing of the material

3.3.1. Horn samples

The freshly cut horn samples were put into labelled bags, frozen at -20°C or preserved in 4 % formalin, and brought to the Laboratory of the University. There, the samples were cut into approximately 1 cm x 1 cm x 0,5 cm pieces and fixed in 4% formaldehyde, containing 1% calcium chloride.

After 3 days of fixation the specimen were sectioned at 10 µm in a cryostat. The slices were later stained floating by using haematoxylin and eosin (HE) and alcian blue periodic acid-Schiff (AB-PAS) stain (Romeis, 1989). The following day the stained specimens were mounted in glycerine-gelatine.

HE stains the nuclei dark blue and the cytoplasm of horn cells within the periople and pad light violet. The horn cells of the other segments stain pink. Cells that are not cornified stain red. Cell membranes with the intercellular glue do not show well and the marrow of the tubules stains bright pink.

AB-PAS stains the nuclei dark blue and the cytoplasm of horn cells within the periople and the pad segment light blue. The horn cells of the other segments appear light red in colour. Cell membranes and the intercelluar membrane coating material stain bright pink.

3.3.2. Feet

The feet of the Indian rhinos, the Black rhinos, and the Asian elephants were measured, weighed, x-rayed, and photographed. They were frozen at -70°C for several days. Using a band saw the frozen feet were cut in half. An approximate 1 cm thick slice was cut off the central hoof. The same was performed on the middle and lateral hoof. Photographs were taken of each sectioned part. The anatomical features within the foot were measured.

The 1 cm thick slice was cut into further pieces. Those pieces were numbered according to the area:

1. = Skin, periople, coronary band

2. = Coronary band, beginning of wall segment

3. = Proximal wall segment

4. = Distal wall segment

5. = Weight-bearing border

6. = Sole (a = apical, b = palmar/plantar part)

7. = Transition between sole and pad

8. = Apical section of the pad

9. = Middle section of the pad

10. = Palmar/plantar section of the pad

Figure 2: Sampling areas

The size of each block ranges around 1 x 1 x 0,5 cm. Each block includes the epidermis, corium and to some extent the subcutis.
The further processing of the blocks was carried out in the same way as it was done with the horn samples.
The interdigital segment of the front and hind feet of one Indian and one Black rhino were cut out with the help of a band saw and were sectioned into four smaller blocks. Those blocks were also prepared in the same way as the other samples.
Altogether, 10 blocks were taken from each hoof. Of the 10 blocks, number 2, 5, 6a, 6b, 7, 8, 9, and 10 were cut on two sides. First, 10 µm thick slices were cut form the horizontal side (a) and then from the sagittal (b) side. Number 1 was only cut sagitally and numbers 3 and 4 horizontally. This resulted in 19 samples from each hoof and 57 histological samples per foot.
6 feet of Indian rhinos resulted in nearly 450 histological samples, including also numerous pathological samples. The collection of the horn samples from the animals living in zoological gardens resulted in further 300 samples from the horn wall and the pad.
From the Black rhinoceros 171 histological samples were taken. The specimens of the Asian elephants were processed in a similar way as described above.

4. Results

4.1. Husbandry

All zoos provide their Indian rhinos with an indoor and outdoor enclosure. Due to the fact that adult males cannot be kept with the females, both genders have to have their own enclosures.

The indoor enclosure is a stable of 25 - 60 m^2 in size. The construction of the doors, walls, and troughs are made of heavy material, such as steel, concrete, or wood. The latter is in some cases used to cover rough surfaces along the wall, with the purpose to prevent abrasions on the horns.

The flooring is made up of concrete. This material is easy to clean and to maintain. Some zoos have provided rubber matting or tartan flooring. Single rubber mats require a lot of work for maintenance; tartan flooring wears off after a certain period of time. As most animals spend the wintertime inside, the material is intensively used. Straw is used in some cases as a bedding material but is generally eaten.

Most zoos have an indoor pool. The access is limited to certain times of the day. All pools are equipped with steps and are up to 1.8 m deep. The size varies between 25 - 30 m^2.

The outdoor enclosures vary with regard to size and furnishing. The ground material ranges from grass, compressed earth, sand, marl, gravel, and other natural substrates. All zoos have equipped their outdoor enclosures with pools and/or wallows. Not all pools are accepted at all times of the year since warm water is preferred. This is especially noticeable in spring and autumn. The access to a pool seems to play also an important role since they do not like steep or slippery entrances. Indian rhinos are very curious but also anxious animals and need a long time to accept changes in their environment.

Further features of outdoor enclosures are shadow places, feeding places, and trees to rub body and horn. Water supply is essential. The design of the outdoor enclosure needs to avoid a dead end. This could turn into a trap for the female during courtship and should be avoided by all means.

4.2. Size and weight

During the study 12 adult animals (5 males and 7 females) were measured in body height and length, as well as in girth and length of the legs. In general, not many animals are weight on a constant basis. The weights in this table come from the collection of data received from various zoos over a longer period of time.

Table III: Size and weight of Indian rhinos

	Males	**Females**
Shoulder height	166 – 187 cm	154 – 166 cm
Height of hindquarter	175 – 194 cm	159 – 170 cm
Girth (behind the front legs)	310 – 360 cm	330 – 390 cm
Length of the front legs	75 – 85 cm	60 – 70 cm
Length of the hind legs	50 – 65 cm	40 – 50 cm
Approximate weight range	1800 – 2400 kg	1600 – 1800 kg
6 -10 years old	2300 – 2800* kg	1800 – 2300 kg
11-25 years old	2200 – 2400 kg	1800 – 2100 kg

* max. recorded weight: 3600 kg

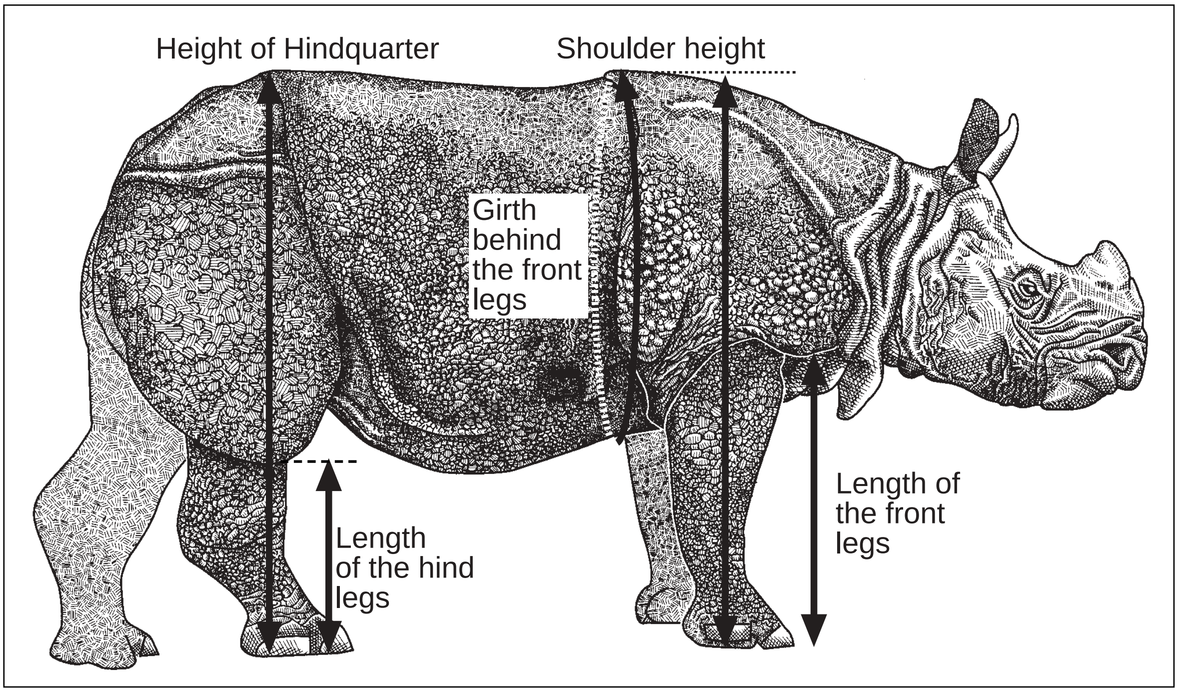


Figure 3: Body measurements of an Indian rhino.

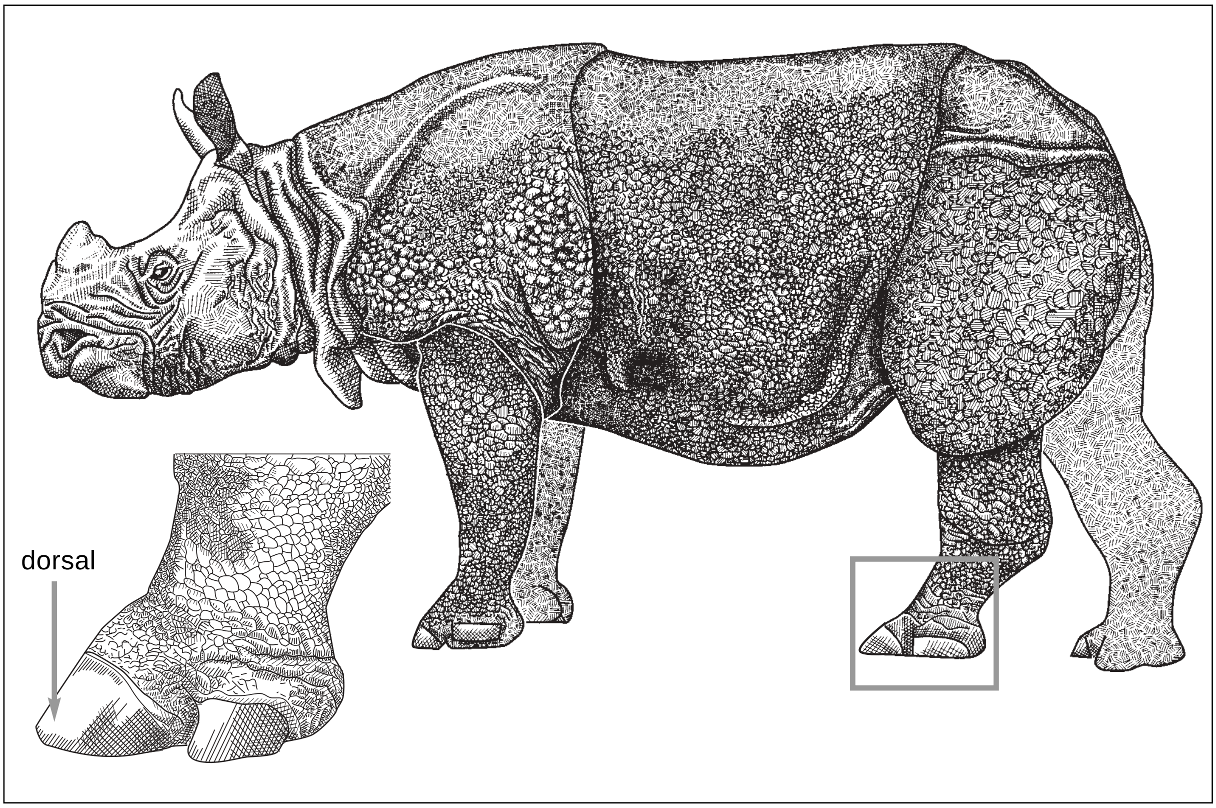


Figure 4: Side view of an Indian rhinoceros.

Figure 4:
Side view of an Indian rhinoceros. The hind feet are placed underneath the abdomen in a standing position. The angle of the central hind hoof to the ground is almost 45˚. The side hooves run perpendicular to the ground. The axis of the front legs to the ground is almost perpendicular.

Figure 5:
Front view of an Indian rhinoceros. The front legs have a knock-kneed appearance, with the feet partly turned outside. The horn wall of all hooves runs almost perpendicluar to the ground.

Figure 6:
Hind view of an Indian rhinoceros. The legs have a cow-hocked apperance with the feet turned outside. The adjacent figure describes the anatomical nomenclature for an Indian rhinoceros foot, used in this study.

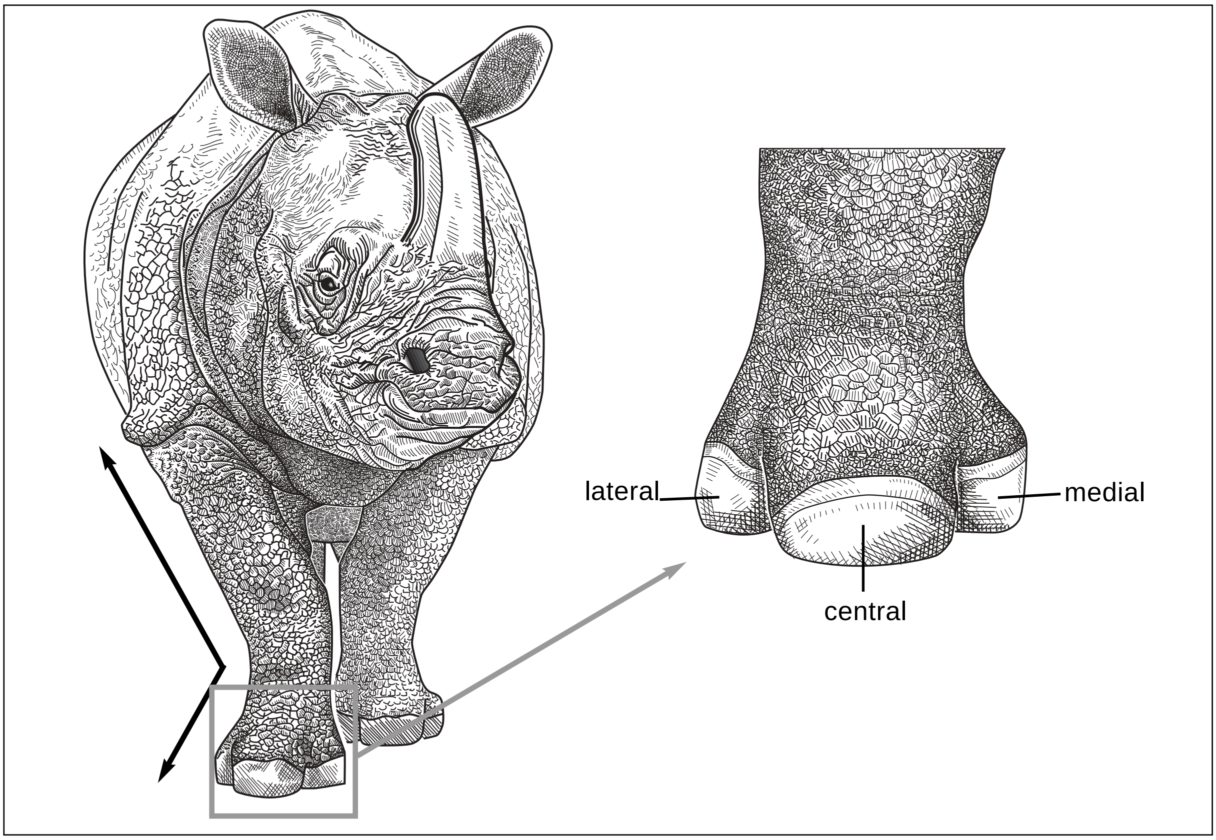
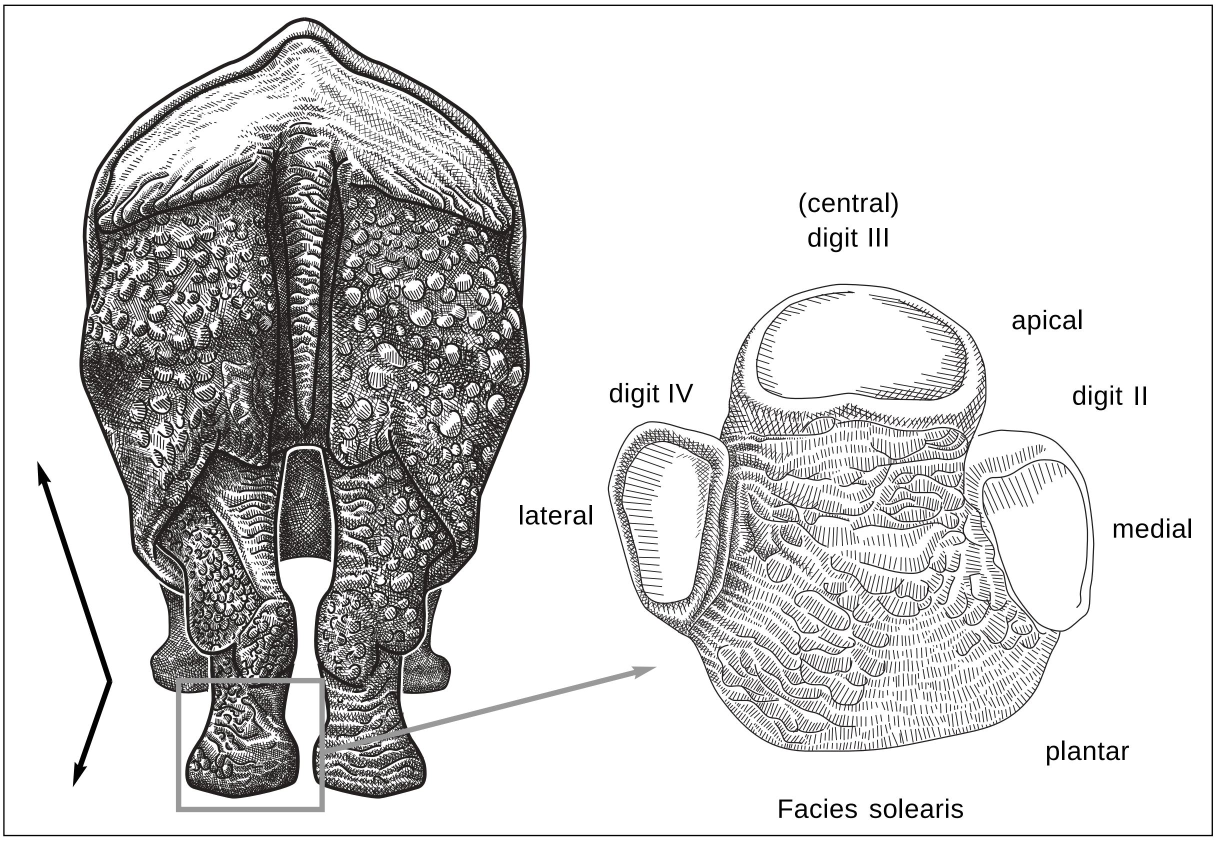


Figure 5: Front view of an Indian rhinoceros.

Figure 6: Hind view of an Indian rhinoceros.



4.3. Status of health

The Indian rhinoceros has compared to other rhinoceros species rarely health problems. Occasional gynaecological problems, infections of the skin, and bacterial infection in young animals can occur. Newborns are very susceptible to bacterial infections. Foot problems are the major health problem of this species in zoological gardens.

4.4. Anatomic description of the feet of captive Indian rhinos

4.4.1. The foot

The Indian rhinoceros belongs to the Order Perissodactyla, or odd-toed Ungulates. Short legs carry a massive, rather plump body. The legs have a knock-kneed appearance with the feet turning partly outside, especially in the standing position (see Fig. 5 and 6). They have specialized feet for weight bearing, with three digits (II, III, IV) (see Fig. 6) and a large expanding digital cushion. The digits are aligned in a semi-circular way around the pad with the hooves touching the ground when standing. The palmar/plantar aspect of the foot is curved. The front feet appear rounder and broader than the hind feet, which appear more elongated. The hind feet are generally larger than the front feet.

The body–foot axis in the front legs is rather straight and a slight bend within the metacarpal joint is responsible for the x-crossed shape of the front legs. The hind legs are positioned almost underneath the body when standing. This is due to a cranial bend in the metatarsal joint. When drawing a line from this joint to the tip of the central hoof, the angle between ground and this line is almost 45°. This angle is also measured between the hoof wall of the central hoof and the ground (see Fig. 4). The surface of all side hooves runs almost perpendicular to the ground.

The nomenclature used in this paper for the rhinoceros foot refers to the Nomina Anatomica Veterinaria (1994). In Artiodactyla and Carnivora the nomenclature refers to the functional axis of the limb passing between the third and fourth digit. For Perissodactyla it refers to the functional axis of the limb passing through the third/central digit.

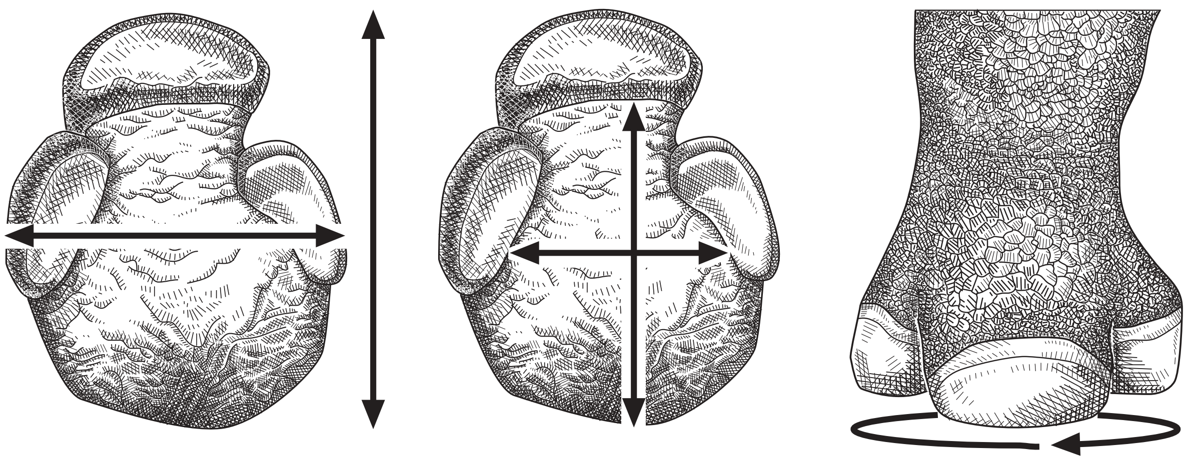
Average length and width of front feet ranges around 32 cm and 27 cm for both sexes. Males have generally larger feet. The pad of the front foot is on average 22 cm long and 13 cm wide. The hind feet have larger pads, so have males compared to females.

In some cases the abnormal length of the central horn wall influenced the measurements. Due to overgrown structures (central hoof wall) the data for the length and circumference of some feet are larger than average.

Table IV: Foot measurements of Indian rhinos (n = 14; M = 7 males, F = 7 females)

	Foot (cm)			Pad (cm)	
Foot	**Length**	**Width**	**Circumference**	**Length**	**Width**
Left Front					
M:	31,5 - 33	26 - 29,5	90 - 98	22,5 - 23	13 - 14
F:	25 - 34	24 - 28,5	87 - 108	19 - 21	11 - 13
Right Front					
M:	30 - 33,5	27,5 - 29	90 - 101	22 - 23	13 - 14
F:	26 - 32	25,5 - 29	88 - 93	19 - 21	13
Hind Left					
M:	30,5 - 34	25 - 28	87 - 97	24 - 26	13 - 14
F:	28 - 33,5	21 - 26	78 - 89	22 - 23	11
Hind Right					
M:	30,5 - 37	25 - 33	89 - 102	24 - 29	13 - 22
F:	29 - 34,5	23 - 28	83 - 90	29	11

Figure 7: Measurement locations of Indian rhinoceros feet.



Length and width of the foot

Length and width of the pad

Circumference of the foot

4.4.2. The hoof

The hooves have an oval (medial and lateral) to semi-circular (central) shape. The central hoof is the largest and longest of all three (measurements see table IV). The palmar/plantar side of the central sole merges completely with the structures of the pad, whereas the lateral and medial hooves remain mobile due to free dorsal edges and a long interdigital segment (up to 6 cm). When standing, the foot enlarges due to this elastic junction between the side hooves and the pad, which proves essential when walking on muddy and wet ground.
In zoological gardens all animals have flat soles. The sole is directly aligned to the pad. Both structures have the same height and adjoin at an even level. The surface of the pad has a soft, smooth appearance. The horn is light (greyish – yellow) in colour. Minor fissures on macroscopical healthy feet are a common finding.
The angle of the central hoof between the dorsal surface and the ground surface is 75 - 80° in the forefoot. In the hind foot this angle is 45 - 50°. The lateral and medial hooves run almost perpendicular to the ground, in the fore as well as in the hind foot (see figure 5).

