JZAR www.jzar.org JOURNAL OF ZOO AND AQUARIUM RESEARCH

JZAR Research article

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Retrospective analysis of elective health examinations as preventative medicine interventions at a zoological collection

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Keywords:
diagnostics, veterinary medicine, zoo animals

Article history:
Received: 6 September 2016
Accepted: 15 November 2016
Published online: 31 January 2017

Abstract
A retrospective survey of outcomes from elective health examinations on amphibians, reptiles, birds and mammals in a zoological collection was carried out in order to compare differences between taxa, type of health examination and age of animal, and to quantify whether the benefits of such interventions exceed potential welfare risks to the subjects. Outcomes of 1651 health examinations, including import, pre-export, first and routine health examinations, were recorded and analysed. At least one problem was found in 45.7% of health examinations, with subsequent action (such as treatment, follow-up or further diagnostics) required in just under half of those animals or 21.1% of health examinations overall. A problem was identified in 52.1% of import examinations as opposed to 32.5% of pre-export examinations, and in 52.2% of routine examinations, compared to 33.6% of first examinations. When analysed further by taxon, these differences were not significant for all taxa. In addition, only for mammals was there a significant difference between age groups, with problems significantly more likely to be identified as age increased. A complication occurred during 3% of total health examinations, with complications significantly more likely to have been caused in birds than in mammals and none at all identified in reptiles and amphibians. Almost 97% of the complications caused during bird health examinations were minor wounds resulting from capture for the procedure. Little has been published previously evaluating the effects of preventative medicine interventions on mortality, morbidity or welfare of zoo animals. This kind of information can be used to make evidence-based decisions on the necessity and frequency of elective health examinations in a particular collection.

Introduction

The role of the zoo veterinarian has evolved from a reactive approach, dealing primarily with injured or diseased animals, to a more proactive approach, where emphasis is placed on preventative medicine (Deem 2007). Preventative medicine is particularly important in zoos where treatment of disease can be logistically difficult and animals often do not show overt signs of illness (Miller 1999). The difficulty of detecting subtle changes means that animals are often presented at a late stage, when disease is advanced and difficult to treat successfully. Several sources give general preventative medicine guidelines for zoo animals, often with an emphasis on reducing the risk of disease transfer when animals are moved between institutions (Junge 1991; Miller 1996; BIAZA 2014). Species or taxon specific guidelines are also available (e.g. Bronson and Terio 2016). A medical intervention can be defined as an activity undertaken to prevent, diagnose, improve or stabilise a medical condition. Table 1 shows the most common preventative medicine interventions for zoo animals.

Although few would doubt the importance of quarantine and post mortem examinations, the need for routine elective health examinations is still controversial, perhaps more so in European zoos than in North American zoos. While some collections carry out frequent elective health examinations, others restrict themselves to importation or pre-export examinations. Other collections prefer a completely hands-off approach unless an animal is obviously sick.

Preventative medicine interventions such as elective health examinations take staff time and financial resources. Veterinary managers working within limited budgets have to allocate resources to ensure maximum overall benefit for the collection. In addition, veterinary examination of captive wild animals is less straightforward than with domestic animals. They are often stressed by handling and chemical restraint

Table 1. Preventative medicine interventions for zoo animals.

Quarantine and pre-import testing of newly acquired animals; pre-export testing
Faecal screening and/or regular anthelmintic treatment for gastrointestinal endoparasites
Treatment for ectoparasites
Vaccination
Regular health examinations, which might include a physical examination, blood sampling for biochemistry, haematology and specific disease testing, radiographs and faecal, rectal or cloacal culture
Neonatal and geriatric examinations
Post mortem examinations
Prophylactic preventative treatment, e.g. for malaria in penguins

may be needed for safe examination. The benefits of preventative medicine interventions must be balanced against the potential complications and risks, such as iatrogenic trauma, anaesthetic death or the physiological stress caused. Little has been published evaluating the effects of preventative medicine interventions on mortality, morbidity or welfare of zoo animals.

This study involved a retrospective survey of outcomes from elective health examinations in a zoological collection where comprehensive preventative medicine protocols, including importation, pre-export and regular health examinations, have been in place for over 15 years. The aim was to compare differences between taxa, type of health examination and age of animal and to attempt to quantify whether the benefits of such interventions exceed potential welfare risks to the subjects. Based on the assumption that preventative medicine protocols within the collection were likely to be more stringent than those of many, but not all, collections transferring animals into the collection, we hypothesised that import examinations would be more likely to identify a problem than pre-export examinations. We also expected that routine examinations would be more likely to identify a problem than first health examinations, when the animals were younger. Similarly we hypothesised that animals in the fourth quartile of their expected lifespan, designated “senile”, would have a higher chance of being identified with a health problem than relatively younger animals, designated “adult” and “juvenile”. We did not expect any differences in the prevalence of identified health problems between taxa.

