Excessive iron storage in captive omnivores? The case of the coati (Nasua spp.)
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Abstract
We collated necropsy reports for 13 coatis (Nasua spp.), revealing four cases of moderate and six cases of massive iron deposition in liver tissue. This survey corroborates an earlier report that noted a high frequency of iron deposits in coatis at necropsy. A comparison of the reported natural diet of coatis and the usually fed captive diets revealed that whereas vertebrate products (dog/cat food, prey items) represent the staple diet items for captive individuals, free-ranging coatis only rarely consume vertebrate prey; their natural diet is dominated by wild fruits and invertebrates. This discrepancy should be reflected in high levels of readily available heme iron in captive diets, with little or no heme iron in the natural diets. Therefore, it could be hypothesized that the use of vertebrate products in animals not adapted to such high levels of readily available heme iron could be a cause for dietary iron overload. Further studies on the relevance of excessive iron storage in omnivores/insectivores, and their etiopathology, are indicated.

Key Words
iron storage disease, hemosiderosis, hemochromatosis, coati, insectivore, omnivore, heme iron, meat, shrew, tenrec

Introduction
Excessive iron deposits in the liver have been reported in a large number of captive wild animal species (Lowenstein and Munson 1999, Dorrestein

1 Division of Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Switzerland, mclauss@vetclinics.unizh.ch
2 Institute of Veterinary Pathology, Munich, Germany
3 Zoological Garden of Cologne, and Institute of Animal Science, University of Bonn, Germany
4 Zoological Garden Schwerin, Germany
5 Animal Park Sassnitz, Germany
6 Institute of Veterinary Pathology, Vetsuisse Faculty, University of Zurich, Switzerland
et al. 2000, Clauss et al. 2002, Wood and Clauss 2004). The clinical relevance of this problem is of little doubt in birds and bats (Crawshaw et al. 1995, Farina et al. 2005); in contrast, in other mammals, the clinical relevance of the problem as well as its incidence remains under debate: In lemurs, a series of publications suggest a very high incidence of iron storage disease in the captive population, including increased serum parameters indicative of iron absorption as compared to free-ranging individuals (Gonzalez et al. 1984, Benirschke et al. 1985, Spelman et al. 1989, Dutton et al. 2003, Wood et al. 2003, Hatt et al. 2004, Schwitzer et al. 2004, Junge and Louis 2005); in contrast, a recent publication that evaluated necropsies from one lemur facility reported only a very limited occurrence of the problem (Glenn et al. 2006). Reports on the coincidence of hemochromatosis and liver tumors in lemurs, however, possibly underline the clinical relevance of the problem (Brygoo et al. 1964, Benirschke et al. 1985, Sanchez et al. 2004). In captive tapirs, increased serum parameters indicative of iron absorption as compared to free-ranging individuals have been reported (Paglia et al. 2000), and a recent survey of captive tapir necropsies revealed a frequent occurrence of hemosiderosis (Bonar et al. 2006). In black rhinoceroses (Diceros bicornis), again, increased serum parameters indicative of iron absorption as compared to free-ranging individuals have been reported (Smith et al. 1995, Paglia and Dennis 1999), as well as high liver iron levels and liver iron storage disease at necropsy (Kock et al. 1992, Paglia and Dennis 1999, Dierenfeld et al. 2005); additionally, there has been explicit speculation on the involvement of the condition in several disease syndromes typical for the species (Paglia and Dennis 1999, Paglia and Radcliffe 2000, Paglia et al. 2001). Final conclusive evidence is lacking but would also be very hard to come by.

So far, iron storage disease in mammals has received most attention in herbivorous species. In birds, frugivorous but also insectivorous species are affected (Lowenstine and Munson 1999). Therefore, one could expect that also mammalian frugi-/insectivorous species (which would usually be called ‘omnivorous’) could be affected. Indeed, excessive iron storage is a recognized problem in callitrichid husbandry (Miller et al. 1997). In a survey on the presence of excessive iron deposition in the liver of zoo animals, we had noted several cases among the procyonids, in raccoons and coatis (Clauss et al. 2002). Therefore, when hemosiderosis/hemochromatosis was diagnosed in two adult coatis from a zoological collection, we attempted to collate more information on this condition in coatis. Additionally, we wanted to compare the feeding practice in coati husbandry with available data on the diet of these animals in the wild.

Necropsy survey

Necropsy reports, and if available, liver tissue of 13 coatis from five zoological institutions were investigated. The staining and semiquantitative scoring of absent (0), mild (+), moderate (++) and severe (+++) already used
Iron Storage in Coatis

In Clauss et al. (2002) was used again, as findings were generally reported in this method. The results are summarized in Table 1. Two juvenile animals did not have abnormal iron deposits in the liver. One adult individual had only a few, four adult individuals had moderate, and six adult individuals had massive iron deposits in their liver tissue. In five of the latter cases, the iron deposition had been considered the main pathological diagnosis. In one of these animals (No. 11), liver tissue was available for iron (Fe) analysis; the content was 2430 mg Fe/kg dry matter (as compared to normal values of 400–1200 mg/kg for dogs and pigs, Puls 1994). In one of these five cases, histological liver cell necrosis was explicitly mentioned. In three animals (No. 9, 10, 13), increased liver enzyme levels in ocular fluid had been interpreted as indicative of massive liver damage.