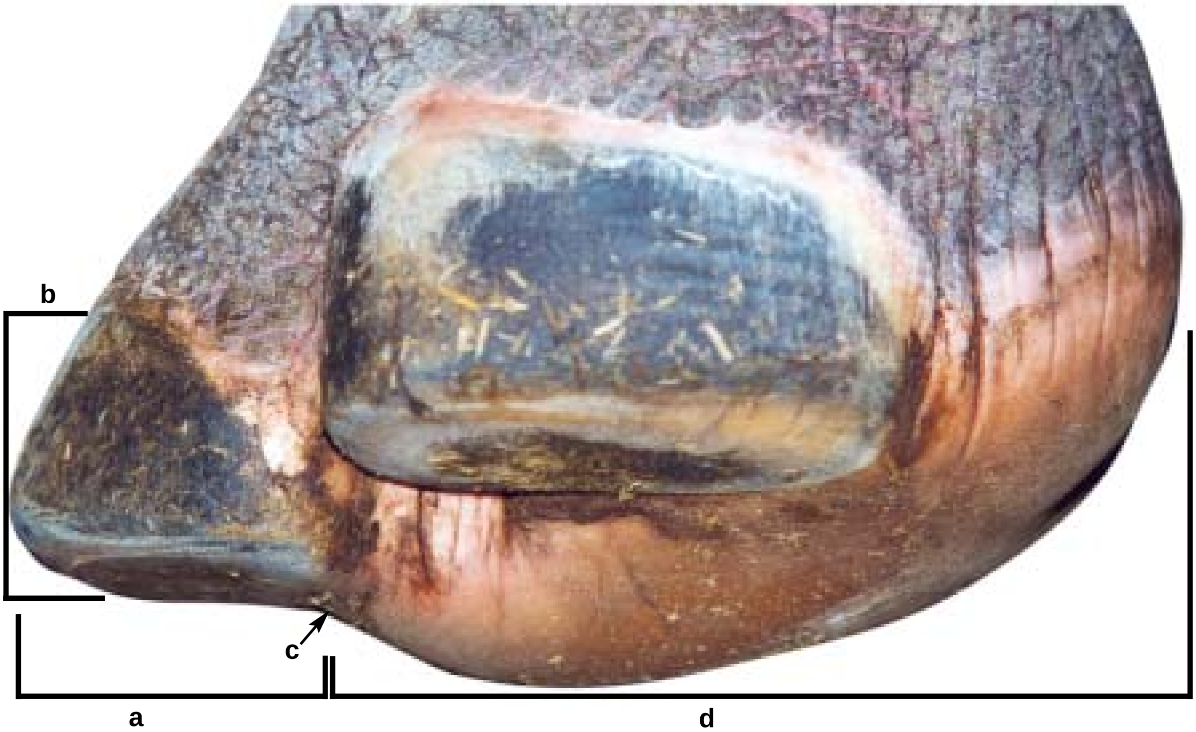
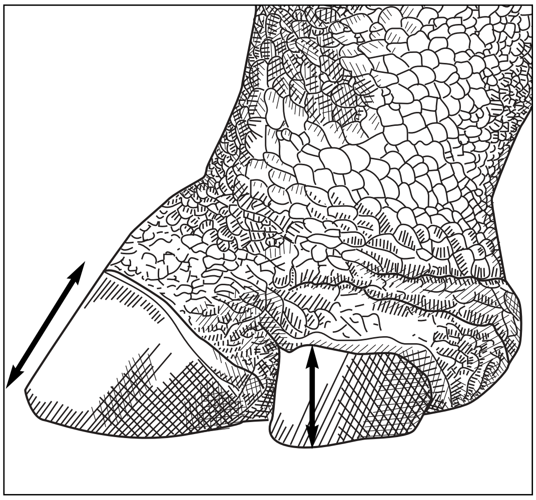
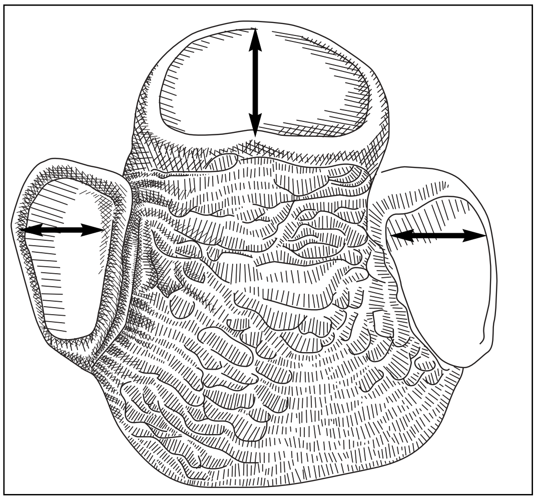


Photo 1: Female adult Indian rhino.
Front foot: flat sole (a), short central horn wall (b), direct alignment of sole and pad (c), smooth pad surface (d).

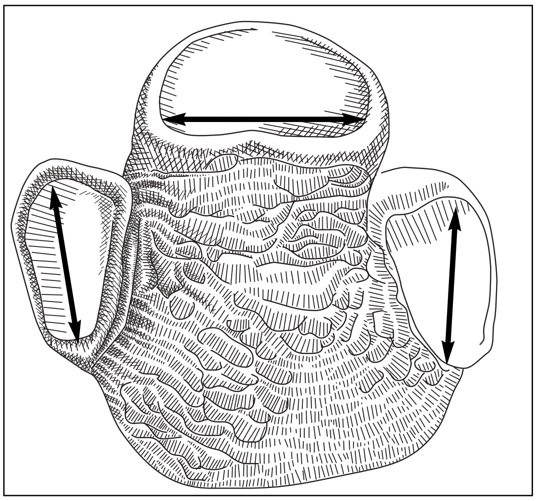
The following measurements were taken from 10 adult animals, 5 males (M) and 5 females (F). Each hoof (central, lateral, and medial) of each foot was measured.
The following features were measured on every hoof:



Length of the hoof wall:
From periople to weight-bearing border



Depth of the sole:
From the weight-bearing border to the transition of the sole to the pad



Width of the sole:
From the lateral to the medial edge or apical to the palmar/plantar edge of the sole

Figure 8: Different measurement locations of Indian rhinoceros hooves.

Table V: Hoof measurements of Indian rhinos

Hoof		Right Front Foot		Left Front Foot		Right Hind Foot		Left Hind Foot	
		M	**F**	**M**	**F**	**M**	**F**	**M**	**F**
CH:	**L**	5.5 - 8	6 - 7	7 - 8	5 - 7.5	8 - 12	7 - 10.5		7 - 11
	D	6 - 9	6 - 9	6 - 9	7 - 7.5	6 - 9	5 - 7.5	6 - 9	5 - 8
	W	14 - 17	12 - 15	11 - 16	13 - 15	10 - 13	10 - 12	11 - 16	11 - 14
MH:	**L**	5 - 7	5 - 6	5 - 9	5 - 6	5 - 8	3	5 - 8	5 - 8
	D	5 - 6.5	5 - 6	5.5 - 6	4 - 6	4 - 7	**3** - 5	4 - 7	**3** - 5
	W	11	10 - 11	10.5	9 - 11	8 - 10.5	9- 10.5	9 - 13	8 - 9
LH:	**L**	5 - 7	5 - 6.5	5 - 7	5.5 - 6	6 - 9	6 - 7	7 - 8	6 - 8
	D	6 - 7.5	4 - 6	5 - 7.5	3 - 6	**2** - 5	**3** - 5	**3** - 5	**3** - 4
	W	12 -13	10 -12	12 - 13	10 - 12	9 - 12	9 - 10	9 - 13	10 - 11

M = 5 males, **F**= 5 females,

CH = Central Hoof, **MH** = Medial Hoof, **LH** = Lateral Hoof,

L = Length, **D** = Depth, **W** = Width

The underlined numbers indicate pathological alterations with regard to abrasions on the side hooves (see section: 4.8.3).

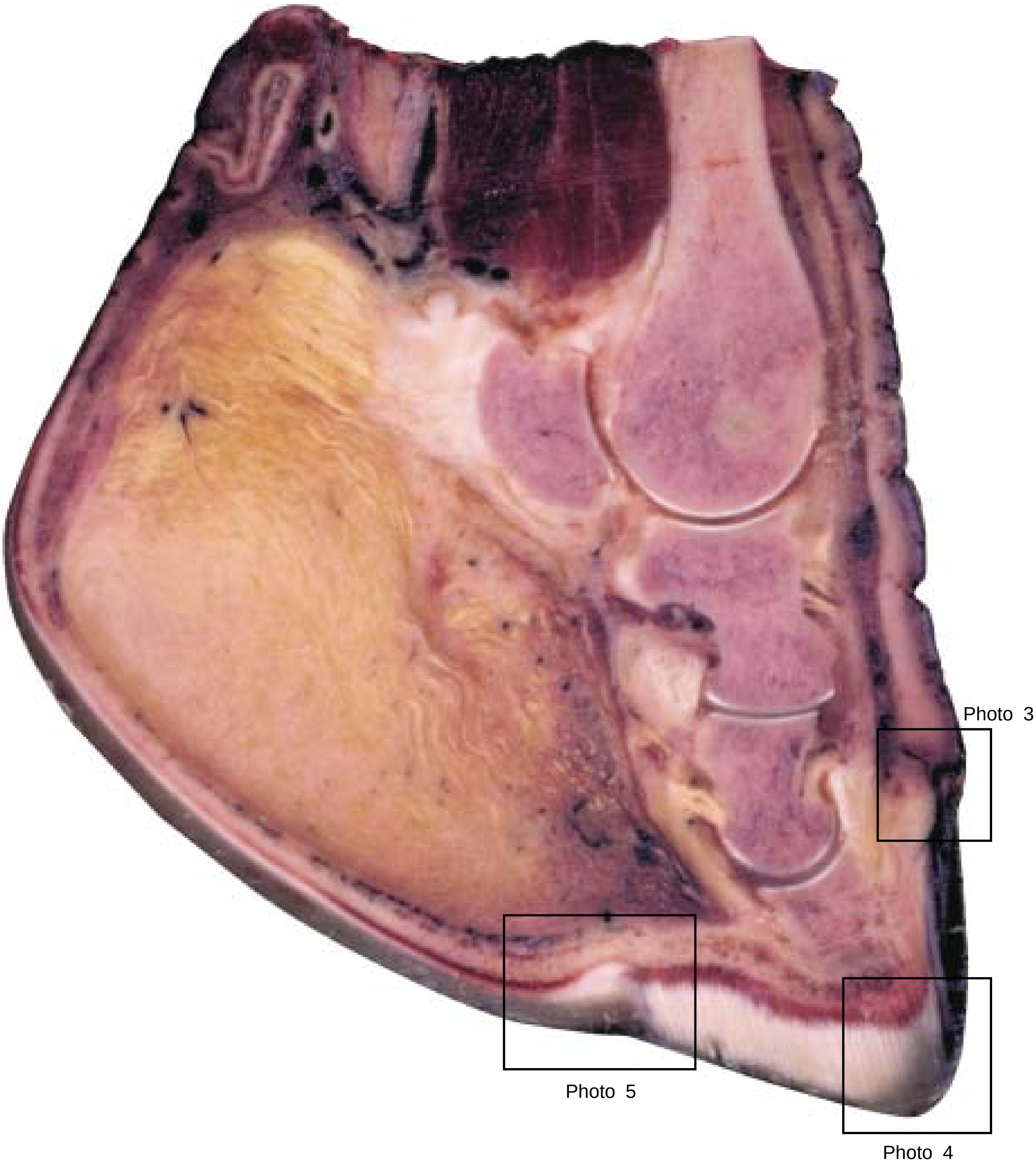


Photo 2:
Longitudinal section of an Indian rhinoceros front foot. The sections enlarged are described on the following page.

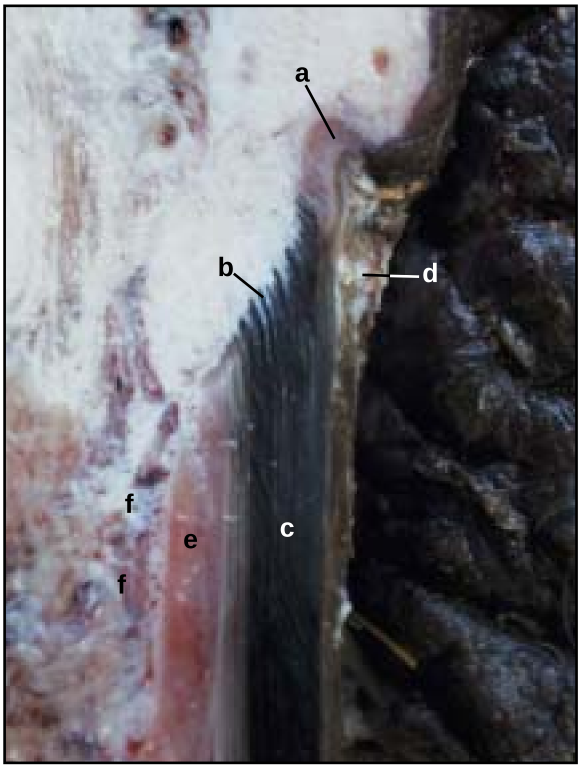


Photo 3:
Enlargement of the coronet/horn wall. Papillae of the periople (a) and coronet (b). Black coronary horn (c). Greyish perioplic horn (d). Red primary leaflets (e). Inner part of corium (f).

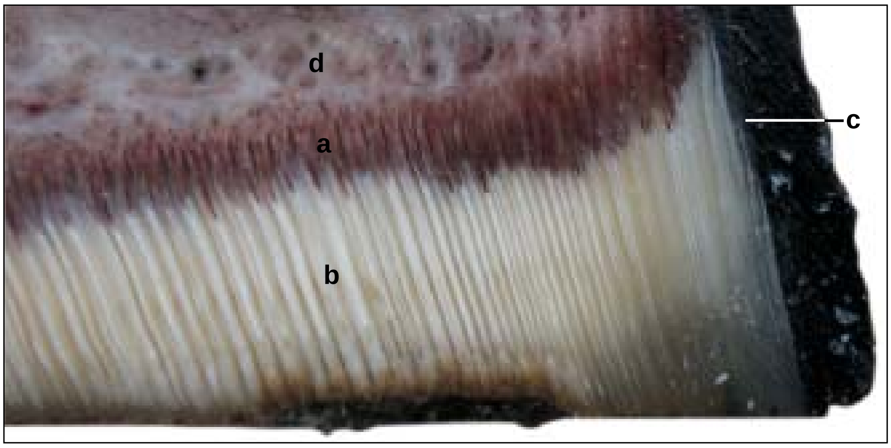


Photo 4:
Enlargement of the sole. Broad, thick, and long papillae (a). White Str. corneum (b). Black coronary horn (c). Inner part of corium (d).

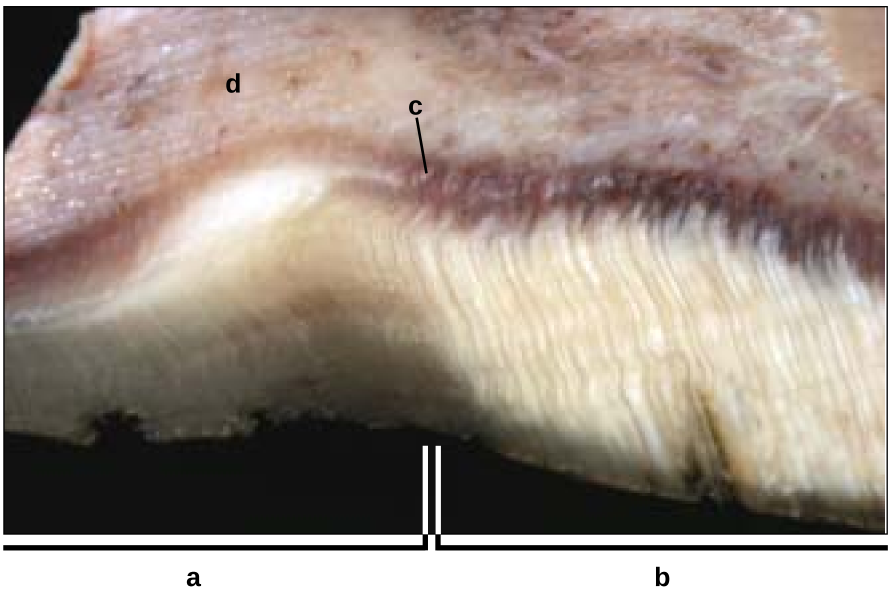
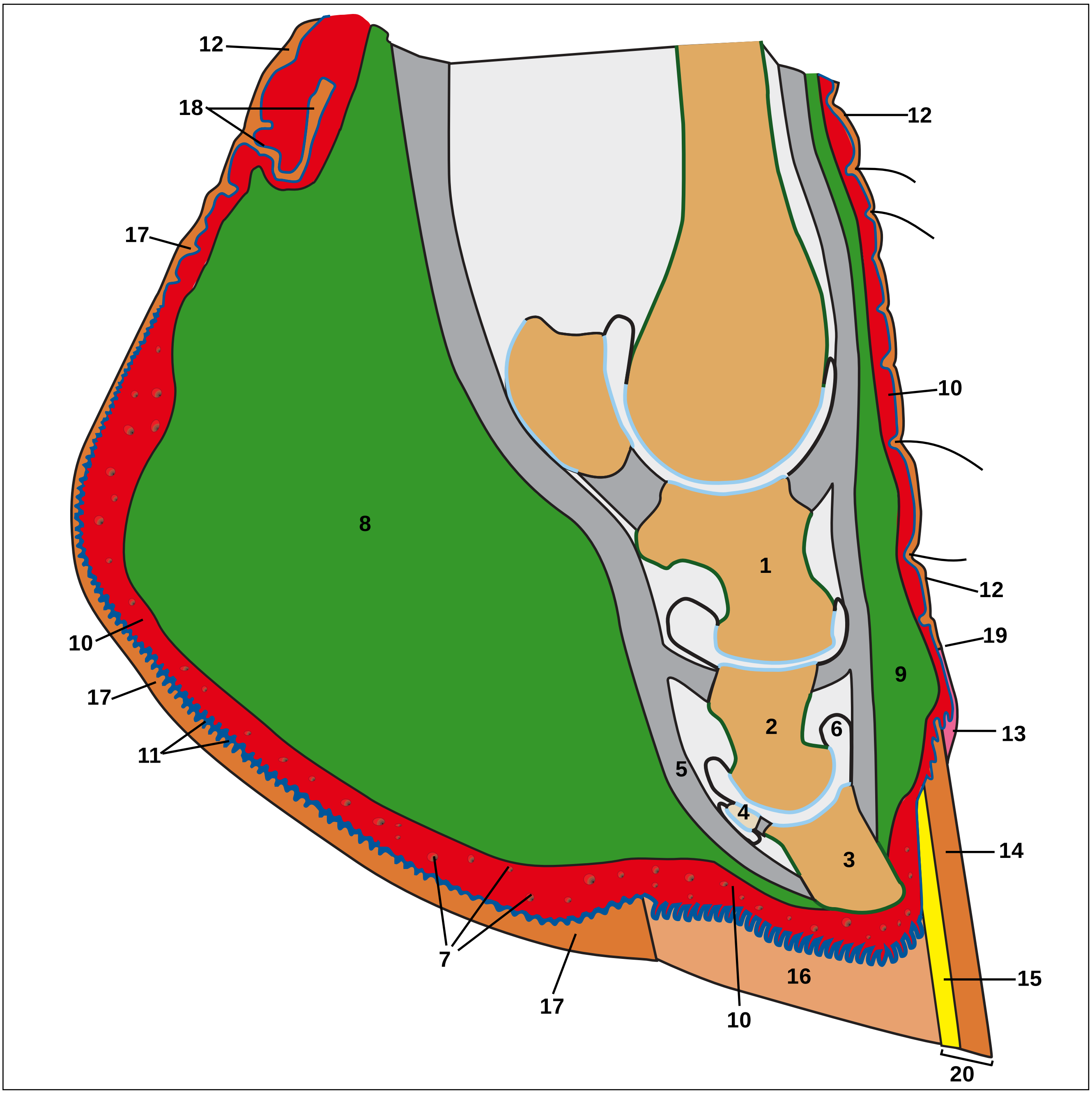


Photo 5:
Enlargement of the transition between sole and pad. Corial and epidermal structures of the pad (a) and of the sole (b). Abrupt transition between sole and pad (c). Inner part of corium (d).

The hoof of the Indian rhino is made up of similar basic anatomical structures as described for domestic animals with some specialities.
The internal structures consist of the third phalanx (‘coffin bone’ in horses), the distal part of the second phalanx (short pastern bone), and the distal sesamoid bone (navicular bone), as well as their adjacent tendons, ligaments, vessels, and nerves. The bones are arranged in an almost parallel line to the dorsal surface of the foot. The bony structures with their adjacent tendons and ligaments take up 1/3 of the space within the foot.
The third phalanx of the central hoof is rather oval and has an elongated form in the side hooves. On x-rays it shows well that the third phalanx is positioned in a 45° angle inside the horn shoe, pointing towards the white zone. The second digit points more towards the weight-bearing border of the sole. Therefore, a slight bend forms between these two bones. The dorsal - proximal edge of the distal phalanx is slightly elevated, serving as attachment zone for the extensor tendon.
The surface of the third phalanx is roughened and looks ‘frayed’ as it contains many holes and ridges. The distal part of this bone takes up half the width of the sole in the central hoof and up to the whole width in the side hoof. Here, the palmar/plantar part of the bone has a protuberance.
The joint capsule towards the second digit expands above the coronary band. The distance to the coronet is just about 2 - 2,5 cm. The caudal edge of the interphalangeal joint capsule is approximately 2,5 - 3,5 cm away from the corial structures of the apical pad.

4.4.2.1. Subcutis

The subcutis is the underlying tissue of the cutis, containing elastic-fibrous tissue as well as fat cells, vessels, and nerves. In certain areas the subcutis is well developed and serves as a cushion to protect underlying structures.
A well-developed subcutis is present between the coronary band and the joint capsule of the third and second phalanx. This cushion is approximately 2 cm thick. In some parts along the wall and the apical part of the sole, the subcutis is thin or cannot be distinguished. There, the corium connects directly with the periosteum and the underlying bone. In the pad, the subcutaneous tissue forms an enormous cushion, which is surrounded by connective tissue. This connective tissue and even the cushion extend apically to the plantar/palmar part of the sole.
The foot cushion (*Pulvinus digitalis*) is very large and takes up 2/3 of the interior space of the foot. Measurements vary between front and hind foot, males and females. On average, the cushion is 20 cm long, 10 – 14 cm wide, and 8 – 14 cm high. It consists of highly elastic tissue and many fat cells that absorb the weight and protect the other structures inside the foot.
Two pedal scent glands can be found next to each other on the palmar/plantar side of the metatarsal region, approximately 7 – 10 cm above the footing surface.



1. 1st phalanx
2. 2nd phalanx
3. 3rd phalanx
4. Distal sesamoid bone
5. Deep flexor tendon
6. Joint capsule
7. Blood vessels

8-9 Subcutis = Hypodermis
8. Foot cushion of the pad
9. Coronary band cushion
10. Corium = Dermis
11. Epidermis, Str.germinativum
12- 17 Epidermis, Str. corneum
12. Str. corneum, hairy skin
13. Perioplic horn

14. Coronary horn
15. Horn leaflets, wall segment
16. Sole horn
17. Pad horn
18. Pedal scent gland
19. Coronary border
20. Weight-bearing border

Figure 9: Nomenclature of the inner structures of an Indian rhinoceros foot

4.4.2.2. Cutis

The cutis is composed of corium and epidermis.

The corium is made up of connective tissue, vessels, and nerves. Its structure is connected with the epidermis by means of corial papillae and leaflets in certain defined areas. It is joined with the subcutis through the Str. reticulare, a ‘web-like’ arrangement of connective tissue. The corium holds the hoof in place by attaching to the deeper structures of the foot.

Due to its vascularity it supplies the epidermal structure with nourishment. In addition, this structure is highly sensible owed to its fine innervation.

On longitudinal sections of the foot (see Photo 3 and 4), the papillae are macroscopically well recognisable in the coronary band and in the sole. The Str. papillare of the corium is also visible as a reddish band in the pad. The corial Stratum papillare of the wall segment consists of leaflets, which are reddish in colour. Under the Stratum papillare the Stratum reticulare of the corium can be seen. It appears white and is 3 - 5 mm thick.

The epidermis is a part of the integument, overlying the dermis and can be divided into a soft and a horny part. The soft part is made up of the epidermal layer next to the corium, the Str. germinativum. This consists of a Str. basale and a Str. spinosum. The Str. basale is linked with a basal membrane to the corium. It is a single layer of cylindrical cells, which proliferate and are afterwards transformed to polimorphic cells of the Str. spinosum. The cells of the Str. spinosum are connected together by desmosomes. In the spinosum cells, keratine fibrils are increasing from the basal to the superficial layers. The keratine fibrils are ending at the desmosomes in the cells. The spinosum cells are later transformed to horny cells of the Str. corneum.

The Str. corneum shows tubular horn or horny leaflets. Horn tubules are found in the periople, coronary band, sole, and pad. The wall segment shows horn leaflets, which are whitish in colour. Corresponding to the configuration of the underlying corium, horn tubules, intertubular horn, or epidermal leaflets are formed.

The horn wall of the three digits consists of perioplic horn, coronary horn, and horny leaflets. The coronary horn is the main part of the horn wall and has a very hard consistency. Both, the perioplic and the coronary horn are pigmented. The horny leaflets are not pigmented. The proximal border of the horn wall joins the hairy skin and is named coronary border. The distal border of the horn wall is called the weight-bearing border.

4.5. Anatomic description of the feet of wild Indian rhinos

The description of the feet from wild Indian rhinos is based on photographs taken from 10 wild animals. All feet have been photographed from underneath and to some extent from the sides.

The central hoof has a semi-circular, the lateral and medial hooves a 'drop-like' shape, with the apical part being broader than the palmar/plantar part. The apical parts of the side hooves border the palmar/plantar side parts of the central hoof. Through this alignment, the soft pad is surrounded by hard horn on three sides. The sole of the central hoof adjoins the apical part of the pad. The lateral sides of the pad border on the axial parts of the lateral and medial soles.

An interdigital gap is found between central and side hooves. This gap varies in size from front to hind foot, appearing slightly larger in the hind feet. This large interdigital gap accounts for the expansion and mobility of the feet on various grounds.

All three hooves have a long horn wall. In the lateral and medial hooves, the apical part of the horn wall does not run straight to the footing surface but bends backwards, reminding of the formation of claws.

The sole is concave. The hooves protrude the pad to some extent. Especially the sole of the central hoof is very long. The palmar/plantar part of the central sole does not adjoin the adjacent pad on the same level. In this area the sole protrudes the pad for some centimetres.

The horn wall and the weight-bearing border are black. The area of the palmar/plantar sole adjacent to the pad is also dark. This gives the sole the appearance that it is surrounded completely by a dark rim. The lateral and medial soles do not clearly show this colouration along the axial sides of their soles. The white zone as well as the main part of the soles is whitish.

The structure of the sole is very unique in different areas. The white zone shows fine stripes and is about 5 mm wide. The concave part of the soles is striped as well but the stripes appear thicker than in the white zone. These stripes run straight to the central section of the sole. Along the sides of the sole they curve towards the middle. This part makes up most of the sole. The rim adjacent to the pad has a punctuated appearance, which is macroscopically visible in all three hooves. The width of this structure is approximately 1,5 - 2,0 cm. In the central sole this rim becomes thicker towards the middle. The rim in the side hooves does not clearly show this feature.

The horn wall and the sole of the three digits surround the pad. The pad has a greyish-brown colour and appears hard and roughened. Each pad shows minor cracks in the superficial horn layer but they do not seem to project into deeper layers. The horn structure reminds of scales, which partly overlap each other.

a Fore feet

b Hind feet

Photo 6 and 7:
Feet from 2 wild Indian rhinos, palmar/plantar view. The soles, especially the central sole protrudes the pad. The rim of the central sole, adjacent to the pad is elevated. The hooves show a slight curve of the horn wall. a fore feet, b hind feet.

The pad joins the soles not on the same level. It attaches to the soles further proximal. On the side hooves the pad seems to connect to the soles by means of a fold. This is especially well visible in a relaxed foot. Between the pad and the central sole exists a step, with the sole protruding the pad.

a Front foot

b Hind foot

Photo 8 and 9:
Feet from wild Indian rhinos, palmar/plantar surface. The soles are concave and elevated. The sole of the central hoove protrudes the adjacent pad. The pad appears hard and shows fissures which seem to be superficial in nature. a front foot, b hind foot.

4.6. Anatomical structures of Black rhinoceros feet

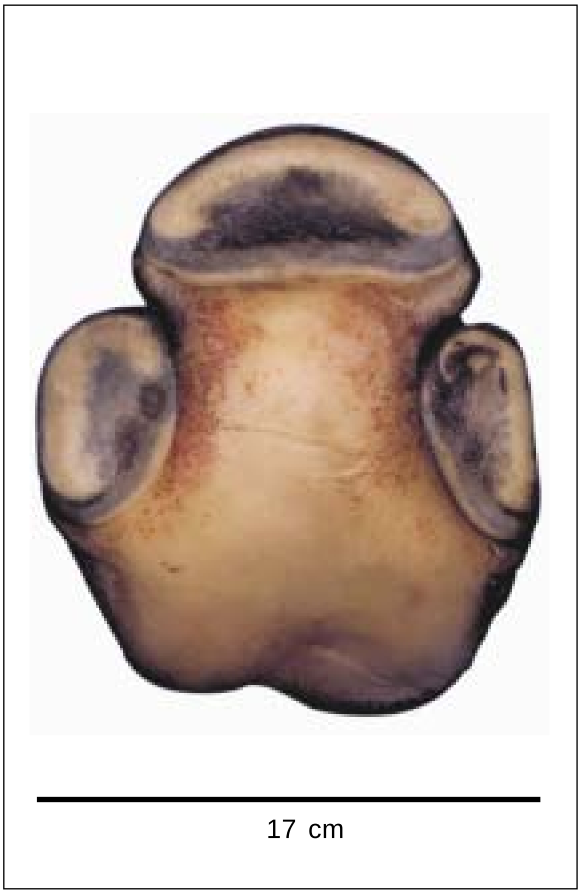
The Black rhinoceros has comparable anatomical foot structures to the Indian rhino. Number and alignment of the hooves are equal. The foot itself and the hooves in particular are smaller in size, so is the species compared to the Indian rhino.

Table VI: Foot measurements of Black rhinos

		Foot			Pad	
		Length	Width	Circumference	Length	Width
Black rhino 2 yr.:	Front left	22	17	61	16	8
	Hind left	23	18	65	16.5	9
Black rhino 35 yr.:	Front right	22	21	64	16	10

The *Facies solearis* of a Black rhinoceros foot shows some specialities. The side hooves are located more towards the axis of the foot than observed in Indian rhinos. The footpad encloses the palmar/plantar area of the soles to a great extent. The dorsal part of the side hooves remains free and curves slightly towards the pad. Pad tissue lies between the central hoof and the dorsal border of the side hooves. The pad protrudes almost to the side edges of the central sole. The width of the pad is very narrow (8 cm compared to 14 in Indian rhinos). Altogether, the feet of Black rhinoceroses appear very compact.
In the front feet, the horn walls of all three hooves run almost perpendicular to the ground. In the hind feet, the side hooves show also an approximate 90° angle between the horn wall and the ground. This angle ranges around 70 – 75° in the central hoof.
Inside the foot, the cushion of the pad takes up almost 2/3 of the space. The three digital bones run parallel to the horn wall. The joint surface between the second and third digit appears relatively flat. The third phalanx has an almost triangular shape in the central hoof and points in a 45° angle towards the tip of the weight-bearing border. In the side hooves the third digit has a more rectangular shape.
The subcutis is well developed in all areas. Between the attachment of the extensor tendon on the proximal edge of the third digit and the coronary band it measures about 1 - 0,8 cm. The corium of the sole and the distal part of the bone are separated by 0,4 cm. The pad cushion is well distinguishable from the underlying subcutis and the adjacent corium. There, the subcutis is approximately 1 - 0,5 cm thick, highly vascularized, and expands on the palmar/plantar part, where the pad merges into the skin.

The horn wall is pigmented and has a thickness of approximately 0,5 cm. The corial and epidermal structures of the sole vary between 1 - 1,5 cm in thickness. Apical, the pad is 1,5 cm thick. The horny part makes up three-fourth of the width. In the middle section the horny part is 0,4 cm thick and close to the skin around 0,2 cm.



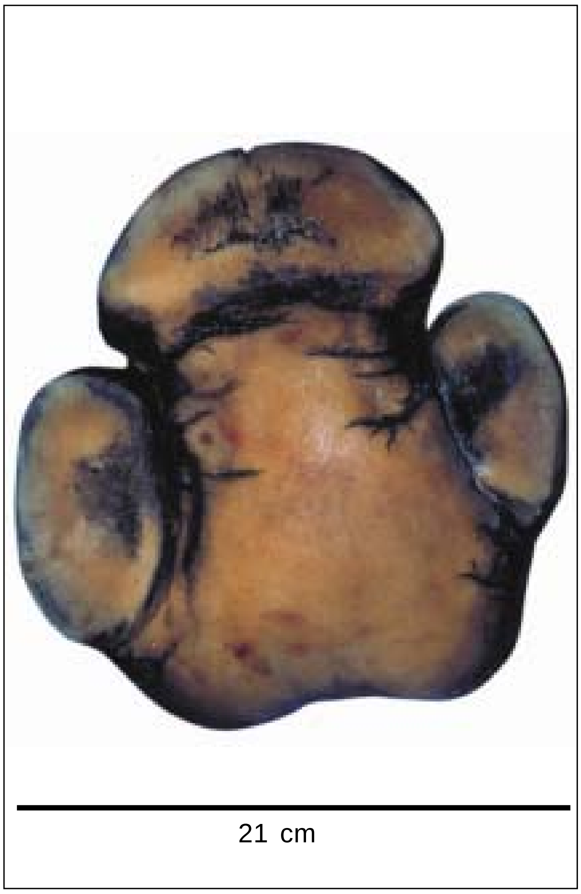


Photo 10 and 11:
Comparison of the foot from a Black (left) and an Indian rhino (right). The foot of the Indian rhinoceros appears wider. The side hooves of the Indian rhino do not extend as close towards the pad and the central sole, as seen in the Black rhinoceros.

4.7. Microscopical structures of Indian rhinoceros feet

For the microscopical work samples were taken from central, medial, and lateral hooves; each sample at a defined area. All measurements, concerning the length of a segment or the beginning of a structure, refer to the distance between the coronary band and the section described.
See figure 2 (section 3.3.2, page 24) for sampling areas.
The sample numbers are:

1. Periople (longitudinal section)
2. Coronary band (a = longitudinal, b = horizontal cut)
3. Wall proximal (horizontal cut)
4. Wall distal (horizontal cut)
5. Weight-bearing border (a = longitudinal, b = horizontal cut)

6a. Sole apical (a = longitudinal, b = horizontal cut)
6b. Sole palmar/plantar (a = longitudinal, b = horizontal cut)

7. Transition from sole to pad (a = longitudinal, b = horizontal cut)
8. Pad apical (a = longitudinal, b = horizontal cut)
9. Pad middle (a = longitudinal, b = horizontal cut)
10. Pad palmar/plantar (a = longitudinal, b = horizontal cut)

4.7.1. Perioplic segment

The periople is a layer of soft, light-coloured horn. It is approximately 1,0 - 1,4 cm long and 0,8 - 1,6 mm wide. It covers the coronary border of the hoof and serves as a transition between the skin and the coronary band. It consists of filiform papillae, which project into the marrow of horn tubules. Their size ranges from 1,4 mm next to the skin to 5 mm adjacent to the coronary band. Due to this rise in size the periople has a bulging appearance, which becomes especially visible in longitudinal sections of central, less in medial and lateral hooves.
The Str. basale consists of a dark-blue, almost black (AB-PAS) cell layer, whose cells are densely packed next to each other. The Str. spinosum varies in size, according to the length of the papillae (150 - 400 µm). The Str. granulosum consists of several cell layers (90 - 150 µm), which contain blue-stained (HE, AB-PAS) granules. The marrows ot the horn tubules, formed by suprapapillary cells, are filled with decaying cell material. They are surrounded by cortical cells, which arise from peripapillary cells, building the cortex of the tubules. Starting from the basis, the tubules are orientated towards the wall surface and undulate slightly. The width of the tubules ranges from 100 to 200 µm.

4.7.2. The coronary segment

The coronary segment gives rise to the main supportive structures of the horn wall and forms the periople distally. The basis of the coronary band, which borders the corium, runs from apical-proximal to palmar/plantar-distal at an angle of approximate 30° - 40°. In front feet hooves, this section is around 0,4 – 1,2 cm long and in hind feet up to 2,7 cm. As a consequence, the latter develops a much thicker horn wall than the former.
The length of the papillae varies between 4 and 10 mm. They are longer and broader than the papillae of the periople. At the basis they appear wide (up to 4 mm) and resemble the figure of a cone.
The Str. spinosum is about one-third the size of that in the periople and a Str. granulosum is missing. The first layers of the Str. spinosum stain blue the last layers appear brownish in colour (AB-PAS stain).
There are no transitional cell stages between periople and coronary band.
The Str. basale form 'frog-finger' like structures, which cover the connective tissue of the corium. In a sound condition, the Str. basale is always separated from the corium by the basement membrane. The cells of the Str. basale stain deep black (AB-PAS). In the distal end of the coronary segment, the transition to the wall segment, the germinative layers of the epidermis produce the horn leaflets. Between them, the corial leaflets are found. Depending on the length of the coronet, the formation of epidermal and corial leaflets starts at 1,2 to 2, 8 cm.
The horn tubules run straight, perpendicular to the weight-bearing border. In cross sections the typical structures of the tubules and their surrounding cortex cells lead to a division into three zones of the horn wall. Depending on the height of the coronary band, the zones vary strongly in size.
The outer zone is made up of small, elongated tubules. The size of the marrow varies from 60 x 20 µm to one-fourth this size. They are 'flattened' on the side that faces the corium and the outer surface of the wall. Due to their shape the cortex is elongated as well, with thin, flattened cells on the narrow part of the tubes and thicker, spindle-shaped cells on the edges. The cortex can be double the size of the marrow.

Photo 12:
Longitudinal section of the periople and coronet; Indian rhino; AB-PAS staining; magnification: **8 x**
a = inner part of the corium
b = perioplic segment: b1 = corial papillae, b2 – b3 epidermis: b2 = Str. germinativum,
b3 = Str. corneum, c = coronary segment: c1 = corial papillae, c2 – c3 epidermis: c2 = Str. germinativum, c3 = Str. corneum

Photo 13:
Longitudinal section of the proximal part of the coronet; Indian rhino; AB-PAS staining; magnification: **16 x**
a = corium, b = inner part, corial papillae, c – g epidermis: c = Str. basale, d = Str. germinativum, e = horn tubules, f = intertubular horn, g = perioplic horn

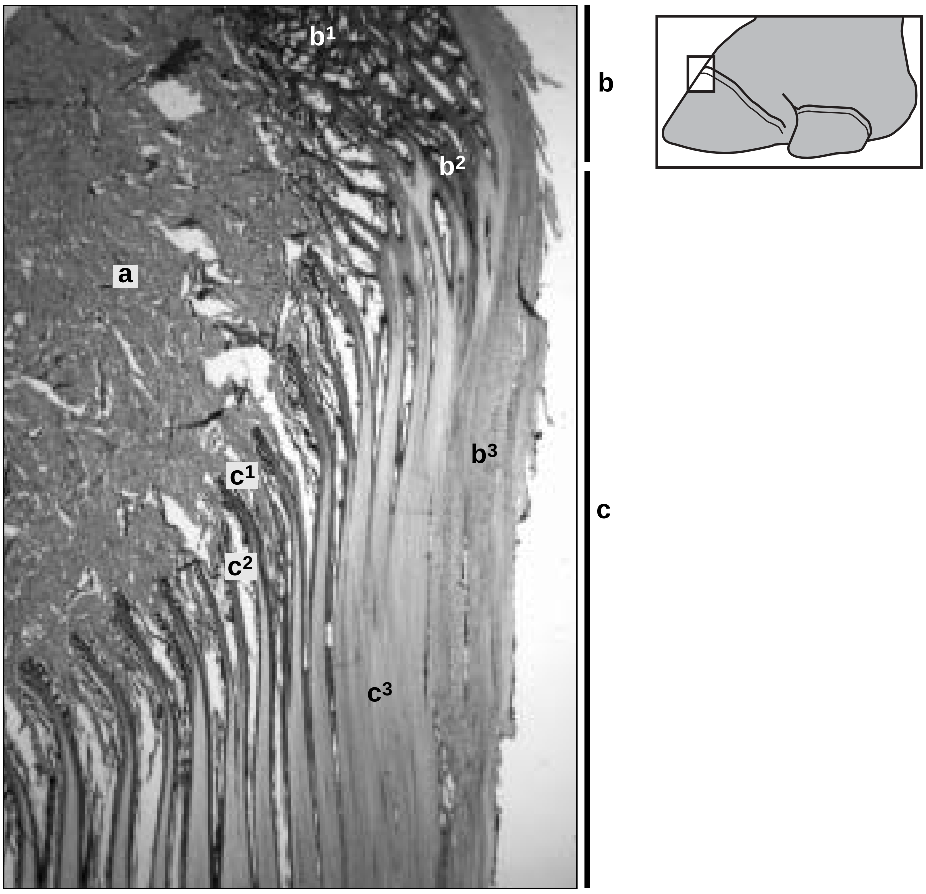


Photo 12: Longitudinal section through the periople and the coronet.

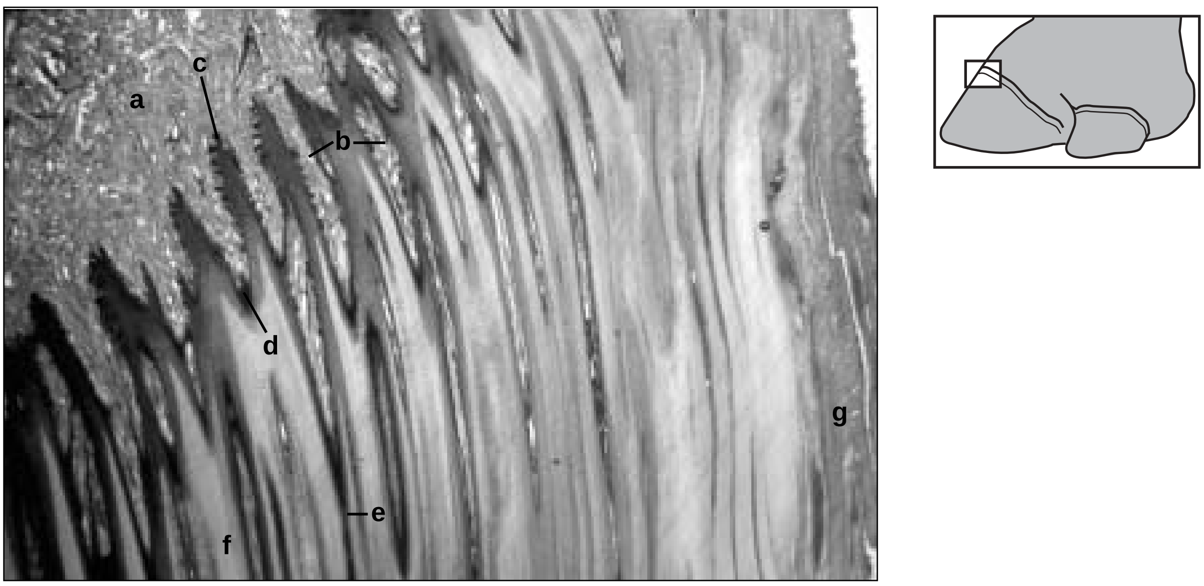


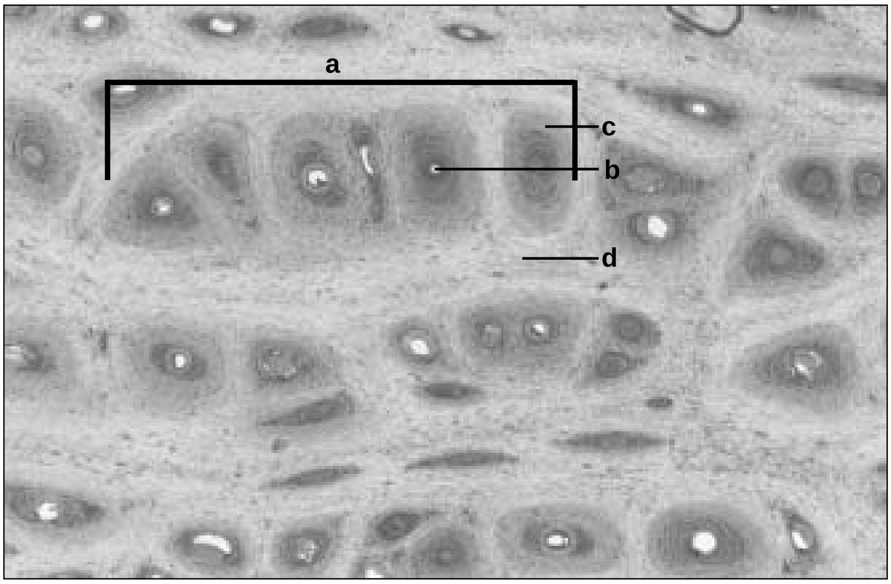
Photo 13: Longitudinal section through the coronary band.

In the middle zone, the tubules are arranged in a linear way. In addition, smaller tubules surround the larger ones, giving the impression of a group formation. These groups can have an almost rectangular shape and can consist of up to 6 tubules. Nevertheless, each marrow has its own cortex that contains pigments. The marrow of the tubule is round to oval shaped and ranges from 90 x 60 µm to 30 x 20 µm. The cortex is about two to three times the size of the marrow. The cells are shaped like flat horn cells, belonging to the Type I tubules, as described by Bolliger (1991). The intertubular horn cells have a large and a short axis and measure approximately 10 x 30 µm in size.
The inner zone consists of round tube marrows. Some of them are accompanied by very small (1/10 the size) tubules but there is no group formation in this zone as it can be seen in the middle zone. The tube marrows are surrounded by spindle shaped cells. The cortex is twice to three times the size of the marrow. Their size varies from 60 x 60 µm to smaller sizes.
Due to the very specific appearance of each zone, it is possible to differentiate the three zones as well as the cortex cells from the intertubular horn masses. Despite the fact that the size of each zone varies according to the thickness of the coronary band, it can be stated that the middle zone is taking up most of the room (up to 1/2). The further distal the cross section is looked at, the smaller the inner zone becomes. The size of the outer zone depends highly on abrasions, which is in particular noticeable in the side hooves. The width of the coronary horn varies between 1,8 cm to 0,8 cm for the proximal part of the wall. The central hooves of the hind feet tend to have a thicker horn layer than the hooves of the front feet.

Photo 14:
Histological cross-section of the middle zone of the coronary horn; group formation of the horn tubules; Indian rhino; AB-PAS staining; magnification: **32 x**
a = group formation of the horn tubules, b = marrow, c = cortex, d = intertubular horn

Photo 15:
Histological cross-section of a horn tubule from the middle zone of the coronary horn; Indian rhino; AB-PAS staining; magnification: **320 x**
a = horn tubule, b = marrow, c = cortex, d = intertubular horn

Photo 16:
Histological cross-section of a horn tubule from the inner zone of the coronary horn; Indian rhino; AB-PAS staining; magnification: **320 x**
a = horn tubule, b = marrow, c = cortex, d = intertubular horn



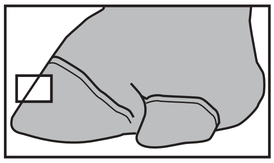


Photo 14: Coronary horn; middle zone: group formation.

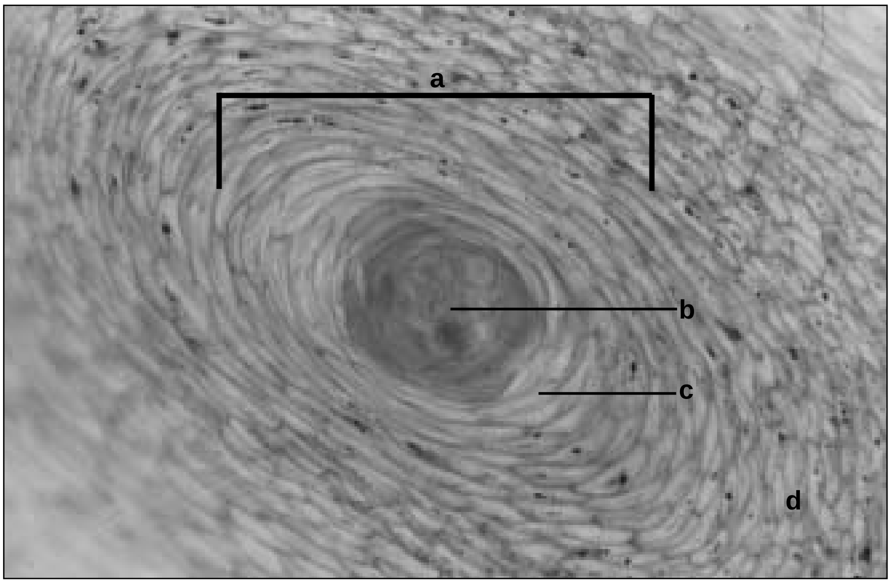


Photo 15: Coronary horn; horn tubule of the middle zone.

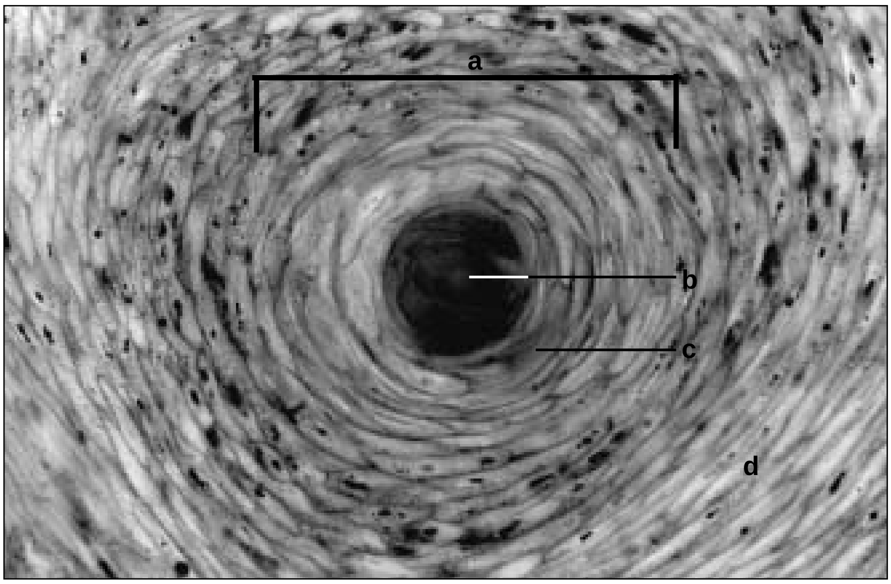


Photo 16: Coronary horn; horn tubule of the inner zone.

4.7.3. Wall segment

The wall segment is the lamellar area, an arrangement of epidermal and corial leaflets. Its formation starts at approximately 1,2 - 1,4 cm in the front and 2,5 cm in the hind feet, under the coronary border where the coronary band merges with the wall segment. The projection of epidermal cells into the corium leads to a distinct formation of leaflets, characteristic for each species.