Table 1: Presence of iron in the liver, the reported diagnosis, and results from the evaluation of liver enzyme levels in the coati cases collated in this study (n.a.=not analysed)

<table>
<thead>
<tr>
<th>Animal</th>
<th>age</th>
<th>Fe in liver</th>
<th>Diagnosis</th>
<th>Liver enzymes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 years</td>
<td>-</td>
<td>Tuberculosis</td>
<td>n.a.</td>
</tr>
<tr>
<td>2</td>
<td>1.5 years</td>
<td>-</td>
<td>?</td>
<td>n.a.</td>
</tr>
<tr>
<td>3</td>
<td>adult</td>
<td>-</td>
<td>Discus prolapse</td>
<td>n.a.</td>
</tr>
<tr>
<td>4</td>
<td>adult</td>
<td>+</td>
<td>Gut tumor</td>
<td>n.a.</td>
</tr>
<tr>
<td>5</td>
<td>adult</td>
<td>++</td>
<td>?</td>
<td>n.a.</td>
</tr>
<tr>
<td>6</td>
<td>adult</td>
<td>++</td>
<td>Tuberculosis</td>
<td>n.a.</td>
</tr>
<tr>
<td>7</td>
<td>adult</td>
<td>++</td>
<td>Parasites</td>
<td>n.a.</td>
</tr>
<tr>
<td>8</td>
<td>adult</td>
<td>+++</td>
<td>Amyloidosis</td>
<td>n.a.</td>
</tr>
<tr>
<td>9</td>
<td>adult</td>
<td>+++</td>
<td>Hemosiderosis</td>
<td>massive damage</td>
</tr>
<tr>
<td>10</td>
<td>adult</td>
<td>+++</td>
<td>Hemosiderosis</td>
<td>massive damage</td>
</tr>
<tr>
<td>11</td>
<td>adult</td>
<td>+++</td>
<td>Hemosiderosis</td>
<td>n.a.</td>
</tr>
<tr>
<td>12</td>
<td>adult</td>
<td>+++</td>
<td>Hemosiderosis</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>adult</td>
<td>+++</td>
<td>Hemosiderosis</td>
<td>massive damage</td>
</tr>
</tbody>
</table>

The Natural Diet of Coatis

Coatis have been described as relying primarily on fruits and insects, supplementing their diet with millipedes, spiders, and gastropods. The consumption of vertebrates has been noted but not systematically quantified, and generally reported to be of little importance (Wallmo and Gallizioli 1954, Ingles 1957, Kaufmann 1962, Russell 1982, Bisbal 1986, Gompper 1996, Beisiegel 2001). A typical example of the over-emphasis that humans intuitively put on vertebrate prey is given by Wallmo and Gallizioli (1954), who report alleged raids of coatis on nests of birds, squirrels, and a poultry yard, but found only insects and wild fruits in the stomachs and faecal samples they examined themselves. Kaufmann (1962) quotes examples that
emphasize the coati’s strong liking for vertebrates and their readiness to accept them when they are easily accessible, but cautions that these should not be taken to mean that coatis normally concentrate on vertebrates; he reports that a wide variety of fruits is eaten, and that for short periods, a single species of fruit may be the staple diet item. The author summarizes other reports: “a number of other authors (Azara 1838, Cabrera and Yepes 1940, Gaumer 1917, Ingles 1957) stressed the importance of invertebrates and fruit in the coati’s diet, and the relatively small part usually played by vertebrates.” Smythe (1970) observed that when fruits are abundant, coatis are almost exclusively frugivorous. Russell (1982) states that “it may be safely assumed that vertebrates contribute only a small amount to the diet.” This author investigated 16 faecal samples, which consisted mostly of beetle fragments. In 50% there were spiders and millipedes. In 25%, there were ants, land crabs, and snail shell. He also notes that coatis eat a variety of fruits, which are not mentioned in connection with the faecal samples. 37% of the faecal samples investigated by Delibes et al. (1989) contained only fruit remains. No vertebrates were found in a total of 86 faecal samples of *Nasua narica* from Barro Colorado Island (Gompper 1996), whereas 25% of 130 faecal samples of *Nasua narica* from Chamela, Mexico, contained vertebrates (Valenzuela 1998); nevertheless, the coatis were found to be mainly frugivorous at both sites. Alves-Costa et al. (2004) analysed 226 faecal samples of *Nasua nasua* from southeastern Brazil. The results, calculated as the relative proportion of the various diet items, are summarized in Figure 1. The consumption of spiders and millipedes was positively correlated with rainfall, and the consumption of fruits was negatively correlated with the consumption of millipedes and insects. Vertebrates were ingested only occasionally.