In the proximal part of the wall segment the basis (adjacent to the coronary horn) of the epidermal leaflets appears broad. Further distal, the leaflets become more pointed.

The primary corial leaflets are frequently branched into two or three leaflets at their border adjacent to the coronary horn (photo 17-18). Between the branched ridge of the corial leaflets, which are covered of a soft epidermis, short horn leaflets can be seen as well. At the side and at the ridges near the coronary horn the corial leaflets are subdivided in secondary leaflets and partly even in tertiary leaflets (photos 20-22). In this way the corium has an enormous surface of connection to the epidermis. The corial leaflets with their secondary and tertiary leaflets are completely covered by a germinative layer of the epidermis. The corial leaflets together with the covering germinative layer of the epidermis can be named like in other species "soft leflets". The germinative layer (= Stratum germinativum) of the soft leaflets produce also cells, which keratinize and join the side of the horn leaflets (photo 20/e). Proceeding in a distal direction more and more horn cells are apposed at the side of the horn leaflets.

Photo 17:
Histological cross-section of the coronary horn in the middle of the wall; **Black rhino**;
AB-PAS staining; magnification: **8 x**
a = wall segment: a1 = epidermal primary leaflets, a2 = corial leaflets, a3 = corium
b = coronary segment: b1 = inner zone, b2 = middle zone, b3 = outer zone

Photo 18:
Histological cross-section of the coronary horn in the middle of the wall; **Indian rhino**;
AB-PAS staining; magnification: **8 x**
a = wall segment: a1 = epidermal primary leaflets, a2 = corial leaflets, a3 = corium
b = coronary segment: b1 = inner zone, b2 = middle zone, b3 = outer zone

Photo 19:
Histological cross-section of the coronary horn in the middle of the wall; **Horse**;
HE staining; magnification: **8 x**
a = wall segment: a1 = epidermal primary leaflets, a2 = corial leaflets, a3 = corium
b = coronary segment, inner zone

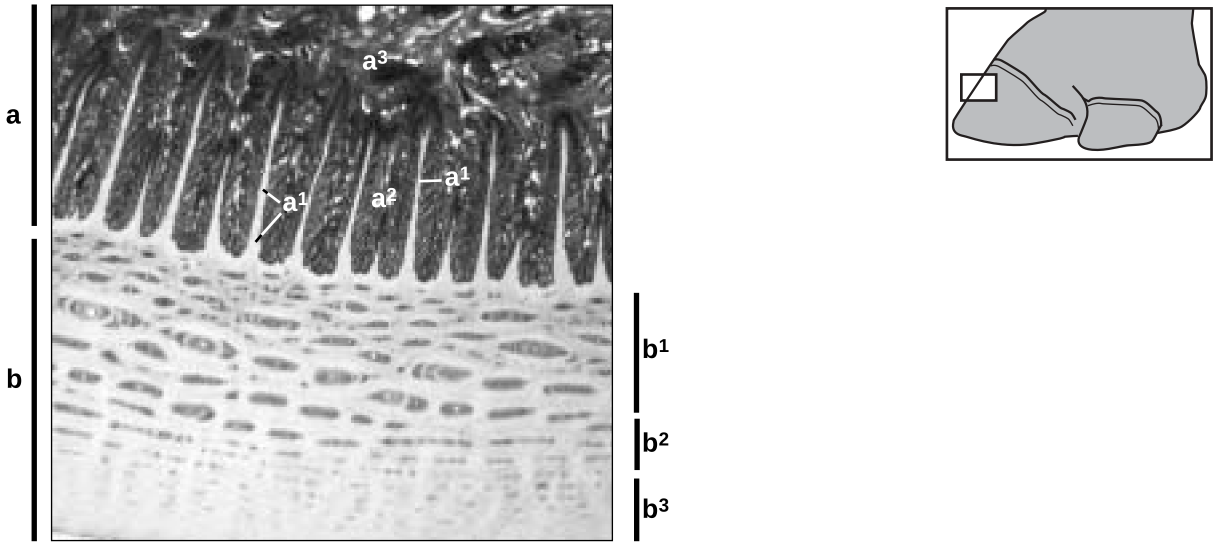


Photo 17: Cross-section of the hoof wall of a Black rhinoceros.

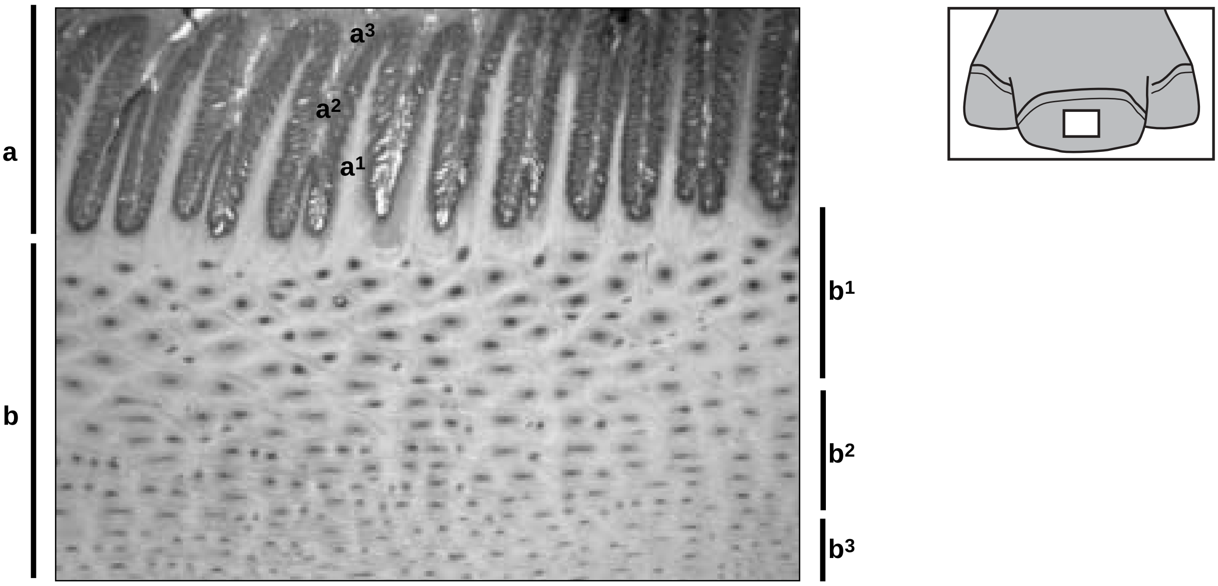


Photo 18: Cross-section of the horn wall of an Indian rhinoceros.

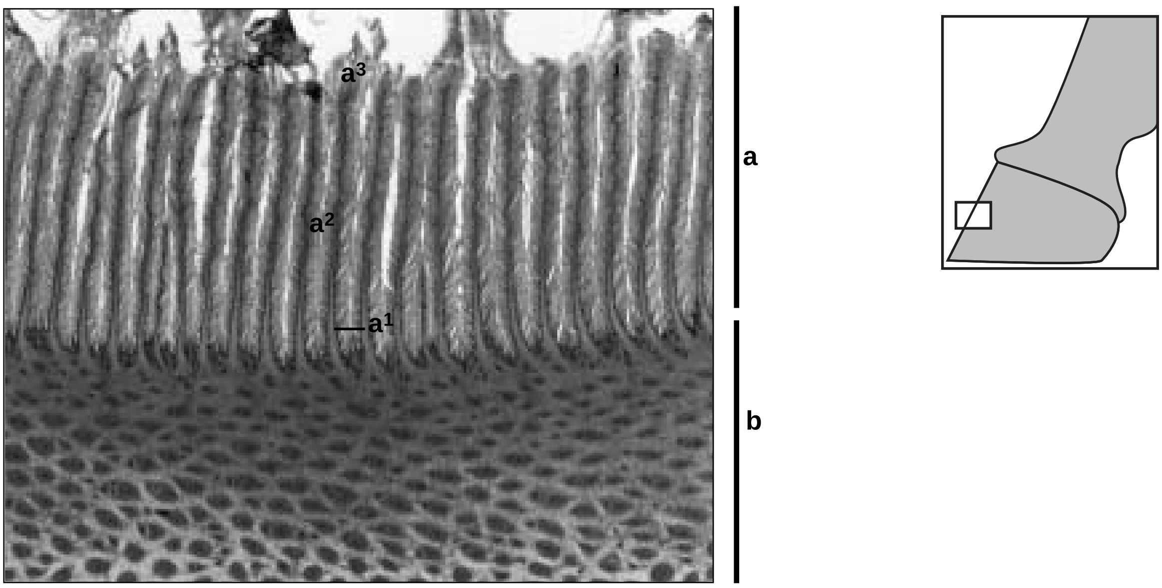


Photo 19: Cross-section of the horn wall of a horse.

Corresponding to the branching of the corial leaflets the epidermis (Stratum germinativum with Stratum corneum) shows suitable branches, which are the negative form of the corial pattern.

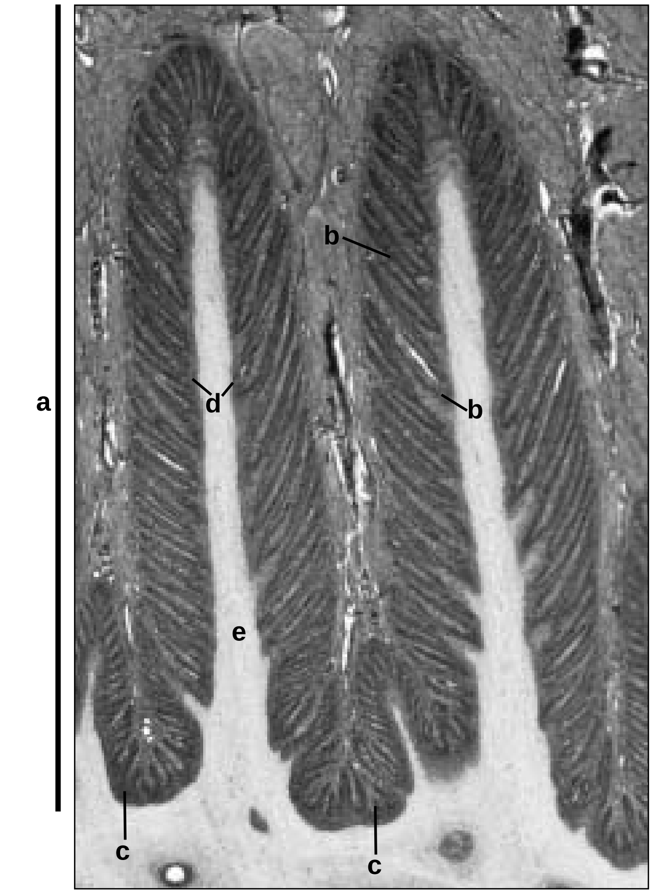
The horn leaflets vary in height from proximal to distal wall sections. They measure from their basis to their ridges (adjacent to the corium) in proximal cross sections around 2,4 mm to 3,5 mm. The maximum height and width of epidermal primary leaflets is 5,6 mm respectively 0,6 mm to 1,4 mm. The maximum height is reached in the middle section of the hoof wall.

In the hind feet, the horn leaflets are slightly larger than in front feet. There seems to be no difference in length with regard to side and central hooves. In the central hoof, the leaflets reach their maximum length further distal (3 - 4 cm) than one can observe in lateral or medial hooves (2 - 2,7 cm).

Photo 20:
Histological cross-section of the middle section of the wall; primary leaflets; Indian rhino; AB-PAS staining; magnification: **32 x**
a = primary corial leaflet, b = secondary corial leaflet, c = tertiary corial leaflet, d = Str. spinosum, e = Str. corneum (horny leaflet)

Photo 21:
Histological cross-section through the middle of the wall. A higher magnification of the circled area is depicted in photo 22; secondary leaflets; Indian rhino; AB-PAS staining; magnification: **160 x**
a = corium of primary leaflet, b = corium of secondary leaflet, c = Str. basale, d= Str. spinosum, e = Str. corneum

Photo 22:
Magnification of the circled area in photo 21; the base of the secondary epidermal leaflet is subdivided; AB-PAS staining; magnification: **320 x**
a = secondary corium leaflet, b = secondary epidermal leaflet, b' = subdivided secondary leaflet, c = basal membrane, d = Str. basale, e = Str. spinosum



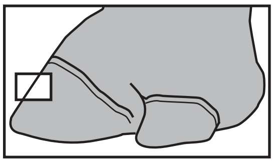


Photo 20: Primary leaflets.

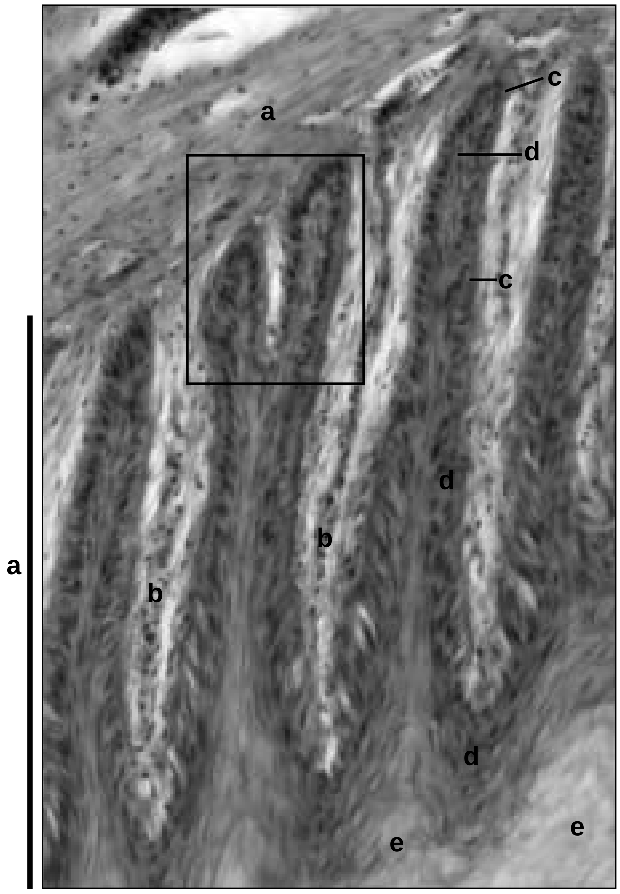


Photo 21: Secondary leaflet.

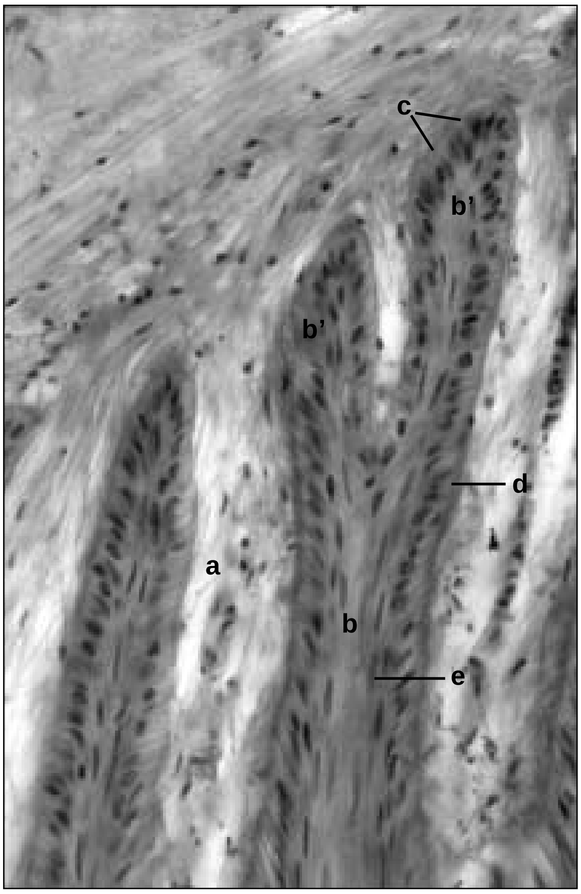


Photo 22: Subdivided secondary leaflet.

The formation of cap horn starts at around 3 cm and the production of terminal horn tubules at around 3,8 – 4 cm distal of the coronary border. The cap horn consists of cells and tubules, which curve over the ridge of the soft leaflets. The concavity of the cap horn is visible on the side of the soft leaflets and the convexity at the side of the coronary horn. The thickness of the cap horn, distal at the wall, is about 1 mm.

2 – 2,5 cm proximal the weight-bearing border, the soft leaflets transform into papillae. The germinative layer of the epidermis, which cover these papillae, form distally tubular horn. This horn is named terminal horn. The tubular horn fills the wide spaces between the horn leaflets.

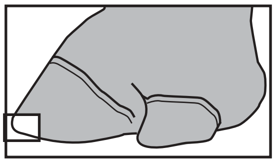
At the weight-bearing border, the horn leaflets and the terminal horn form together the white zone, also often named ‘white line’. The white zone is per definition the junction between the wall and the sole on the ground surface of the foot.

The width of the white zone is about 5 mm and is therefore not a ‘line’, but a ‘zone’. The coronary horn at the weight-bearing border is dark and is easily differentiated from the adjacent white sole.

Photo 23:
Histological cross-section of the distal part of the hoof wall; Indian rhino; AB-PAS staining; magnification: **8 x**
a = inner zone of the coronary horn, b = epidermal (horny) leaflets, c = terminal papille, c’ = terminal horn (tubular and intertubular horn), d = cap horn

Photo 24:
Higher magnification of photo 23; AB-PAS staining; magnification: **32 x**
a = horny leaflet, b = terminal horn, c = cap horn

Photo 25:
Macroscopic view of the footing surface of the sole of a central hoof, hind right foot, adult female Indian rhino; AB-PAS staining
a = weight-bearing border, b = stripped appearance of the sole, c = macroscopically visible group formation of the horn tubules, d = apical part of the pad.



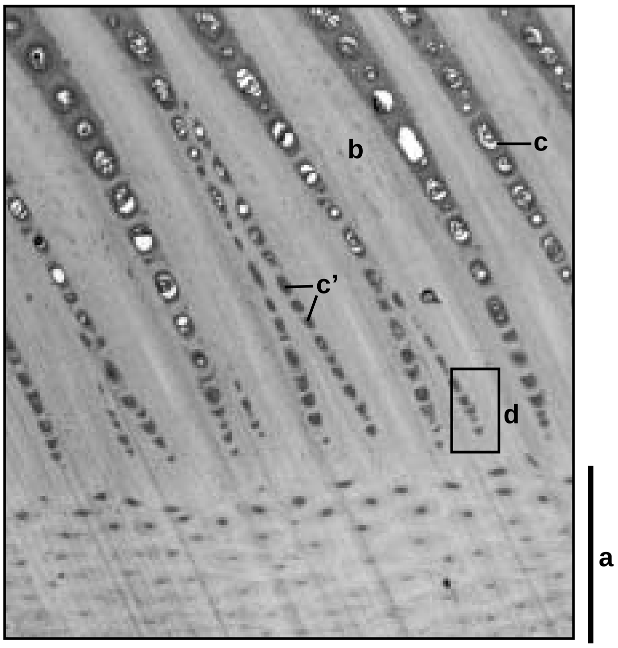


Photo 23: Terminal horn

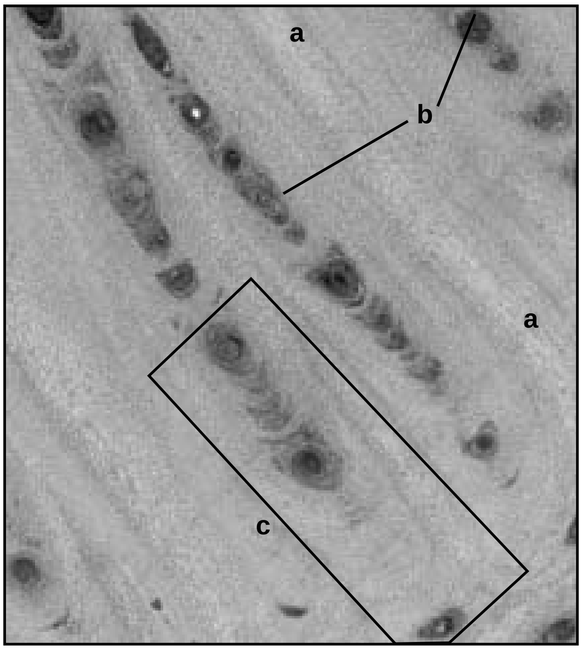


Photo 24: Close up of encircled area in photo 23.

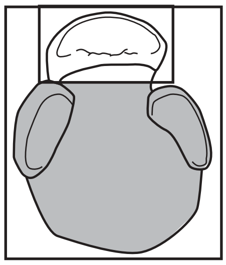


Photo 25: Macroscopic view of the ground surface of a sole.

4.7.4.The Sole Segment

In the central hoof, the width of the sole is up to 9 cm, in the side hooves up to 7 cm. The sole is joined to the wall by the white zone and shows some specialities.

It consists in the apical part and side parts, joining the white zone, of tubules. These tubules are arranged in radial lines, which seem to continue to the terminal horn of the white zone. Small tubules can be found within the lamellar-looking intertubular sole horn. The colour of the sole horn is bright white. The quality of the horn in this section, especially towards the middle of the sole, is inferior.

The linear arrangement of the tubules gets lost in the palmar/plantar part of the sole. There, the papillae form groups that can vary in size. In those groups, one large tubule is generally surrounded by several medium to small size tubules. The formation of these groups is macroscopically well visible as dots and gives the rim its special appearance (see photo 25). The palmar/plantar area of the sole, which borders the adjacent pad, is often pigmented and consists of very hard horn.

The papillae of the sole are long and broad. The length can reach up to 7,2 mm and their cone-shaped basis is 0,4 - 0,8 mm wide. They run almost perpendicular to the footing surface, with a slight bend apically. The Str. spinosum measures 1,2 mm. A Str. granulosum does not exist. These structures resemble highly the structures described in the coronary segment.

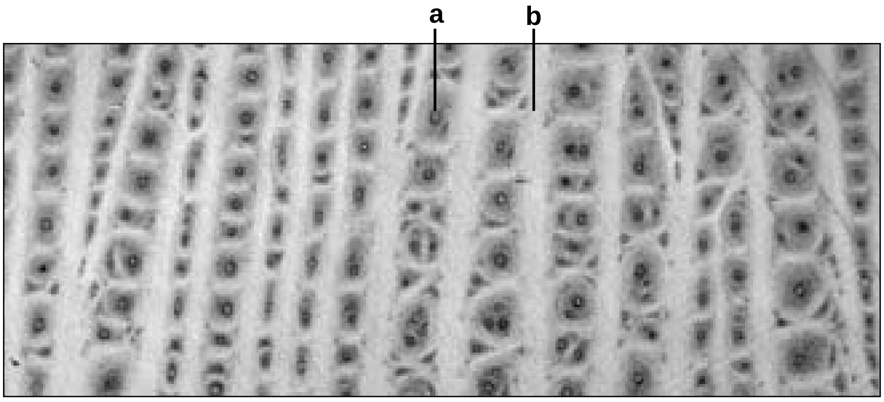


Photo 26: Linear alignement of horny tubules in the apical, distal part of the sole.

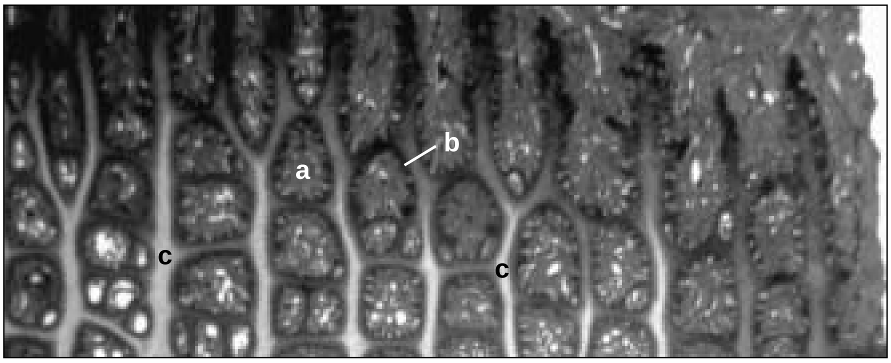
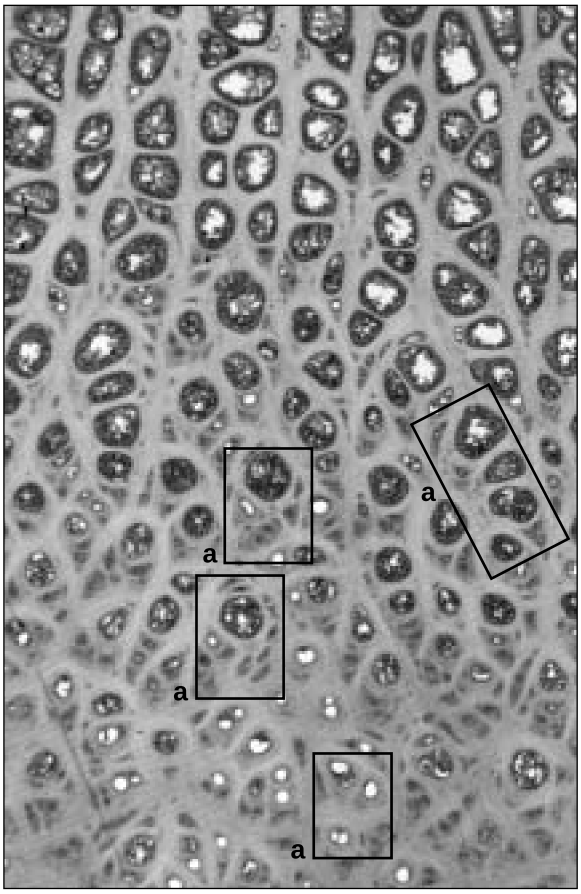


Photo 27: Apical, proximal region of the sole, linear arrangement of tubules.