**The diet of captive coatis**

Allen et al. (1996) state that the distinction between ‘facultative carnivores’ and ‘omnivores’, indicating whether animal prey is the major or just an incidental food item, is of little relevance for the feeding practice of these animals, as the diets fed to these animals in zoos are often quite similar – consisting of “commercial canned, frozen, or dry diets formulated for domestic dogs and cats”, supplemented with prey items. Recommendations from the internet for the feeding of pet coatis are similar: “a high quality cat or dog food should be fed. Small amounts of fruits can be used to supplement the diets.” (www.okagnet.com/coatiinfo1.html). The detailed daily diet of one of the adult coatis diagnosed with hemosiderosis in this study consisted of day chicks, chicken throats, canned dog food, rice and pasta, fruits, and mealworms as treats.

**Discussion**

In addition to the findings reported here, Lowenstine and Munson (1999) mention regular findings of excessive iron deposits in coatis at necropsy.
Thus, coatis could be considered among the species susceptible for excessive iron storage. The fact that juvenile animals might be not affected (see Table 1) agrees with the assumption of a diet-related problem, resulting from a chronic oversupplementation and accumulation.

Whether this problem represents a medical risk for the animals cannot be proven; however, in five cases the iron deposits were the major pathological finding. Reported blood values of captive coatis show a deviating pattern from the values normally found in domestic carnivores in terms of parameters indicative of liver damage (Table 2). Whether this is in correlation with excessive iron storage in the liver remains to be demonstrated. In particular, blood values of free-ranging coatis would be interesting in this respect, as well as a comparative evaluation of serum iron metabolites.

The discrepancy between the natural diet of coatis and the diet fed in captivity offers a ready explanation for a hypothesized susceptibility of captive coatis to iron storage disease. The vertebrate products used in captive diets are most likely to contain high levels of heme iron (from hemoglobin and myoglobin); in contrast, even if the natural diet of coatis might have comparable levels of iron as such, due to the accidental ingestion of soil

Figure 1: Frequency of food items occurring in 226 faecal samples of coatis (calculated from Alves-Costa et al. 2004).
when eating insects and molluscs, it will be basically free of heme iron. Heme iron is known to have a drastically higher availability in humans as compared to non-heme iron, and this availability is additionally enhanced by another, yet unknown meat factor (Lopez and Martos 2004). Therefore, the practice of feeding a diet with a high level of readily available iron to a species that is not evolutionarily adapted to such high levels of available iron could be hypothesized to be the underlying cause of frequent reports of iron storage disease in captive coatis.

If this consideration was correct, other species with a similar discrepancy between their natural and their captive diet would be expected to show a similar pattern. For example, Allen et al. (1996) state that “species, including shrews (Soricidae), tenrecs (Tenrecidae) and hedgehogs (Erinaceidae) can be maintained and bred on diets consisting of [..] canned meat-based products.” Lowenstine and Munson (1999) report frequent findings of excessive iron storage in house shrews “which suggests the possibility of a primary iron storage problem […] in the house shrew”. Thaller et al. (2005) reported a high frequency of hemosiderosis in captive tenreks from a colony that was fed on dog food. Other investigations on iron storage disease in captive insectivores/omnivores are lacking so far, to our knowledge. However, together with the cases observed in coatis, these reports suggest that the possibility of excessive iron storage in omnivores and insectivores should be further considered, and that the clinical relevance of the condition and its etiopathology should be further investigated. In particular, the option of feeding these species on similar diets as those used in frugivorous/insectivorous birds susceptible to iron overload should be evaluated.

Table 2: Serum enzyme levels for domestic dogs, cats and for coatis from the International Species Inventory System (2005).

<table>
<thead>
<tr>
<th>Enzyme (U/L)</th>
<th>Dog</th>
<th>Cat</th>
<th>Coati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatinine kinase</td>
<td>30–570</td>
<td>40–1800</td>
<td>470–5020</td>
</tr>
<tr>
<td>LDH</td>
<td>25–1200</td>
<td>49–630</td>
<td>570–1240</td>
</tr>
<tr>
<td>GGT</td>
<td>0–19</td>
<td>0–10</td>
<td>0–55</td>
</tr>
<tr>
<td>Alanine aminotransferase</td>
<td>13–180</td>
<td>17–180</td>
<td>90–780</td>
</tr>
<tr>
<td>Aspartate aminotransferase</td>
<td>13–90</td>
<td>11–80</td>
<td>150–170</td>
</tr>
</tbody>
</table>
References


hepatic iron concentrations and hepatic histopathology. J. Zoo Wildl. Med. 36: 212–221