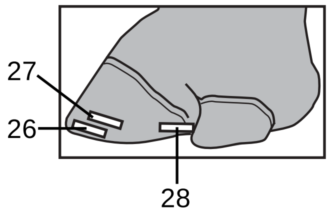


Photo 28: Palmar/plantar, proximal region of the sole, group formation of the tubules.

Photo 26:
Histological cross-section through the apical, distal part of the sole. Well visible is the linear alignement of the horn tubules (a) and the intertubular horn (b). This alignement is macroscopically visible (see photo 25); Indian rhino; HE staining; magnification **8 x**
Photo 27:
Histological cross-section through the apical, proximal part of the sole; Indian rhino; AB-PAS staining; magnification: **8 x**
a = corial papille, b = Str. germinativum, c = intertubular horn
Photo 28:
Histological cross-section through the palmar/plantar part of the sole. The linear arangement is no longer visible, the horn tubules show the formation of groups (a); Indian rhino; AB-PAS staining; magnification: **8 x**; a higher magnification of the group formation is depicted in photo 36.

The diameter of a group of horn tubules can reach up to 1 x 1 mm. The individual size (cross section) of the tubules ranges from 120 x 180 µm to 60 x 60 µm. In the cortex (60 - 180 µm thick), some cells are spindle shaped some have the form of a honeycomb. The interior layers surround the marrow like leaflets of an onion. The intertubular horn cells (10 - 30 µm) have a polygonal shape and can well be distinguished from the cortical cells. The membrane coating material stains bright pink (PAS positive reaction). The intercellular space is well visible and facilitates the differentiation of the cells.

4.7.5. The pad segment

The pad is the largest structure of the Indian rhinoceros foot and borders the axial side of the lateral and medial and the palmar/plantar area of the central hoof. They surround the pad to three fourth of its size in a semi-circular way. Each sole attaches to the structure of the pad. The lateral and medial hooves have free palmar/plantar and dorsal edges, which help the foot to expand on different surface structures.

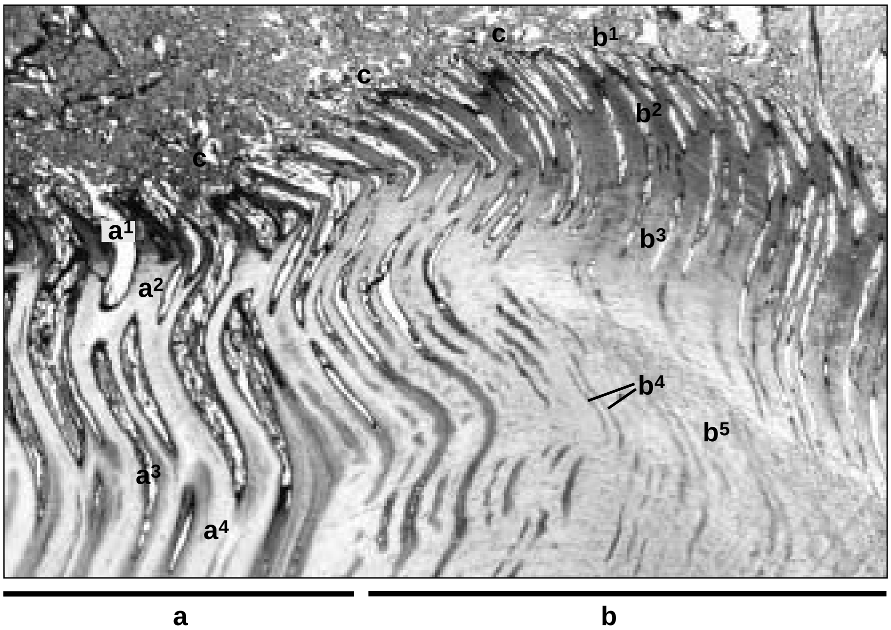
The papillae of the pad are short and thin. They are up to 4,0 mm long and up to 0,2 mm wide at the basis. The Str. spinosum is approximately 2,0 mm thick and the Str. granulosum 0,6 mm. Vacuoles are frequently seen in the cells of both layers.

The horn tubules undulate in their course of direction, pointing apically at an 80° angle. The cortex cells stain blue and are difficult to distinguish – apart from the colour – from the intertubular horn. There is no sharp demarcation between the cortex cells and the intertubular horn cells. The blue colouration of the cortex cells gives them a ‘fussy’ appearance. The cell membranes have an intense light pink colouration and are in some cases difficult to make out. The cells are half the size of the cortex cells in the sole.

The intertubular cells have a shape of a honeycomb. This is well visible in cross sections underneath the area of the Str. granulosum. The membrane coating material is visible as it stains pink (PAS positive reaction). The area of the cell membranes is very thin compared to the ones seen in the sole horn. Further down, the horn cells have a brick shape or are flat, with the flat side facing the palmar/plantar surface. The approximate length is 30 µm and the height varies around 5 - 10 µm.

Towards the palmar/plantar part of the pad, cross sections through the Str. spinosum show a very regular arrangement of the papillae. The course of direction of the tubules is orientated towards the weight–bearing border of the sole, leading to an angle of 45 ° in the middle part of the pad and less than 30° further palmar/plantar.

The proportion of the Str. germinativum to the horn layer ranges from 1 : 3 in the apical section, to 1 : 2 in the middle, and to 1 : 1 in the palmar/plantar part of the pad. The horn layer is in all sections very thin, with a maximum height of 1 cm adjacent to the sole (see



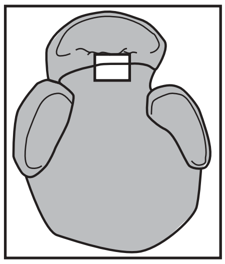


Photo 29: Transition between sole and pad.

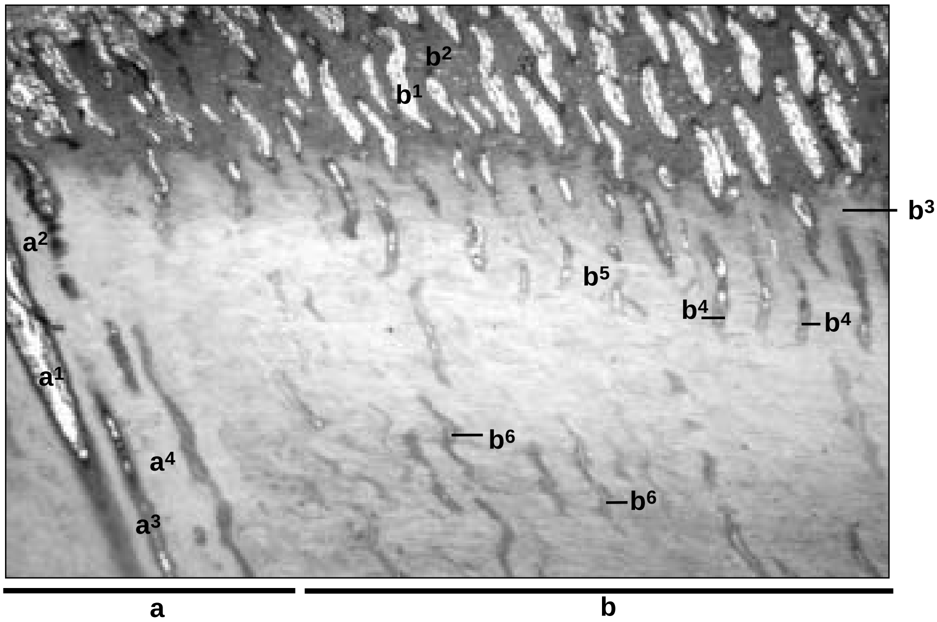


Photo 30: Transition between sole and pad.

Photo 29, 30:
Longitudinal section through the transition of sole and pad; Indian rhino;
AB-PAS staining; magnification: **8 x**
a = sole segment, a1 = corial papillae, a2 = epidermal papillae, a3 = horn tubules,
a4 = intertubular horn
b = pad segment, b1 = corial papillae, b2 = epidermal papillae, b3 = str. granulosum,
b4 = horn tubules, b5 = intertubular horn, b6 = duct of a gland
c = corium inner part

also Photo 2).Ducts of glands, looking like tubules, lay within the cutis of the pad. They have an extreme corkscrew-like course of direction. They are filled with a pink contest (AB-PAS stain) and are surrounded by a cortex. This cortex is composed of the same cells like the ‘normal tubules’, with the difference that the cortex cells loose already their connection towards each other and with the membranes already vanished within the Str. spinosum. They are always found near two or three other ‘normal’ tubules, generally in close proximity. On cross sections they form a triangular shape. In horizontal cross sections of the apical pad, 4 to 5 of these tubules are found per 25 mm^2. In the palmar/plantar part, 1 tubule per 25 mm^2 is present. These tubules are comparable in structure with sweat glands found within the cutis of footpads from dogs and cats (Krölling and Grau, 1960). The end of the glands is found in the corium and subcutis of the pad. The functional importance of these glands is not completely known but may have something to do with spending humidity to the horn or scent distribution.

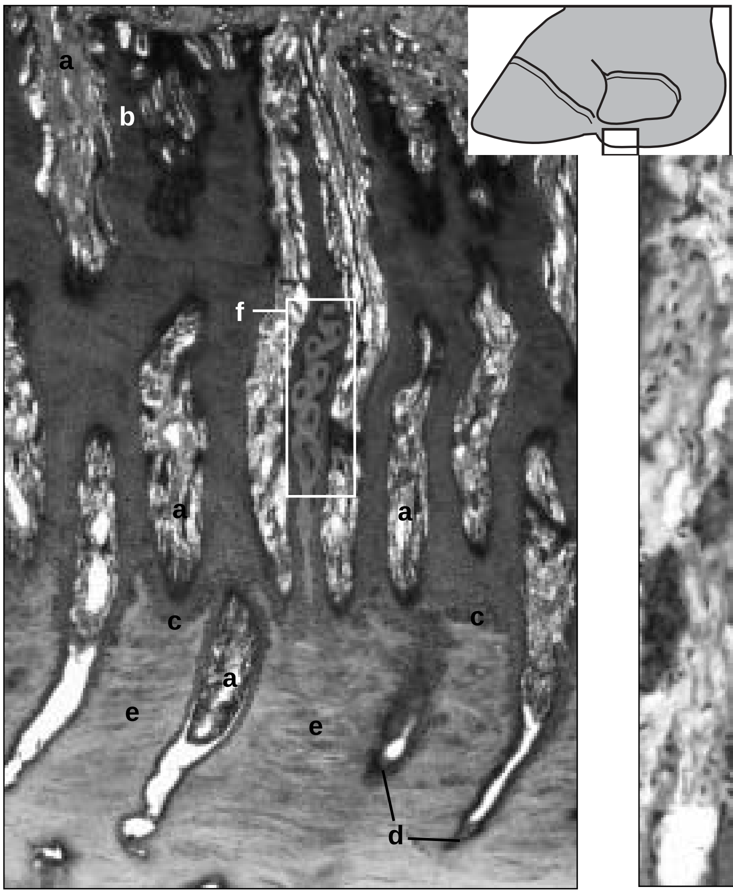


Photo 31: Apical part of the pad.

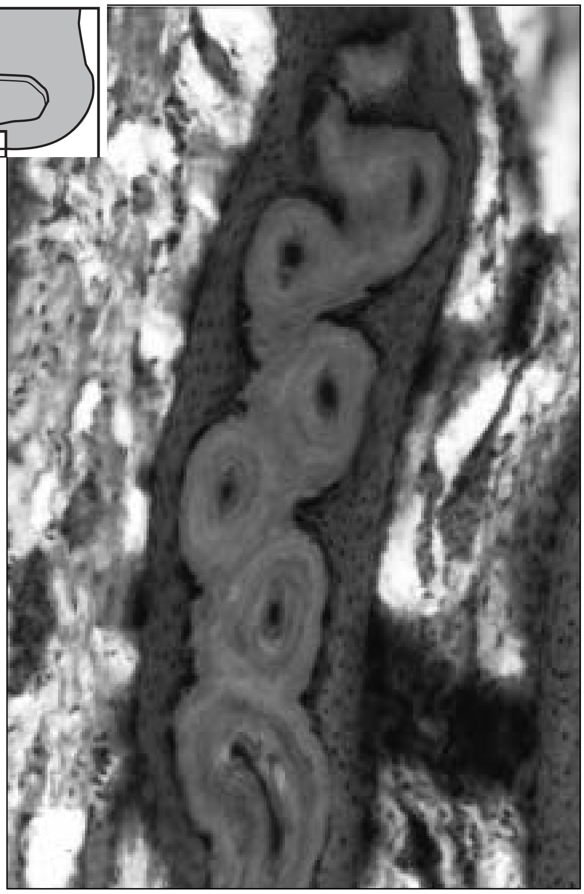
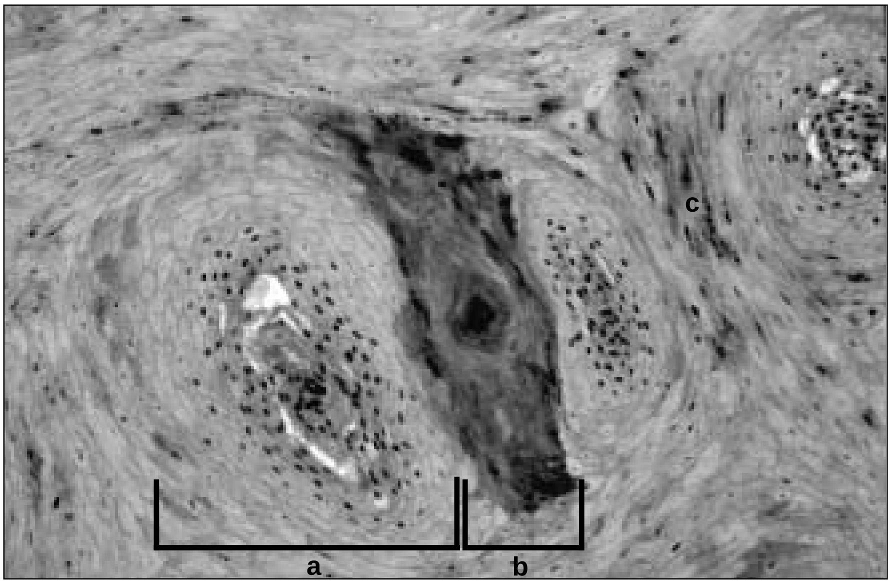


Photo 32: Close up of photo 31.



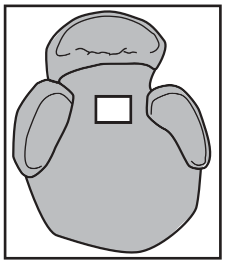
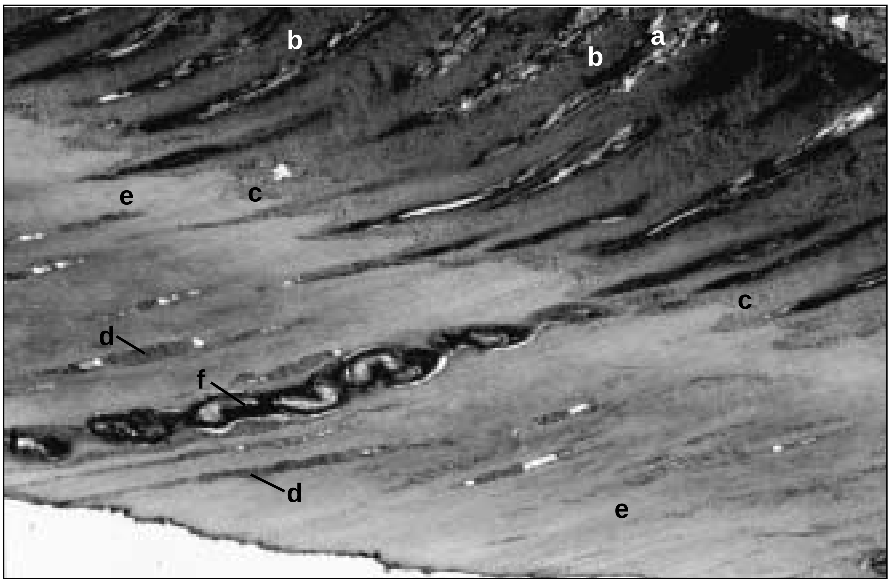


Photo 33:
Cross-section through the Str. germinativum of the pad.



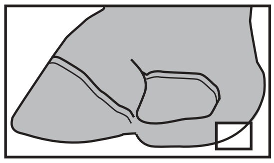


Photo 34:
Palmar/plantar section through the pad.

Photo 31:
Longitudinal section through the apical part of the pad; Indian rhino;
AB-PAS staining; magnification: **32 x**
a = corial papillae, b = epidermal papillae, c = Str. granulosum, d = horn tubules, e = intertubular horn, f = duct of gland

Photo 32:
Close up of the duct seen in photo 31; AB-PAS staining; magnification: **160 x**

Photo 33:
Histological cross-section through the Str. germinativum of the pad and duct of a gland; Indian rhino; AB-PAS staining; magnification: **126 x**
a = horn tubule, b = duct, c = Str. granulosum

Photo 34:
Longitudinal section through the palmar/plantar part of the pad; Indian rhino;
AB-PAS staining; magnification **8 x**
a = corial papillae, b = epidermal papillae, c = Str. granulosum, d = horn tubules, e = intertubular horn, f = duct of gland

4.7.6. Special features of the transition between sole and pad

The transition between sole and pad has a remarkable structure. In this area two histological very different structures are connected with each other. The following table gives an overview of the most distinctive differences:

Table VII: Comparison of sole and pad structures

	Sole	Pad
Papillae	Long and thick	Short and thin
St. spinosum	Thin	Thick
Str. granulosum	Not existent	Existent
Exocrine glands	Not existent	Existent
Tubules	Straight and broad	Undulating and thin
Intertubular Horn	Large cells, well distinguished from each other	Small, flat cells membranes difficult to make out
Thickness of Horn part	2 - 3 cm	Max. 1 cm
Quality of Horn	Very hard	Soft and elastic

There is an immense distinction between the structures of the sole and the pad. Both are unique in themselves, the sole resembling the structure of the coronary band, the pad the one of the periople. Areas where very different structures align next to each other are frequently ‘loci of minor resistance’. They are highly susceptible to traumatic impacts.

Photo 35:
Longitudinal section through the transition of sole and pad; Indian rhino;
AB-PAS staining; magnification: **8 x**
a = sole segment, a1 = corial papillae, a2 = epidermal papillae, a3 = horn tubules,
a4 = intertubular horn
b = pad segment, b1 = corial papillae, b2 = epidermal papillae, b3 = Str. granulosum,
b4 = horn tubules, b5 = intertubular horn, b6 = duct of a gland

Photo 36: Histological cross-section through the Str. corneum of the palmar/plantar region of the sole. Close up from photo 28, showing the group formation of the horn tubules;
AB-PAS staining, magnification: **160 x**
a = group formation of the horn tubules, b = cortex, c = marrow, d = intertubular horn

Photo 37: Histological cross-section through the Str. corneum of the apical region of the pad; Indian rhino; AB-PAS staining; magnification: **32 x**
a = horn tubules, b = cortex, c = intertubular horn, d = duct of a gland

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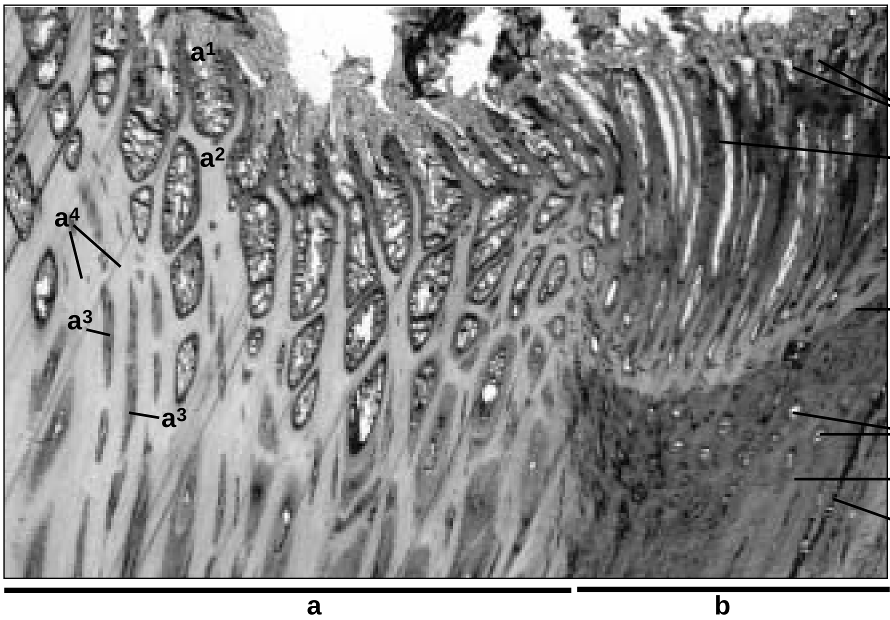


Photo 35: Transition between sole and pad.

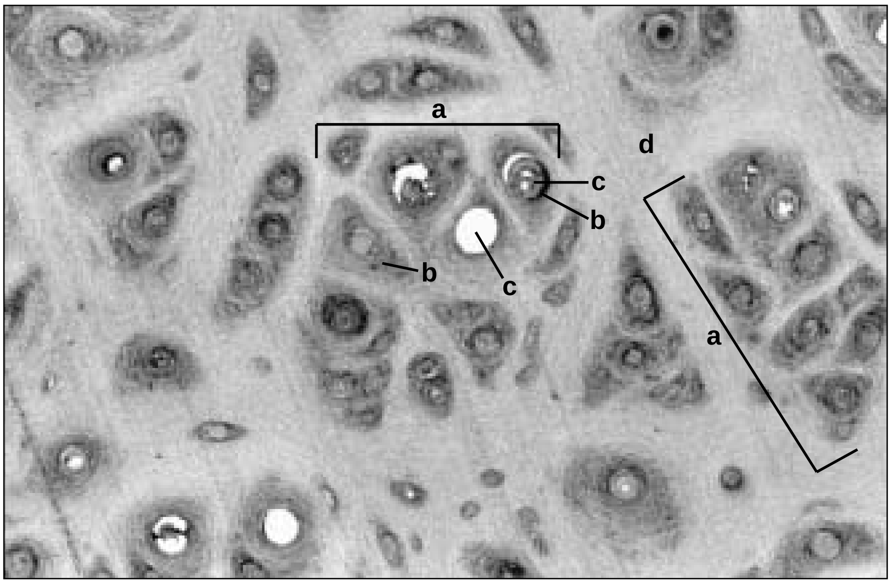


Photo 36: Cross-section through the sole.

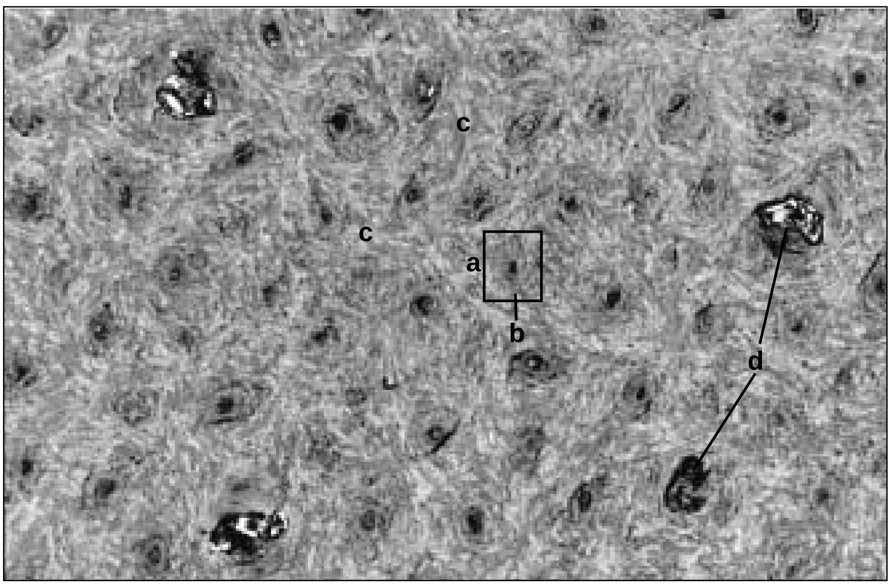
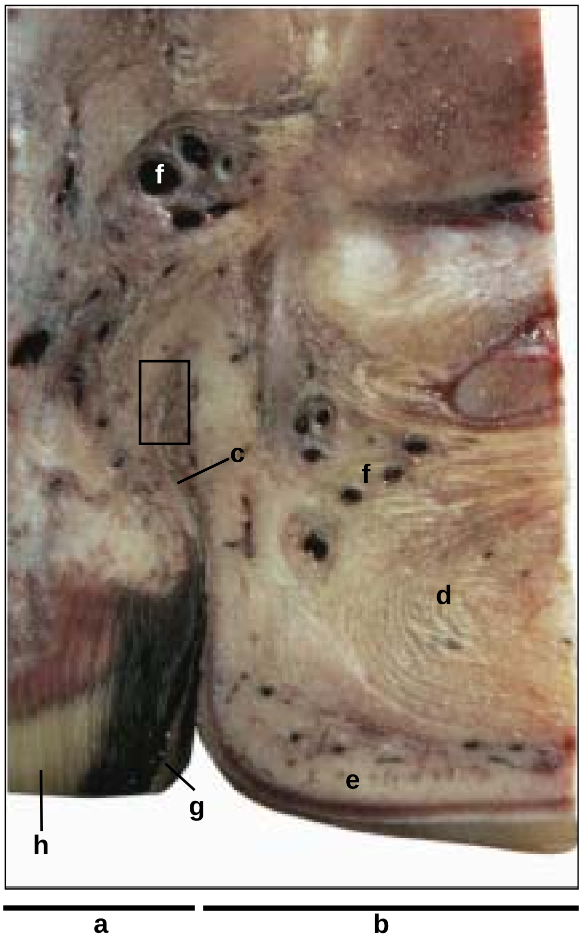


Photo 37: Cross-section through the pad.

4.7.7. The interdigital segment

The interdigital segment in Indian rhinos is located between the sides of the central and the dorsal part of the lateral, respectively the medial hoof. The gap reaches up to 6 cm and enables the enlargement of the footing surface. When placing the foot on the ground, the side hooves move several centimetres away from the adjacent central hoof and the foot-pad.
In histological sections this area consists of a Str. papillare, which is approximately 4 mm thick. The papillae are long and thin and have a web-like appearance in their course of direction. A Str. granulosum of several cell layers exists. The Str. corneum is very thin, with a maximum height of 0.2 - 2 mm. The horn cells are layered and tubules are rarely seen. The interdigital segment resembles the structure of the skin.



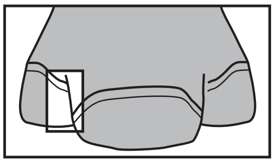


Photo 38: Longitudinal section through the interdigital gap between the central and lateral hoof; Indian rhino
a = lateral hoof, b = central hoof, c = interdigital gap, d = digital cushion, e = corium,
f = vessels, g = coronary horn, h = sole

The area encircled was histologically prepared and is shown in photo 39.

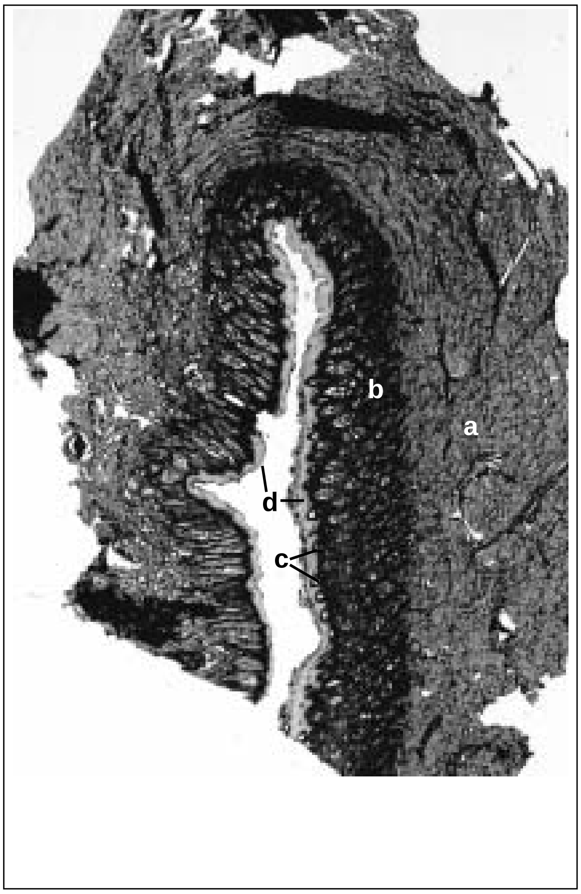


Photo 39:
Interdigital gap

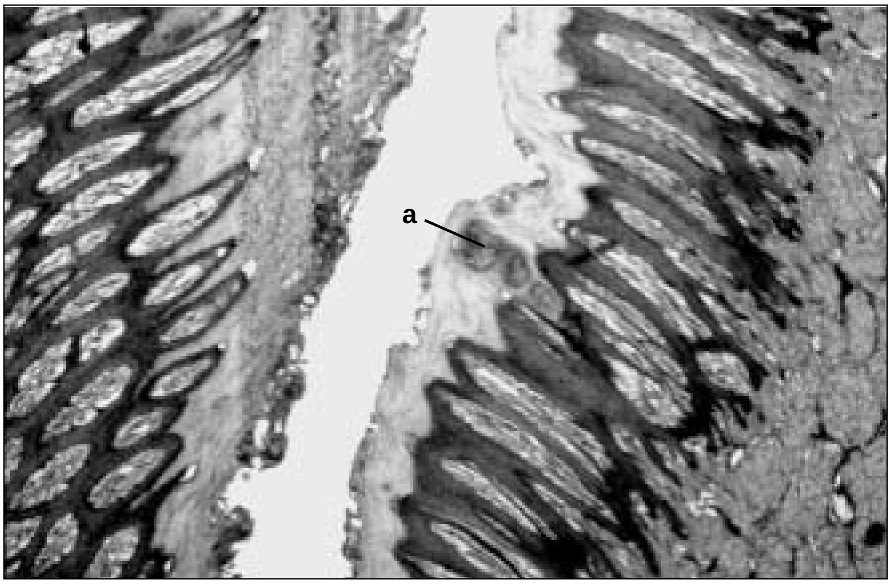


Photo 40:
Duct of a gland

Photo 39:
Longitudinal section through the proximal part of the interdigital gap between the central and lateral hoof; Indian rhino, AB-PAS staining; magnification **8 x**
a = subcutis, b = Str. spinosum, c = Str. granulosum, d = Str. corneum

Photo 40:
Duct of a gland (a) in the epidermis of the interdigital gap;
AB-PAS staining; magnification: **20 x**

4.8. Pathological alterations in the feet of captive Indian rhinos

Pathological changes found on the feet of Indian rhinos in zoological gardens can be divided into four categories. For this evaluation 32 animals were examined. The results of my personal observations will be described in the following section.

Table VIII: Survey of pathological changes in Indian rhinoceroses feet:

	Males		Females		Total	
	Young	**Adult**	**Young**	**Adult**	**Nr.**	**%**
Animals in the study	2	11	4	15	32	100%
Cracks between Sole and pad	0	**11 (100%)**	0	**8 (53%)**	**19**	**59%**
Without foot problems	2	0	4	7	13	41%
Cracks in the Horn wall	1	7	0	6	14	44%
Abraded Horn wall	0	12	0	12	**24**	**75%**
Ulcers and fistules in the pad	0	3	0	2	5	16%

Young = animals under the age of 6 Adult = animals over the age of 6 4.8.1.

4.8.1. Cracks between the pad and the sole of the central hoof

The typical clinical picture shows the formation of a crack between the pad and the sole of the central hoof in the hind feet. Front feet show also these pathological changes. They occur less often and are generally seen in those animals, which already suffer from chronic problems in their hind feet. In most cases the formation of the crack starts at the medial side of the pad and leads in advanced cases across the whole surface. The split can appear directly in the transitional area of the pad and sole, or up to 1 - 3 cm further palmar/plantar within the apical section of the pad. Chronic cracks can reach up to 6 cm into the living tissue, forming deep holes, fistules, and possibly abscesses along the side of the foot. The average depth of cracks ranges around 2 - 4 cm. So far no proven case of joint infection due to a crack in that area has been reported.

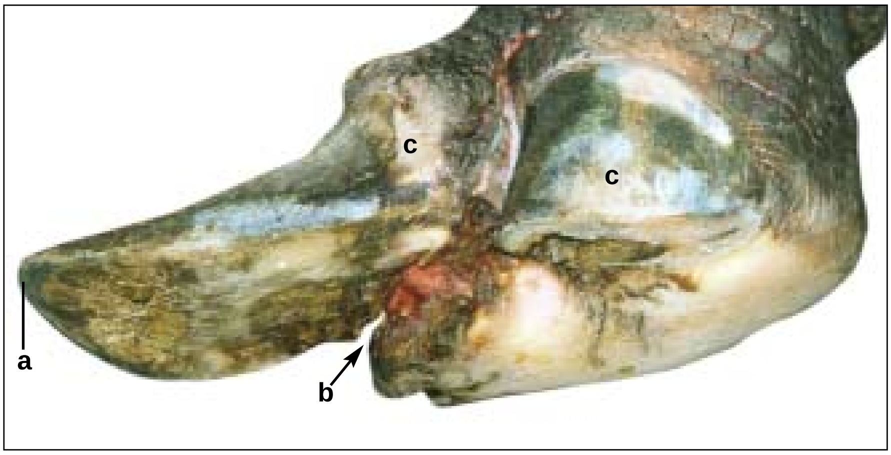


Photo 41:
Male Indian rhino, with a severe case of chronic foot problems in a hind foot (category I). Overgrown central horn wall (a), crack and inflammatory tissue (b), abrasions on central and lateral horn wall (c).

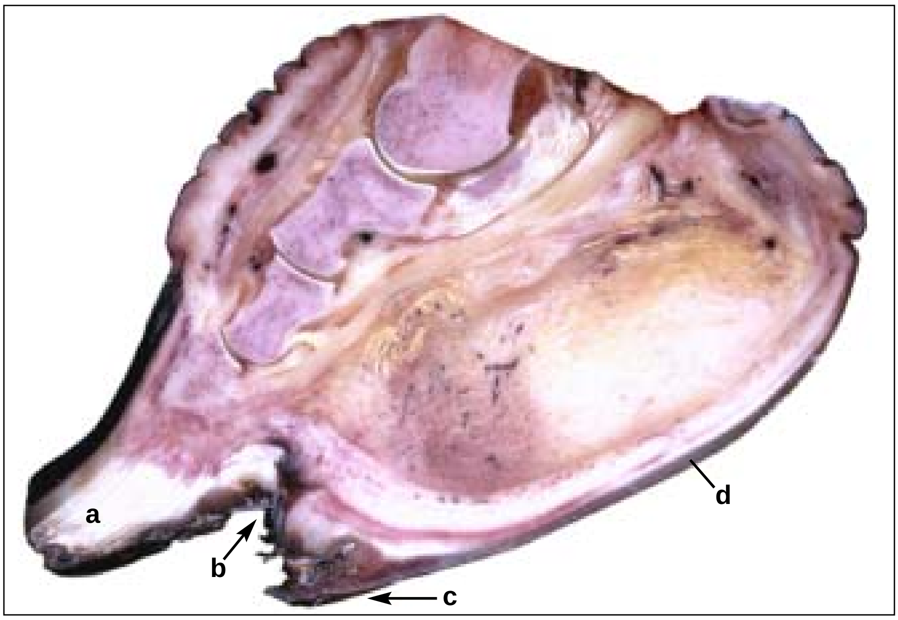


Photo 42:
Longitudinal section through a foot (category I), overgrown sole (a), crack (b), granulation tissue (c), thin pad (d).

Photo 43:
Female Indian rhino, showing the beginning of a crack (a), (category III).

Bacterial investigation of the infected cracks revealed in several cases the presence of common bacteria such as Streptococci and Staphylococci. On one occasion a fungus was detected but it seems likely that it is a secondary invader like the bacteria.
As a reaction to the crack, granulation tissue forms alongside the injured tissue. This granulation tissue bulges out on the sides of the central hoof, which becomes well visible when the animal stands. The granulation tissue grows fast and produces horn of inferior quality. Only minor and small fissures are likely to heal completely. So far no report exists of completely healed wounds, which did not reoccur. Improvement of the wounds is noticeable during the summer time. In the wintertime most cases worsen.
Signs likely to be noticed, are blood tracks on the floor, granulation tissue bulging on the side of the central hoof into the interdigital space, increasing resting periods, and relieving the pain from the affected foot by lifting it partly up. In severe cases the animal will show signs of lameness. This can be observed after mating periods. When walking, most animals will shift the weight away from the crack to the non-affected areas of the mid- and palmar/plantar part of the pad. This will eventually lead to an overload in that area, to increased abrasions, and in the course of time to pathological alterations within the palmar/plantar structure itself.
Of the 19 rhinos, I observed that 8 animals had numerous haematoma localized on the footing surface of the pad. They were predominantly found in front, but also in hind feet. They are seldom serious and do not seem to impair the animal's gait, but arise due to contusions and bruises.
As table VIII shows 19 animals out of 32 (13/19) animals show the typical clinical picture of chronic cracks in their feet (59%).
All 19 animals are adults. In this study no young animal was affected. The youngest animal ever recorded to have foot problems was 4 years old. In general, this problem starts with the onset of sexual maturity, i.e. 6 – 8 years for males, 5 – 6 years for females. Of these 19 animals, 11 males and 8 females suffer from foot problems. The figures show that all breeding bulls within Europe (with the exception of one Zoo, whose animals were not incorporated into the study) are affected. More than 50 % of the breeding females show pathological changes.
According to the degree of severity of the cracks, I assigned the animals to three different classes.

I. Severely affected, with hind feet and front feet showing cracks. The cracks in the hind feet run either across the whole width of the pad or are very deep (> 3 cm).
II. Severely affected, with the presence of cracks only in the hind feet.
III. Affected animals, which have cracks in one or both hind feet. They do not run across the whole surface and/or are very shallow (1 - 1,5 cm).

Table IX: Classification of different degrees of pathological alterations

Classification	Total Nr. of Animals	Males/Females		Percentage
I	**5**	**4**	**1**	**26%**
II	9	6	3	48%
III	5	1	4	26%

This table can be interpretated in the following way:

- Males are more seriously affected than females. They make up the main part of category I and II.
- Out of the 19 cases, 5 animals showed severe problems not only on their hind feet but also on their front feet.
- Females make up the main part of class III. They show problems, which are generally not as severe as the problems found in males.

Photo 44: Male Indian rhino with haematoma (a) on a front footpad.

4.8.2. Vertical and horizontal cracks in the horn wall of the hooves

The second category of pathological alterations describes the occurrence of vertical and horizontal cracks, which form within the horn wall. These cracks can reach into the living tissues, a predisposing factor for the onset of an infection.

44 % of the population within European zoos show cracks of either form. Vertical cracks occur more often than horizontal.

Cracks were observed in all age categories with the youngest recorded animal being two years old. They occurred more often in males than in females.

Vertical cracks appear mostly in the side but also in the central hooves. They run from the coronary band to the weight-bearing border of the horn wall and can vary in width and length. The course of direction is generally not straight but looks rather frayed. They seldom run parallel to the tubules. In some cases the crack continued to run along the whole width of the sole, separating the sole almost into two halves.

These cracks are often related to injured coronary bands and abraded horn walls. Front feet are in the same way affected as hind feet.

Horizontal cracks are mainly seen in front feet on the central, and to a lesser extent on the side hooves. The horn walls of some hooves show grooves that run across the hoof. Clinical signs are seldom apparent. Most affected animals suffer additionally from cracks in their pad of the hind feet. It was not possible to distinguish correctly whether an animal increased its resting periods due to the cracks in the horn wall, due to the cracks between the central sole and the adjacent pad, or out of other reasons. Lameness was not specifically observed with these cracks.

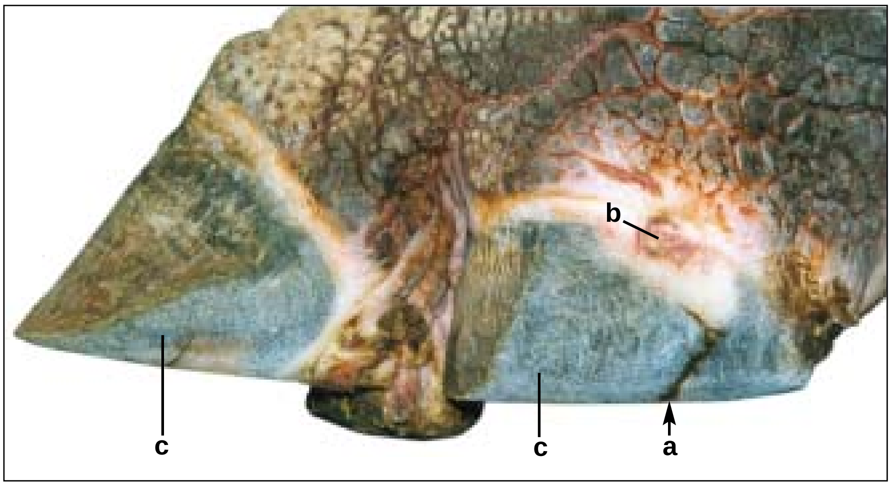


Photo 45:
Adult male Indian rhino. Hind foot, crack on the lateral hoofwall (a). Inflammation of the coronary band (b), abrasion on the lateral and central hoof wall (c).

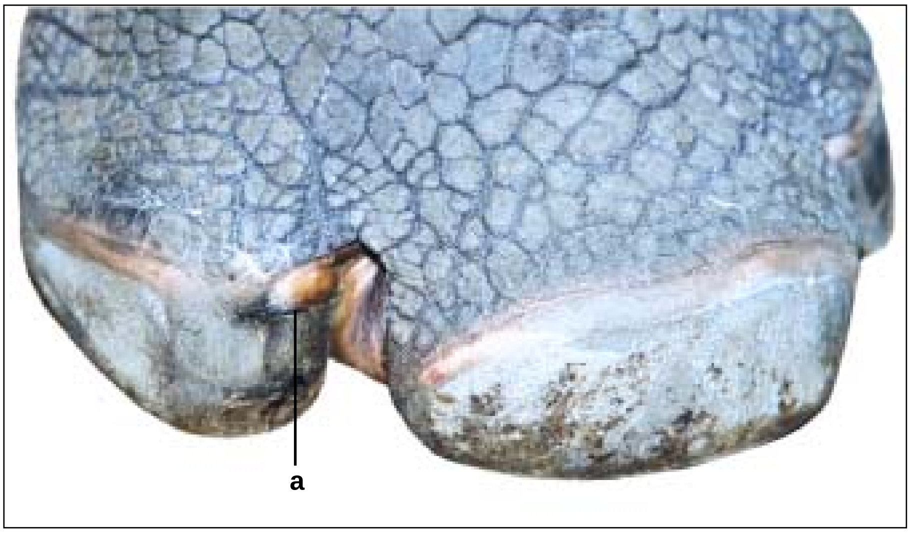


Photo 46:
Adult male Indian rhino. Right front foot, horizontal crack in the lateral horn wall (a), close to the coronary band.

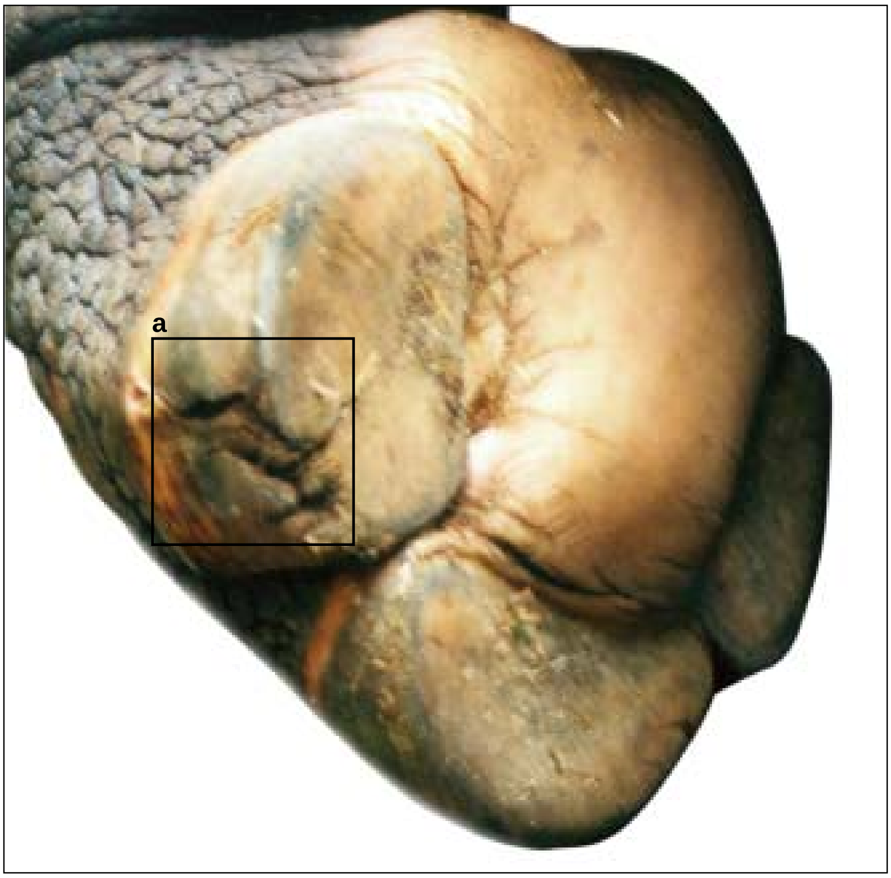


Photo 47:
Adult male Indian rhino. Vertical crack reaching into the sole (a) of the left front foot.

4.8.3. Abraded horn wall

Grating or scraping of horn and skin tissue will consequently lead to abrasions. The skin shows signs of inflammation along the coronary band and the thickness of the horn wall is reduced.

75 % of all animals in Europe have abraded side horn walls. The lateral hooves are in general more affected than the medial and central. As shown in table V the low numbers indicate already the problem. In some cases the central hoof of the hind feet showed abrasions on the sides. These abrasions gave the hoof an almost triangular shape. The horn walls of the front feet are less affected but show also signs of abrasion.

The typical signs are flattened, square like (viewed from the footing surface) hooves. The black horn, build by the coronary band is worn off and the white, soft part of the wall segment is visible. The coronary band is reddened and shows in some cases signs of inflammation.

Those hooves, which show already changes in the coronary band, had horizontal cracks on the same hoof. The thinnest hoof was only 2 cm thick, compared to its normal width of 7 cm.

All recorded animals with cracks between sole and pad have abraded lateral horn walls.

4.8.4. Fistulae and ulcers

For the description of the occurrence of the following pathological changes I define a fistula as an abnormal, tube like passage between the body surface and an internal tissue. An ulcer is a local defect of the surface of the pad tissue, produced by necrotic inflammatory tissue.

The pad has a rather soft and thin layer of horn that is followed by highly sensible internal connective tissues. Of the 32 animals 5 had ulcers and fistulae in their pad. The size of the lesion ranges from 1 - 4 cm in diameter, protruding into the living tissue for several centimetres. Each of the lesions was well circumscribed and infected. Most ulcers occur due to penetration of rocks, flint stones, or other sharp material. Healing is well after proper treatment.

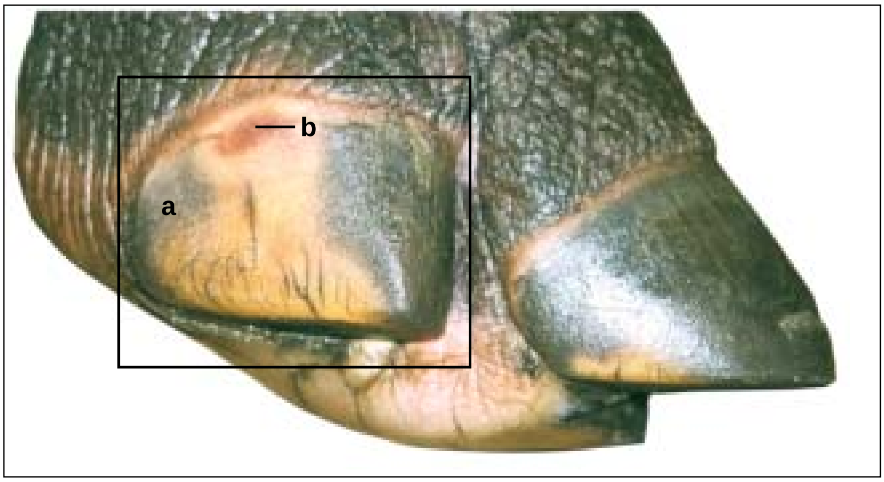


Photo 48:
Adult male Indian rhino. Abrasions on the hind foot, lateral hoof wall of the right hind foot (a). Inflammation of the coronary band (b).

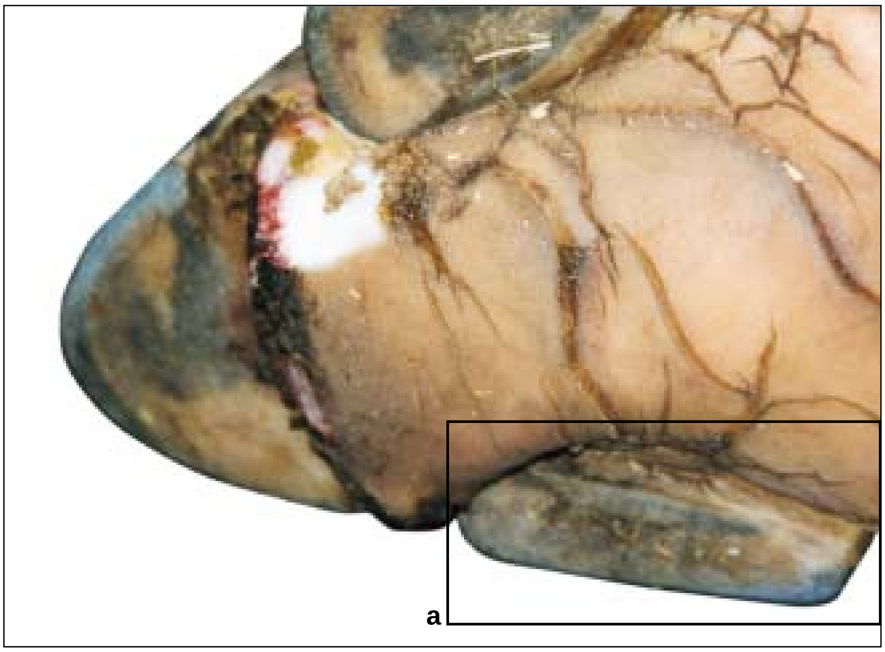


Photo 49:
Adult male Indian rhino. Hind right foot. The lateral hoof is highly abraded and has an almost rectangular shape (a).

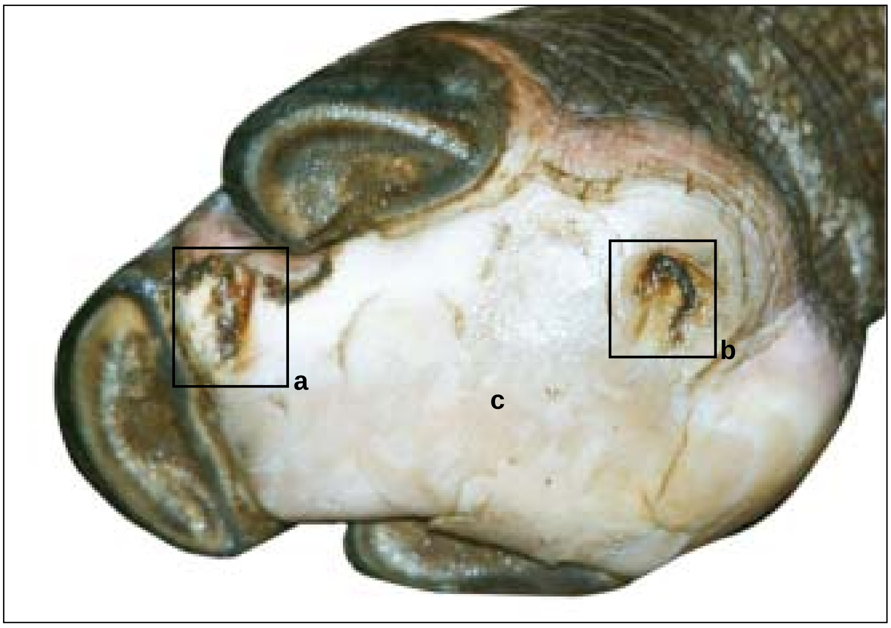


Photo 50:
Adult female Indian rhino. Hind right foot. Ulcer between the medial and central hoof (a), as well as on the plantar part of the pad (b). The horn appears white and abraded (c).

4.9. Pathological alteration of feet of wild Indian rhinos

The informations concerning this chapter base on the photographs and personal comments from Dr. Jacques Flamand. He was familiarised with the pathological alterations seen in captive animals and was therefore able to assess whether or not wild animals show similar or other clinical problems.

Evaluation of the pictures showed that none of the 10 animals had cracks somewhere in the pad or in the transitional area between pad and sole, which are comparable to those found in captive animals. The superficial fissures, seen on all pads did not seem to reach into deeper tissue layers and can be interpreted as clinical normal structures. None of the hooves showed either vertical or horizontal cracks in the horn wall, or abrasions. On some hooves vertical grooves were visible. These seem to stand in correlation with seasonal changes in the diet or with a previous birth as it can be seen in other domestic and wild animals. Dr. Flamand reported that he came across a few animals, which had ulcers in the pad. These ulcers varied in size, were infected but did not seem to impair the animal's health seriously. As none of the wild animals were inspected on future occasions it is difficult to assess whether ulcers cause serious problems or not. It seems almost 'normal' that traumatic impacts will cause lesions in the pad. The hooves appear altogether strong and healthy. The quality of the horn seems to be good.

4.10. Histopathological alterations of the horn structures in certain hoof segments

The horn samples were collected over a period of one year in 3 to 5 months intervals. There was no histological proof that the horn quality or the pathological alteration of the 'donators' showed an improvement or healing over the year of investigation.

4.10.1. Periople

Most of the tubules, cortex, and intertubular cells show pathological defects. Cracks, loose cells units, and broken tubules give the periople the appearance of poor quality horn. The cracks are found along the cortex of the tubules and also within the intertubular horn. The cells of the periople, which adjoin the coronary horn, are less affected than those of superficial layers. Bacteria are often found between the loose cells of the superficial layer.

4.10.2. Coronary horn

Pathological changes within the coronary horn occur mainly in the distal part of the hoof. Abrasions of the cells of the outer zone occur already in the proximal part of the wall. This is regarded as a normal sign of wear. The different zones of the coronary horn show a variety of pathological alterations:

1. The outer, middle, and to some extent the inner zone are completely missing. This is especially visible in the lateral hooves. Macroscopically, the horn is very thin and non-pigmented.

2. Cracks are found between the cortex and intertubular horn cells. These cracks can appear in the outer zone but are more often seen in the middle and partly in the inner zone. The extent ranges from fine fissures to large gaps. The further distal the histological samples were taken the more serious the alterations appeared.

3. The horny leaflets, the adjacent terminal horn cells, and the tubules were separated by cracks. These cracks were seen already in the middle part of the wall, where the formation of terminal horn had just begun. The further distal the sample was taken, the larger the gap. The terminal horn was partly missing.

4. The corial leaflets had separated from the epidermal Str. germinativum. This separation was either partly or showed the complete absence of any corial structures.

4.10.3. The Sole

Except for the abrasion of some superficial cell layers the sole structure appeared healthy in macroscopically unaffected feet. Those feet, which had severe cracks between the sole and the pad showed the following alterations:

1. The papillae were enlarged in width and length.
2. Some tubules had wide marrows, filled with decayed cell material and occasionally with white blood cells.
3. The intertubular horn showed cracks, gaps, and infiltration of bacteria. The structure was disordered.

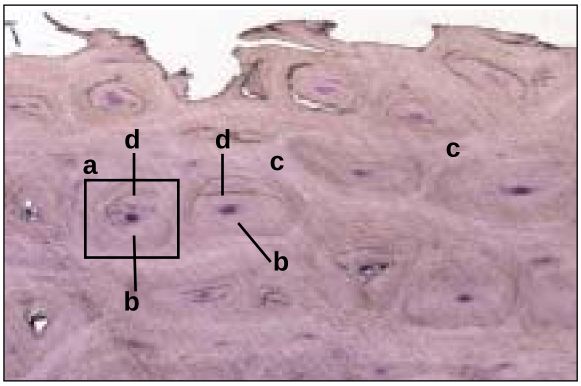


Photo 51:
Histological cross-section through the outer zone of the coronary horn; histopathological findings: minor cracks between the cortex cells of the horn tubules and the intertubular horn cells; Indian rhino, AB-PAS staining, magnification: **20 x**
a = horn tubules, b = cortex, c = intertubular horn, d = cracks

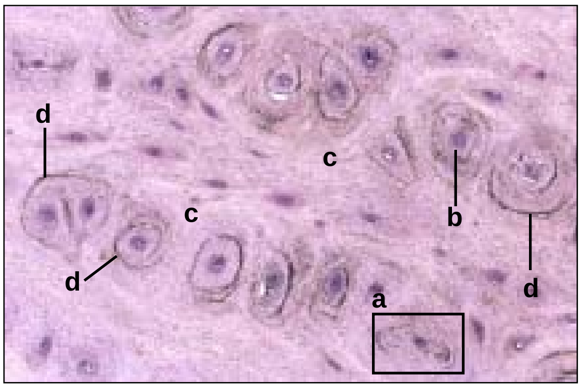


Photo 52:
Histological cross-section through the middle zone of the coronary horn; histopathological findings: minor cracks between the cortex cells of the horn tubules and the intertubular horn cells; Indian rhino; AB-PAS staining; magnification: **20 x**
a = horn tubules, b = cortex, c = intertubular horn, d = cracks

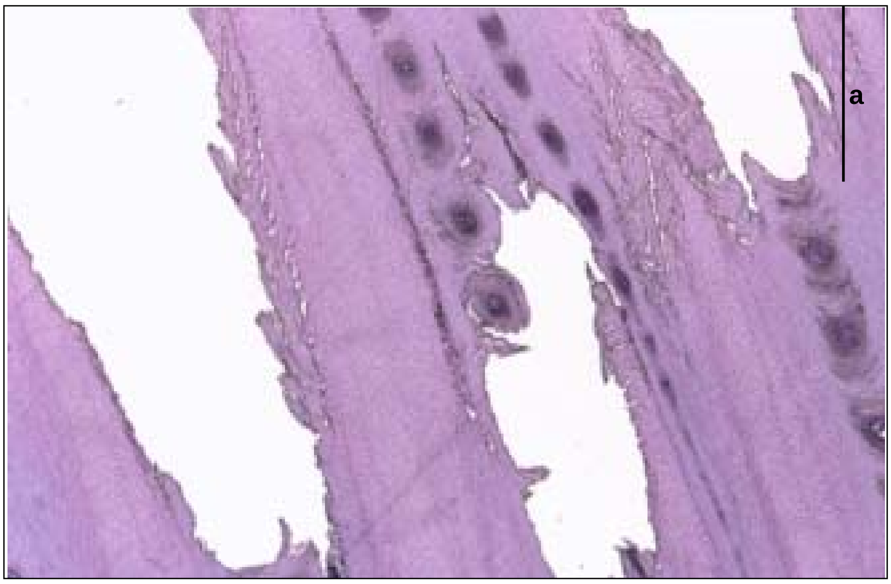


Photo 53:
Histological cross-section through the distal part of the horn wall. Histopathological findings in the terminal horn (a), which is partly missing; Indian rhino;
AB-PAS staining;
magnification: **32 x**

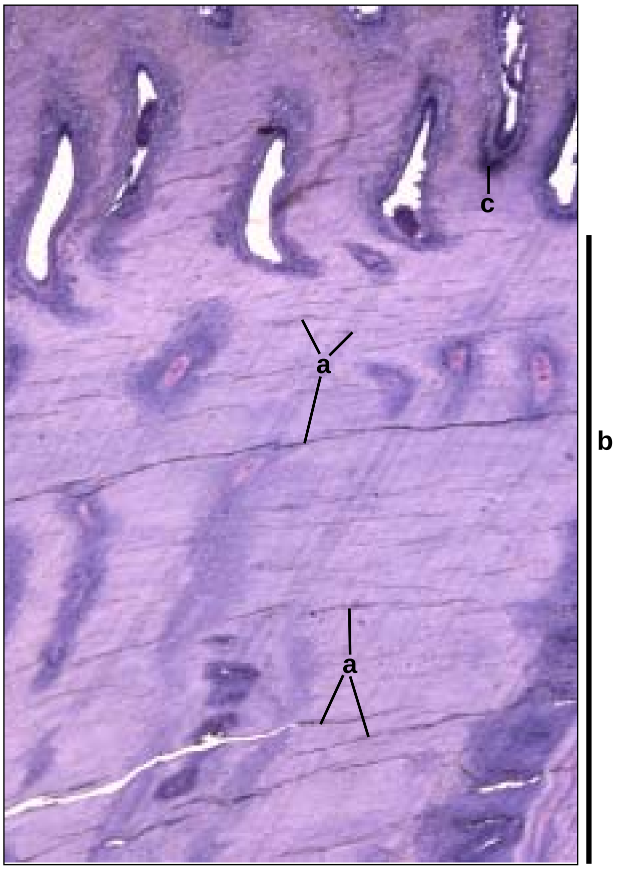


Photo 54:
Longitudinal section through the apical part of the pad. There are horizontal cracks (a) within the Str. corneum (b), up to the Str. granulosum (c). In most cases the cracks appear between two cell membrans; Indian rhino; AB-PAS staining; magnification: **32 x**

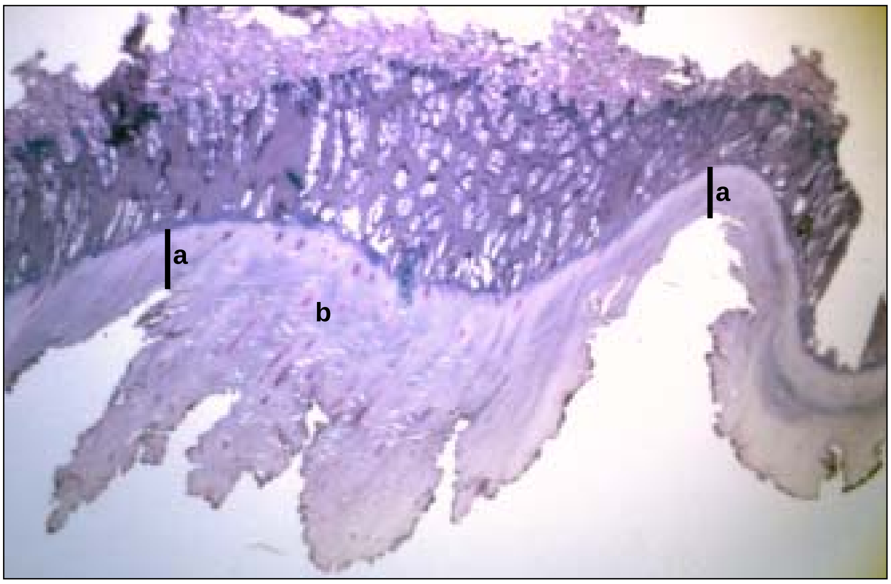


Photo 55:
Longitudinal section through the palmar/plantar part of the pad. The Str. corneum is partly very thin (a) or consists of inferior horn quality, with cracks and gaps (b) between the horn cells. Indian rhino;
AB-PAS staining; magnification: **32 x**

4.10.4.Pad

The cranial part of the pad, especially the area, which adjoins the central sole, shows a broad spectrum of pathological changes:

1. The basis of the papillae is broader and the papillae longer. In severely affected feet, the corial structures were degenerated to such an extent that the papillae appeared round and 10 times the normal size.
2. Horizontal cracks up to and partly within the Str. granulosum were found in <u>every</u> histological sample. These horizontal cracks start with the beginning of the pad structures adjacent to the sole. They are predominantly found between intertubular horn cells and run along the cell membranes. The intertubular horn of the sole adjacent to these cracks showed in comparison no alterations at all.
3. In horizontal sections it became visible that the cracks affected also the tubules. The cortex cells were separated from the marrow.
4. In macroscopically altered pad structured vertical cracks reached through the Str. corneum and the Str. granulosum into the Str. spinosum and to some extent into the corial structures. In one case the subcutis was affected as well and showed severe signs of inflammation and reactive tissue.
5. The cells of the Str. spinosum and Str. granulosum contained vacuoles. They were found in all sections and are regarded to some extent as normal. In most samples the amount of vacuoles reached beyond the 'normal limit' and the cells appeared almost empty. In addition the cells looked round and enlarged.
6. Within the Str. spinosum some cells were completely degenerated. The cells were not stained, appeared transparent, and had no cell membranes.
7. The ducts from the glands within the corial and epidermal structures showed in all cases loose cell structures with almost non-existent cell membranes.
8. The pathological changes are less apparent in the palmar/plantar part of the pad, but still present. As it is seen in apical sections, the Str. granulosum seems to be the barrier for the spreading of horizontal cracks to the corial structures.

4.10.5. Horn quality

In some zoos the attempt was made to improve the horn quality by supplementation of the food with biotin. The dosages ranged around 100 mg per adult animal, once daily. Most animals had been supplemented over years and it was only possible to assess its effect through personal reports of the keepers and veterinarians. The general impression was that the horn became harder. Biotin did not improve the health status with regard to the prevention or healing of the cracks. Due to the stronger structure of the horn, the general statement was that the animals needed more often foot care. It was thought that they did not wear the horn sufficiently.

4.11. Selected microscopical and histopathological findings in the Black rhinoceros foot

4.11.1. Microscopy

The primary epidermal leaflets in the horn wall branch at their basis (towards the coronary horn) into two to three smaller leaflets. The shape can be irregular and wave-like. The size of the primary leaflets is approximately 2,5 - 3,5 mm and the width 0,75 mm. 1 primary leaflet is counted per 0,8 mm2 and has between 70 - 90 secondary leaflets. The secondary leaflets are small, especially towards the ridge of the primary epidermal leaflet. The shape is wave-like and alternates constantly. They are approximately 0,12 to 0,5 mm long and branch very seldom into tertiary leaflets. Most commonly, tertiary leaflets are found towards the corial side of the primary epidermal leaflet.

The coronary horn is rather thin (max. 0,5 cm) and can be divided into three zones. Cell structures are similar to those found in Indian rhinos. Variations exist within the size and arrangement of the tubules.

The inner zone consists of relatively small tubules that are occasionally accompanied by larger ones. The marrow size ranges from 40 µm to 80 µm in diameter. The cortex is small and is, along with the intertubular horn, arranged in a similar way to the structures seen in Indian rhinos.

In the middle zone the tubules are arranged almost in rows. They do not form groups but rows and can lie close nearby, with the cortex cells next to each other. The tubules have a round to oval shape and the width of the marrow ranges around 75 µm. The cortex extends to the sides up to 225 µm. Apically as well as towards the palmar/plantar side it is up to 130 µm broad. The tubules of the outer zone vary in size and have an elongated shape. The marrow ranges in size around 50 - 175 µm x 10 – 30 µm. The sole and the pad structures resemble those of Indian rhinos. The transitional area between the sole and the pad shows also comparable features.

4.11.2. Histopathology

Histopathological alterations were mainly found in the pad. Horizontal cracks are located between intertubular cells. These cracks do not occur as frequently as it was observed in the pad of Indian rhinos. They do not reach the Str. granulosum and are only found within the Str. corneum. The further palmar/plantar the sample was taken the less cracks became visible. The coronary horn appears in some samples very thin, with the outer zone completely and the inner zone partly missing.

5. Discussion

Why do Indian rhinos have foot problems in zoological gardens?
This main question of the study will be discussed in the following section. First, I will recall the stages of development in order to answer the questions how and why foot problems (FP) in Indian rhinos arise. The findings from the wild Indian rhinos will explain, how healthy feet can be expected to look like. With the additional help of the histological findings, I will support the thesis that the Indian rhinoceros is naturally a ‚sole-walker'. This means that it uses to a high degree the sole and the bearing border of its digits for bearing weight. Furthermore, I will compare the pathological findings with FP of domestic and other captive species and will give recommendations concerning husbandry conditions, treatment schemes, and preventive medicine.

5.1. Stages of development

Primary causes

Wild animals do not have this problem, whereas captive animals are severely affected. 85 % of the males and 50 % of the females (young animals are not included) in European collections have these cracks. I regarded the animals, which I did not include in the study (2 males and 1 female), as FP-free and included them in the above-mentioned numbers. Without them 100 % of the males and 53% of the females have foot problems.
The husbandry conditions play an important role in the occurrence of FP in Indian rhinos. Most zoos use for the inside flooring, for the pool, as well as for the outdoor enclosure generally abrasive materials, such as concrete, sand, gravel, marl, or compressed earth. When walking, the footing surface rasps over these materials and in the course of time the footpad becomes smooth and thin. The soles becomes flat, thin, even leveled, and will adjoin the pad at ground level. Most hooves have shortened hoof walls.
The only part, which is not rasped away in the course of time, is the weight-bearing border of the central hoof in the hind feet. This occurs out of several reasons. The animal puts physiologically the weight on the middle part of its foot. It does not drag the feet behind. The hind feet are generally placed underneath the abdomen, with an angle of almost 45° between the metatarsal bones – central hoof and the ground. The front feet in contrast run almost perpendicular to the body/ground. In the course of time the horn wall of the central hind hooves become longer and the pad and the side hooves thinner. As a consequence, a weight shift to the palmar/plantar and mid part of the footpad will take part. This leads to less pressure on the weight-bearing border of the central hoof, which will continue to grow. The horn walls of the central hooves in the front feet are physiologically shorter and the

angle to the ground wider than in the hind feet. Therefore, the front feet are evenly rasped on all structures, including the weight-bearing border.
In the course of time the whole footing surface will eventually become very thin and flat. The side hooves show further signs of alterations. When laying down or getting up the animal uses the support of the side hooves to find the grip to do so and presses the side hoof walls firmly onto the ground. While at rest, the animal moves the side hooves over the ground, especially when being in the water. These movements leave their marks on the horn wall, especially of the lateral hooves, as they become thin and thinner. The average width ranges around 7 cm; the thinnest sole measured only 2 cm. The horn wall becomes white. This is a sign that almost all pigmented horn of the coronary segment has been worn off. A further sign of wear is visible along the coronary band, which shows reddened skin and inflammation.
The horn structures become fragile and of inferior quality. The potential protective layer of all horn structures of the foot becomes vulnerable to any impact. Due to the chronic nature, the first pathological alterations are only visible in histological samples and eventually macroscopical alterations will become evident. Cracks will form within the weakened horn walls and in the apical part of the footpad, a highly sensible area. From the histological point of view the transitional area between the sole and pad is a 'locus of minor resistance', as two different structures are aligned next to each other. These structures are very sensitive and prone to any chronic trauma.
Captive husbandry conditions have led to a change in the foot anatomy in Indian rhinos and turned them into a 'pad-walker'.

5.2. Secondary causes

The natural high **weight** of the animals, as well as their rather small feet and the positioning of the legs and the feet, contribute all to the development of foot problems.
With regard to body size (1,6 - 1,9 m at shoulder height) and body weight (1,800 - 2,800 kg) the circumference of the feet (88 - 100 cm) appears rather small. The feet are partly turned outside, more weight is put on the medial part of the foot and contrary forces are more likely to alter the medial foot structures when walking. This explains why the cracks start to develop at the medial angle. It is comparable with the development of ulcers that appear frequently on the axial part of lateral claws in cattle. The outside positioning of the feet as well as the high weight renders this area especially vulnerable (Fessl, 1992). Under most zoological conditions these animals are feed high quality **food** the whole year round. It needs further evaluations in how far this species is fed the right food and the right amount. Basic knowledge concerning the digestibility of the food and the true energy intake for the Indian rhino are not available. According to Dierenfeld (1995) the average

intake of browse for Black and Sumatran rhinos ranges around 1 - 2 % of their body weight. Due to seasonal changes the availability of certain plants changes as well. The Indian rhinoceros consumes a variety of different plants (Laurie, 1978). Under captive conditions this species is fed with food of our market and supplemented with special formula pellets. In how far this diet supplies this species with all essential nutrients cannot be said. In order to do so, more research needs to be undertaken. All in all it can be stated, that many animals receive a diet that is not ‘burnt’ during the activities of the day, resulting in overweight animals.

The animals’ **behaviour** also seems to contribute to the development of FP. Males suffer much more from FP than females and the degree of severity is also higher in this gender. The age of onset ranges around the beginning of sexual maturity (6 – 8 years). It is likely that hormones play an important role in the behavioural change of males. They become more aggressive, very nervous, and exited when the female comes into oestrus (cycle length is 34 – 48 days, peak oestrus lasts 24 hr). Females can show also signs of nervousness and restlessness but this is not a ‘must’ and the older a female gets, the calmer is usually her behaviour. Males differ in this regard and when it comes to mating they forget all pain. As mating takes a long time (generally one day with several copulations, each lasts around 1 hour) and is a rather rough happening (chasing, lifting, and biting the female), most males will show a worsening of the cracks in the footpads afterwards. In addition, males tend to make sharp turns and twists on their hind feet. Through this way of ‘walking’ enormous contrary forces within the structures of the pad appear. The feet of zoo animals do not seem liable to withstand those forces in the course of time. Females are by nature usually calmer animals and the ‘action field’ is mainly concentrated on finding food, water, and a place to rest.

A further significant cause that plays a main role in the development of FP is the access to **water**. In the wild, this species spends up to 70 % of the day in the water. They do not only rest but also feed in water. It is likely that water protects the animal against heat and flies, smoothens the skin and horn structures, and renders them elastic. An additional factor is that all strain will be taken from the bones and the feet when resting and ‘floating’ in the water. A feature, known from the hippopotamus. If the animal has no access to water, skin and horn become eventually dry and brittle. Therefore, these structures are predisposed to alterations. In most zoological collections the access to water is limited to several hours of the day or night. The outside pools are often not accepted in the spring and fall unless the temperature of the water ranges around 18°C.

All above-mentioned factors participate to some extent in the formation of foot problems in Indian rhinos. Husbandry conditions, especially abrasive materials are the primary causes as it changes the anatomical structures of the foot and predispose the feet to further impacts.

5.3. The Indian rhinoceros: A 'Sole-Walker'

The evaluation of photos from wild animals showed clearly that wild Indian rhinos have different anatomic foot features than Indian rhinos in zoological gardens. All described characteristics (see section 4.4 and 4.5) allow the conclusion that the wild rhino is a 'sole-walker' and the captive animals have turned into a 'pad-walker' due to above-mentioned abrasions.

Wild rhinos have long horn walls and soles. The soles are concave and the rim of the sole, adjacent to the pad, is elevated. This is especially visible in the central hooves. The horn of the pad appears hard and thick. All these features are not present in captive rhinos. The histological and histopathological findings support this thesis. 18 hooves and 19 footpads of Indian rhinos, as well as 9 hooves and 3 footpads of Black rhinos were histologically examined. The hooves itself show features, which allow the assumption that they are specialized to bear enormous weight.

1. The wall segment shows the formation of primary, secondary, and tertiary leaflets. The additional formation of tertiary leaflets remains so far unique to the Indian rhinoceros and to some extent to the Black rhino, which shows less tertiary leaflets. The horse is the only domestic species, which developed secondary leaflets. These structures increase the surface of attachment of the dermis and epidermis and 'aid in the dissipation of concussion and the movement of blood' (Stashak, 1987). It is thought that the horse needs this special feature due to the massive strain on the feet during different locomotion phases. The rhinos surely do not jump or run continuously as high, fast, and long on hard ground as horses but the formation of tertiary leaflets increases the attachment surface in these relatively small hooves. In addition, it helps to cope with the weight (which is up to 5 times higher in rhinos than in horses) and to distribute it. The length of the primary leaflets in Indian rhinos equals almost the length of the leaflets in equines. Differences exist in quantity, thickness, and organisation of the secondary leaflets. Indian rhinos have less primary leaflets and much thicker horny leaflets than horses. The thickness increases towards the weight-bearing border. In addition, the secondary leaflets are thicker and vary much more in size/length than observed in horses. These distinct features are likely to stand in close correlation with the absorption and distribution of the massive weight the rhinos have to bear on their relatively small feet.

2. The coronary horn is pigmented and of very hard consistency. It is the main supportive structure of the horn wall, as it is in other domestic animals, especially the horse (Bolliger, 1991).

3. A unique structure is the formation of a special elevated horn rim in the central sole adjacent to the pad. This rim is made up of groups of horn tubules. Those groups can contain up to eight tubules of different size, which build together one round structure. These round ‘spots’ are macroscopically well visible and are only found for 1,5 - 2 cm along the palmar/plantar border of the central sole. These structures can be found along the axial side of the lateral and medial soles but do not show as clearly as noticed in the central. Additionally, this horn is pigmented and of very hard consistency. Together with the weight-bearing border of the horn wall, those two structures surround the sole completely. On the feet of wild animals this rim is clearly visible as an elevated structure. This special feature is meant to endure pressure in contrast to the much softer and fragile horn of the footpad. By being higher in size, this hard structure protects the fragile pad and will deflect the strain of the weight away, especially from the apical part of the footpad towards the sole.
4. The footpad is made up of soft and elastic horn. In zoo animals the maximum thickness of the protective horn layer is 1 cm. Adjacent to the palmar/plantar skin, the horn is less than 0,2 cm thick. Wild Indian rhinos were not examined but their footpads appear all in all stronger and harder. The pad in wild Indian rhinos attaches to the sole **not** at ground level, but further proximal on the sole. This leaves the impression of a sulcus or fold formation between the sole and the footpad. In the lateral and medial hooves this sulcus allows the foot to expand to the sides during locomotion phases. In the central hoof the sulcus protects the cranial part of the pad from bearing weight. Underneath the Str. corneum lies the very sensible and highly vascularized corium. Histology shows that neither the corium nor the epidermal structures of the footpad are made to bear too much weight, pressure, or contrary forces. The horn tubules are thinner than in the sole, the intertubular horn consists of small horn cells with hardly visible cell membranes. The membranes and the membrane coating material are thought to be mainly responsible for the cohesive strength within the entire horn (Budras and Bragulla, 1991). The horn of the footpad is of inferior quality when compared to the structures found in the sole. Size, length, and cohesion of the cells appear inferior compared to the sole structures. The small horizontal cracks found in each sample, were always located between cells. Comparative evaluations in normal and affected hooves in horses (Leu, 1987) have shown that cracks often start to occur within the intercellular gap. This is related to the fact that the membrane coating material (MCM) is held to a great part responsible for the quality of the horn. The thicker the intercellular membrane appears, the better the quantitative distribution of the MCM and therefore the quality of the horn itself (Budras et al., 1991). In the footpad of Indian rhinos the MCM appears weak and less in quantity than it is seen in the sole. The footpad is affected by constant pressure when walking and turning. This results consequently in fissures and later on in cracks. It was inter-

esting to notice that the horn samples from all footpads have showed horizontal cracks up to and partly within the Str. granulosum. These cracks were found in feet, which appeared clinically healthy and were found in apical, middle, and palmar/plantar sections. These horizontal cracks are the beginning of a constant irritation to the horn structure and lead possibly to further alterations in the footpad. To some extent these cracks were visible in the footpad of Black rhinos. They did not occur as often and did not reach as far up into the Str. granulosum as it was observed in the Indian rhino.

Table X: Comparison of microscopic structures of the hoof between the Indian rhinoceros and the horse

	Indian rhino	Horses
Nr. of primary leaflets per hoof	200 - 250✶	600
Lenght of secondary leaflets	max. 5.6 mm	max. 4 mm
Nr. of secondary leaflets per primary leaflet	60 - 80	100 - 200
Width of horny lealflets:		
middle part of horn wall	1.4 mm	1.5 mm
distal part of horn wall	5 - 6 mm	3 mm
Thickness of the coronary horn	0.8 - 1.8 cm	1 - 1.2 cm

✶ Central hooves tend to have more primary leaflets than side hooves.

In 1895 Eber has given already a description of the anatomical structures of a rhinoceros foot. He writes about Perissodactyla feet but does not mention the species described. His results are similar with regard to the location and description of the three hooves in a rhinoceros foot. Differences exist with regard to measurements. Therefore, I suspect that he wrote about the Black rhinoceros, which has smaller feet than the Indian rhinoceros. Interesting to notice is that Eber mentions specifically the occurrence of a deep sulcus between the central sole and the adjacent pad. It is likely that he evaluated the feet of an animal, which has not been for long under captive conditions. Due to his information as well as due to the histological evaluations and the histopathological findings, the question arises whether the Black rhinoceros has naturally also different horn structures than captive animals. As they do not have the same foot problems like Indian rhinos one can suggest that they have generally ‘tougher’ feet than Indian rhinos, an aspect that can correlate with the habitat they naturally live in. The question remains open whether the Black rhinoceros is in the wild also a ‘sole-walker’ or not.

5.4. Comparison of foot problems in Indian rhinos with other species

Any status quo of the feet, which does not resemble its natural appearance renders a foot, hoof, claw, and nail vulnerable to chronic and negative influences. Husbandry conditions play a major role in the occurrence of most FP in domestic as well as in zoo animals. Unsanitary conditions, abrasions due to hard flooring, inadequate width of gaps in slatted floors, or not enough exercise are common problems in domestic (Geyer and Tagwerker, 1986; Zenker, 1991; Fluri, 1998; Wehrle, 1998) as well as in zoo animals (Fowler, 1993; Göltenboth, 1995). In the course of time they will impair the health of the feet and render them vulnerable to further impacts.

The location of these specific cracks between the sole and pad in Indian rhinos allows a comparison with foot problems in pigs (Geyer and Tagwerker, 1986) and cattle (Mülling et al., 1994). Those animals show under certain husbandry conditions similar alterations on their feet. Like Indian rhinos, these species have 'loci of minor resistance', which render the feet vulnerable to chronic trauma. In pigs this zone lies between the wall-heel border, as well as the sole-heel border. In these areas, horn types of different structure and hardness are adjoined (Geyer and Tagwerker, 1986). In cattle a predisposed area lies between the hard part of the pad and the softer middle part of the pad (Rusterholz, 1920). Once cracks arise, granulation tissue and horn of inferior quality will develop. The cracks become infected and due to the high weight and the location of the lesions, the regenerated structures will shatter immediately. The cracks become chronic and even more difficult to treat. In most cases domestic animals (Geyer and Tagwerker, 1986; Wehrle, 1998) will be slaughtered. Euthanasia had to be considered in several Indian rhinos (Pagan pers. com., 1998).

Horses (Pollitt, 1999), cattle (Fessl, 1992), elephants (Fowler, 1993) as well as wild hoofed animals in zoological gardens (Göltenboth, 1995) can show horizontal and vertical cracks. Nutrition, genetic, environmental, and/or traumatic factors are likely to favour their development (Fowler, 1993). In the literature cited here, it has not been mentioned that abraded horn walls seem to stand in close causal correlation with the appearance of horizontal and vertical cracks as well as with infections along the coronary band. Furthermore, there were no reports found that describe the enormous extent of horizontal cracks, which can run not only through the dorsal horn wall but can also continue into the structures of the sole.

The footpads in elephants (often called soles) as well as in camels (Göltenboth, 1995) are prone to develop pododermatitis if the horn has grown to such an extent that pockets developed within the horn. These pockets attract bacteria and will finally show signs of degeneration. In Indian rhinos the horn of the footpad is infected alongside the cracks in the pad. In the former, the reason of infection is due to not enough abrasion of the horn; in the latter too much abrasion has favoured the development of cracks.

Black rhinos do not show these specific cracks in zoological gardens like Indian rhinos. Due to the lack of data from wild rhinos and the relatively small sample size in this study it is not possible to describe the anatomical features in detail and to compare wild and captive animals. But from the histological evaluation it was interesting to see that the footpads in Black rhinos were also affected by horizontal cracks. These cracks did not occur as often in number and did not reach into the Str. granulosum as it was observed in Indian rhinos. Nevertheless, the occurrence of these minor defects allow the assumption that those alterations are pathological and serve as an indication that the horny part of the pad is irritated by constant pressure and other irritations. It is not possible to come to a full conclusion unless further investigations have been carried out.

5.5. Special features of the feet of Indian and Black rhinos

Besides above-mentioned macroscopic structures that are unique to the *Rhinocerotidae*, the Indian rhinoceros is so far the only known and investigated species, where wild animals have elevated soles, a protruding rim adjacent to the footpad, and a hard horn layer on the footing surface.
Both rhinoceros species have ducts of glands within the corial and epidermal structures of the footpads. The Indian rhinoceros has more ducts per cm^2 than the Black rhino and both have fewer ducts in the palmar/plantar part of the pad than in the apical section. These glands are thought to be associated with sweat distribution and possibly territorial markings. Similar ducts were found in the footpads of dogs and cats (Krölling and Grau, 1960). They were not found in the examined footpads of the elephants.

5.6. Recommendation to husbandry, treatment, and prevention

In order to keep animals that show the same natural foot structures as wild animals, some husbandry conditions should be thought over and changed in the future.

5.6.1. Husbandry conditions

Indian rhinos have been kept in zoological gardens for almost one century now. They have been exhibited along with White and Black rhinos. Due to the rather cold climate during the European wintertime, most zoos have to keep these species indoors for at least 4 - 6 months. Occasional access to the outside enclosure is possible, depending on the weather. This means that the majority is kept indoors for a rather long period of time.
Most zoological collections supply the Indian rhinoceros with a pond and/or wallow outside and some with a pool inside. Apart from this, they are generally kept under the same con-

ditions as the African species: The ground of the outside enclosure consists of sand, gravel, marl, or highly compressed earth. Only a few provide grass.

The indoor facilities have for the most parts concrete floors. Some zoos started to install rubber flooring in the indoor enclosures. The flooring of the pools inside is either made of concrete or tiles.

In the wild, Indian rhinos live in and around riverine areas. They inhabit swampy grassland and woodland but are more or less always found in the proximity of water. During the day they spend up to 70 % of the time in the water, either feeding or resting (Laurie, 1978). Certain housing conditions have contributed in the past to the occurrence of FP. Changes need to be considered if the aim is to allow horn structures of the feet to grow naturally and to look like feet of wild rhinos.

The following section includes suggestions to improve some husbandry conditions:

1. The flooring should be made of soft and non-abrasive material. For the outdoor enclosure this can be wood chips, loam/mud, earth (non-compressed), and/or grass. Generally all material can be used, which is elastic and non-abrasive. Despite the fact that the European climate will render each ‘earth enclosure’ into a complete mud wallow during the rainy season, considerations need to be given to the fact that it is almost imperative not to use any abrasive material where the animal spends most of its time. A good drainage system can help to keep this problem under control. Feeding places are not considered as areas of ‘constant use’.
2. The floor and walls of the pool as well as the floor of the indoor housing facility need to be covered with elastic, non-abrasive material. Some zoos recently started to use a special rubber material. At the moment a special material, provided by Relatex Company[6] is tested. The material is made up of a primary fluid rubber material that is poured onto a previously prepared floor or wall and will harden within the next days. The thickness of the rubber can vary and depends on the way the space is used, how the animal foots and on which part of the foot the main weight will rest. First thoughts with regard to the Indian rhino indicate that the thickness of the material should be at least 2,5 cm. This proves very essential if the indoor facilities are rather small. The material has the following advantages over tartan flooring and rubber mats:

a. It can be poured onto a prepared area. This allows the material to fill the smallest gaps and increases the adhesion of the material with the ground.

b. This material has proved non-abrasive and very durable for many other different zoo and domestic species. In how far it will prove valuable for the Indian rhino cannot be said yet. Only in the combination with an improved outdoor enclosure future statements are possible in how far the feet show less signs of abrasions

6 for further information: www.relatex.de

than in prior times. No dirt or moisture can spread underneath the material due to the tight attachment with the floor. It is easy to clean and maintain, even with high pressure.

c. The material is elastic and allows the weight to spread. The height can be adjusted, which is an advantage against any other material.

d. It is easily repairable.

3. Every indoor housing facility should provide more room than the standard 25 m^2 per animal, especially if animals are kept indoors for a longer period of time. In addition, every indoor facility needs to be equipped with a pool. In the wild, these animals spend a long time per day within the water. This improves not only the health status of the skin but is also a way to relief the weight from the feet and bones, as it is known from the hippopotamus. Access should be possible at most times during the day/night.

4. Out of just mentioned reasons I recommend a pool and a wallow for the outdoor enclosure as well.

5.6.2. Treatment schemes: past and future

Previous treatment schemes included cutting and rasping of the horn wall, soles, and horn of the pad. This should be avoided as the overall aim is to have animals with natural long soles and hard pads.

If the weight-bearing border is already overgrown, this structure needs to be shortened. It is imperative not to flatten the whole sole completely and not to cut any horn from the sole surface apart from the overgrown weight-bearing border. Before shortening the horn wall, the different angles of the hoof to the ground in hind and front feet should be considered. The horny part of the pad should be left alone unless deep cracks develop. Those cracks need debridement and cleaning. In many cases, this is only possible under sedation. Any painful operation should only be carried out under sedation and the anatomical structures need to be considered prior to any operation. Photo 2 (page 35) shows the structures within the foot and demonstrates how thin and fragile some of them are.

Those animals, which have already foot problems, do need aggressive treatment. Apart from the fact that the wounds need cleaning and debriding, the soles should be elevated by means of an artificial support. For this purpose different polymer material with similar properties as the hoof could be useful. An elevated sole will ‘copy’ the natural state of the sole. This will enable the wounds to close in the course of time as less pressure is put on the apical part of the pad. This treatment scheme needs continuous repetition before a success will be seen. The application of artificial blocks on only one occasion or on only one sole does not prove successful and must be avoided. As most animals do not tolerate this procedure, they need either to be trained to do so or will need tranquilisation in some sort of matter. All other treatment schemes have been very unsuccessful and did not lead in a single case to a complete healing. Anaesthesia has proven safe in Indian rhinoceroses on several occasions. Atkinson (2001) sedated a male Indian rhino on 25 occasions within a 58 months period. Despite aggressive treatment the healing success is still not 100%.

The healing process is better in the summer time and seems to be associated with the fact that the animals spend more time outside and in the water. Animals with minor problems might overcome their problems by changing the husbandry conditions.

In the past, cracks within the horn wall were dealt with in a similar way as known from the horse. Most horizontal cracks will grow out if the causing agent is stopped.

Vertical cracks that start from the ground/weight-bearing border can be ‘stopped’ to extent proximally by rasping a horizontal rim above the utmost proximal edge of the crack. Those, which start from the coronary band and are associated with highly abraded horn walls, are difficult to treat. The danger of these pathological changes lies in the proximity of the corium, a highly sensible structure. New, healthy horn can only be produced if the corium and the Str. germinativum of the epidermis of the coronary band are not impaired.

In many animals vertical cracks are a common finding for years and will not grow out. In how far these cracks impair the animal's health is not know. The only cure for severely affected animals lies in the provision of soft and non-abrasive ground material in order to stop further abrasions and traumatic impacts on the hoof wall.
Ulcers and fistules need proper cleaning and debriding. Those lesions tend to heal well if not neglected.

5.6.3. Prevention

The aim of preventive medicine is to have healthy animals with no abrasions or cracks in the horn wall and footpad and with a foot structure that resembles those of wild animals. Any zoo that considers keeping this species in the future should give serious thoughts to the husbandry conditions. Soft ground, constant access to water, and a larger indoor facility are prime recommendations. For detailed information concerning construction, management, veterinary care, etc., individual husbandry guidelines for this species are in the process of writing and will be available at Basel Zoo.
Some other aspects need to be considered:
Poor supplementation with different feedstuffs especially zinc, sulphur or sulphur-containing amino acids as well as poor biotin supply can result in the production of a poor hoof horn quality. It has also to be considered that a sufficient blood supply of the corium, which nourishes the epidermis, is present and not diminished in some areas of high pressure (Koller, 1998; Lischer et al., 2000).
Supplementation with biotin is thought to have a therapeutic effect on the improvement on the quality of the horn. This has been found out for pigs (Geyer, 1986), horses (Josseck, 1991; Zenker, 1991; Schmitt, 1998), and cattle (Schmid, 1995; Koller, 1998). In how far biotin effects the horn quality in Indian rhinos could not be evaluated. It is likely to have a positive affect on the horn quality and to strengthen the horn structure. Used in preventive medicine biotin can help to maintain a healthy foot structure under improved husbandry conditions. It cannot solve the problems arising from environmental factors. The dosages ranged in different zoos around 100 mg per animal, per day. Horses received a dosage of 20 mg per day and an improvement of the horn quality of the white line took part after 19 months (Zenker, 1991).
A further aspect, which needs to be considered, is a possible genetic predisposition to poor quality horn, as it has been observed in Lipizzaner horses (Zenker, 1991). In most horses the coronary horn showed alterations already near the germinative layer of the epidermis, the location, where new horn is produced.
These findings gave rise to the assumption that they are not primarily associated with husbandry problems but due to a genetic default in producing good quality horn from the

beginning. This thesis cannot be transferred to the Indian rhino as the pathological changes in the coronary horn occurred mainly in the last third of the horn wall. After Zenker (1991), pathological findings in the more distal area were associated predominantly with husbandry conditions. Therefore, it seems that in Indian rhinos the horn quality is primarily impaired by husbandry conditions. An evaluation of the family tree (von Houwald and Flach, 1998) has shown that most animals with foot problems are related to each other. This is primarily due to the small breeding stock in Europe and the difficulties in exchanging animals from different continents for breeding purposes. Basel Zoo has been the most successful breeding station within Europe and most animals are somehow related to the founders previously kept in this zoo. From the known data it is difficult to assess whether foot problems just appear to have a genetic predisposition (one is tempted to see an inherited predisposition due to the small captive populations of only 136 animals) or if the horn quality is truly affected by a genetic factor.

5.7. Conclusion

The study shows that Indian rhinos are confronted with severe foot problems in captive collections. A causal correlation between husbandry and pathological changes is found due to the comparative, histopathological investigation with FP in domestic animals, as well as due to the structural comparison of the feet of 32 zoo animals with 10 wild rhinos. Due to this study, an anatomical gain in knowledge concerning the basic foot structures in this species has helped to enlighten some of the pathological findings and supports the thesis that the Indian rhinoceros is naturally a 'sole-walker'.

Primary causes for the occurrence of FP are hard floors, which lead to abrasions on the horn walls, the soles, and the surface of the footpad. In the course of time, pathological alterations will appear within the horn walls and on specifically predisposed areas on the footpad.

Wild Indian rhinos do not seem to show foot problems of this kind. The anatomical features of the horn structures of their feet look different, compared to zoo animals. The anatomical structures of their feet allow the conclusion that they are naturally 'sole-walkers'. Under captive conditions the animals turned into 'pad-walkers'.

The conclusion of this study is that zoo animals are kept under inadequate husbandry conditions that have led to the development of lesions on the footpad and horn walls.

The chronic lesions, especially those seen in the footpad do not show signs of complete regeneration, as most regenerated horn is of functional inferior quality. This inferior quality cannot withstand additional forces. As a consequence, these cracks will enlarge and granulation tissue is increasingly produced. This vicious circle can only be interrupted by means of a correct therapy and the simultaneous changing of husbandry conditions. In order to maintain healthy foot and skin structures, the Indian rhinoceros needs a habitat where the feet do not wear and that supplies them with enough water to keep skin and horn structures elastic. Hard material is highly abrasive and should be replaced by soft, elastic flooring. In addition they should have constant access to water.

The aim of the future is to keep Indian rhinos whose feet are healthy and resemble in structures those of wild animals.

All the above-mentioned aspects are recommendations. They base on histological and comparative anatomical results of 32 captive and 10 wild animals.

6. Summary

Foot problems are a common finding in Indian rhinos in zoological gardens. Causes and prevention were up to now not scientifically examined. This study was set up to evaluate the occurrence and causes as well as the basic anatomical knowledge of the feet structures from zoo and wild animals. For this purpose 32 (13 males and 19 females) of 35 (15 / 20) Indian rhinos, living in 11 European zoos, were examined. In addition, a detailed anatomical study was performed on 6 feet of 2 deceased Indian rhinos. Samples of 18 hooves and 19 foot pads from 10 adult zoo animals were histologically studied. These results were compared with the findings of macroscopic foot structures from 10 wild Nepalese animals.

The results show that all breeding bulls (11) as well as 50% of the adult females suffer from chronic foot problems. These problems show as cracks behind the central sole and the adjacent pad. Histologically, this area is made up of two different structures. The horn of the sole is hard and consists of long, thick, and almost straight running horn tubules. The adjacent soft pad is made up of small, thin und undulating horn tubules. Wild animals do not seem to be affected by these pathological alterations. Their pad appears hard and thick and the soles are long and concave. The apical part of the pad does not seem to carry much weight. Due to hard and abrasive flooring material in indoor and outdoor enclosures, most zoo animals have thin pads and short and flat soles. They foot mainly on the pad. Chronic strain on this highly sensible and fragile area will lead to pathological alterations.

To prevent foot problems husbandry aspects need to be changed with emphasis on the provision of soft and non-abrasive flooring material. It is likely that less pathological problems will occur if the feet have a natural shape and if the weight is mainly carried by weight-bearing border and the soles.

The aim of the study was to give a detailed description of the anatomy of Indian rhinoceros feet, to enlighten the courses and to give recommendation how to prevent the occurrence of foot problems in Indian rhinos in zoological gardens.

7. Zusammenfassung

Fussprobleme stellen ein häufiges Problem bei Panzernashörnern in zoologischen Gärten dar. Ursachen und Prävention sind bis heute nicht erforscht worden. Die vorliegende Arbeit befasst sich mit dem Vorkommen und den Ursachen der Schäden, sowie der normalen Morphologie des Zehenendorgans von Panzernashörnern aus Zoos und der Wildbahn. Es wurden 32 (13 männl. und 19 weibl.) von insgesamt 35 (15/20) Tieren aus 11 europäischen Zoos untersucht. Des weiteren wurden anatomische Studien an 6 Füßen von 2 verstorbenen, sowie histologische Untersuchungen an 18 Hufen und 19 Zehenballen von insgesamt 10 adulten Panzernashörnern durchgeführt. Die Ergebnisse wurden mit den Befunden von 10 nepalesischen Wildtieren verglichen.

Die Resultate der Arbeit zeigen, dass alle untersuchten Zuchtbullen (11), sowie 50% der adulten weiblichen Tieren an chronischen Fussproblemen leiden, die sich als Risse zwischen der zentralen Zehe und dem anliegenden Ballen darstellen. Dieser Bereich ist anatomisch-histologisch gekennzeichnet durch hartes Sohlenhorn, welches aus langen, dicken und fast gerade verlaufenden Hornröhrchen besteht, sowie angrenzendem weichen Ballenhorn, dessen kleine und dünne Hornröhrchen stark geschlängelt verlaufen. Wildtiere scheinen von diesen pathologischen Veränderungen nicht betroffen. Ihr Ballenhorn erscheint fest und hart und die Sohlen sind lang und überragen das Ballenhorn. Der vordere Abschnitt des weichen Ballenhorns wird wenig belastet. Bedingt durch hartes, abrasives Material in Innen- und Außenanlagen der Gehege, sind die Ballen der meisten Zootiere dünn und die Sohlen flach und kurz. Die im Zoo gehaltenen Panzernashörner fussen vornehmlich auf dem Ballen. Chronische Belastungen dieser sensiblen Strukturen führen zu pathologischen Veränderungen.

Die Prävention dieser Veränderungen liegt in der Umgestaltung der Bodenbeläge der Innen- und Außenanlagen mit Schwerpunkt auf weichem und nicht-abrasivem Material. Es ist anzunehmen, dass es zu weniger pathologischen Veränderungen kommt, wenn die Tiere eine den Wildtieren entsprechende Hufform aufweisen und das Gewicht zum größten Teil vom Tragrand und vom Sohlenhorn übernommen wird.

Es war das Ziel dieser Studie, Grundlagen zur Morphologie des Zehenorganes beim Panzernashorn zu erarbeiten, sowie Ursachen und Vorschläge zur Prävention von Fussveränderungen für diese Tierart in zoologischen Gärten darzulegen.

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