Methods

Details of elective health examinations carried out on amphibians, reptiles, birds and mammals in a single zoological collection between 2009 and 2016 were obtained from computerised records (Zoological Information Management System, ZIMS; Species360, previously known as the International Species Information System, Eagan, Minnesota, USA) and retrospectively analysed. A health examination was defined as a hands-on physical examination by a zoo veterinarian of an animal that was either conscious or anaesthetised and where at least one diagnostic test was performed. Tests performed depended on species but included radiography, ultrasonography, blood sampling for biochemistry and haematology, electrocardiogram analysis, cytology (for example of the crop in birds), bacterial culture (usually rectal or cloacal) and specific tests for one or more infectious agents (Table 2). Results of faecal tests were excluded from analysis since these could be performed without the need for restraint and physical examination by a veterinarian. The following types of health examinations were included:

- Import health examinations, where an animal was new to the collection and the health examination was usually carried out during the animal’s 30 day quarantine period
- Pre-export health examinations, where an animal was given a health examination prior to transfer to another collection
- First health examinations, typically carried out at 6–12 months of age on animals that had been born in the collection. These often provided an opportunity to determine the sex, microchip the animal for the first time, assess its health and, in some cases surgically neuter the animal.
- Routine health examinations, normally carried out at 1–5 year intervals depending on species and including pre-hibernation examinations.

Several mammals, mainly primates, were given routine examinations specifically to monitor existing dental disease. These examinations were excluded from analysis. Where the age of an animal was known, it was assigned to the relevant quartile of expected lifespan in captivity for that species. Expected lifespans for 88 species were calculated based on the age reached by 80% of animals (both sexes averaged) according to source data in European Association of Zoos and Aquaria (EAZA) or international studbooks from 1980 onwards. For statistical analysis, animals in the second and third quartiles were grouped together and labelled as “adult”. Animals in the first and fourth quartiles were labelled as “juvenile” and “senile” respectively.

Clinical notes were examined and outcomes recorded and categorised for each health examination. Potential outcomes included:

1. A significant abnormal finding on physical examination; this could include a specific diagnosis such as pododermatitis or dental disease, or a non-specific finding such as poor body condition or abnormal coelomic swelling. Abnormalities considered minor and inconsequential, such as missing nails, were excluded, as were pre-existing medical

Table 2. Infectious agents (diseases) tested for.

Taxon	Infectious agent
Amphibians	*Batrachochytrium dendrobatidis*
Reptiles	Adenovirus, arenavirus (inclusion body disease), *Campylobacter* spp, chelonian herpesvirus, *Mycoplasma* spp, ophidian paramyxovirus, *Salmonella* spp.
Birds	*Aspergillus* spp., *Atoxoplasma* spp., avian influenza virus, *Campylobacter* spp., *Chlamydia psittaci*, Marek’s disease herpesvirus, paramyxovirus (Newcastles disease), pigeon circovirus, *Plasmodium* spp., polyoma virus, psittacine circovirus (beak and feather disease), *Salmonella* spp.
Mammals	Bluetongue virus, *Bordetella* spp., *Campylobacter* spp., *Chlamydia felis*, distemper virus, Feline calicivirus, feline coronavirus, feline herpesvirus, feline immunodeficiency virus, feline leukaemia virus, *Giardia* spp., hepatitis A virus, hepatitis B virus, herpes B virus, *Leptospira* spp., *Mycobacterium* spp., ovine herpesvirus 2 (malignant catarrhal fever), *Salmonella* spp., simian foamy virus, simian immunodeficiency virus (SIV), smian T-cell leukaemia virus (STLV), *Toxoplasma gondii*

Table 3. Body condition scoring systems (ZIMS, Species 360).

Descriptor	Score out of 5	Score out of 9
Emaciated	1	1
Very underconditioned		2
Moderately underconditioned	2	3
Slightly underconditioned		4
Ideal condition	3	5
Slightly overconditioned		6
Moderately over-conditioned	4	7
Very overconditioned		8
Obese	5	9

conditions that had already been diagnosed, either on previous health examinations or noted by keepers. Body condition was usually recorded, either out of five or out of nine (Table 3). It was defined as abnormal and included only when scores of ≤ 2 or ≥4 out of five, or ≤3 or ≥7 out of nine were recorded.

2. A positive result on a diagnostic test for a specific infectious disease
3. A significantly abnormal finding on a diagnostic test which, again, could include either a specific diagnosis, such as spinal spondylosis noted on a radiograph, or a non-specific finding such as an enlarged liver on a radiograph, or an increased white cell count on haematology. Abnormal results from diagnostic tests, such as radiographs and blood results were recorded. They were identified as such and assessed by the veterinarian involved as significant or not, based on published reference ranges where available, previous results from the animal itself and clinical experience.
4. A complication or problem caused by the health examination procedure itself.
5. No significant findings or complications.

When one of the first four outcomes was identified, it was noted whether an action was subsequently required. These would include treatment or ongoing monitoring of a medical condition, husbandry changes, e.g. a diet review, or further diagnostics to investigate an identified abnormality.

Comparisons were made between findings in amphibians, reptiles, birds and mammals and also between age of the animal at time of health examination and type of health examination.

Statistical analysis

The analytical units were "problem identified on examination", "action required" and "complication caused by examination". All were binary. Comparisons between study groups were screened using the chi-square test. Where the minimum expected cell frequency assumption was not met, the Fisher–Freeman–Halton test was used instead of collapsing study groups (Conover 1980). Post-hoc pairwise comparisons were undertaken when the P value was smaller than 0.05. The distribution of age quartiles between taxa was non-parametrically compared to evaluate the fidelity of interpretation of data when ordered by taxon. The same was performed for the distribution of taxa between age groups. All statistical analyses were performed with Minitab or StatXact software. Statistical significance was assessed at a 95% confidence level (P<0.05) for all tests.

Results

1651 elective health examinations were recorded on 185 different species from one amphibian, three reptilian, 14 avian and 12 mammalian orders. An accurate age and expected lifespan was known in 1450 cases. Findings are presented in Tables 4–8.

At least one problem was found in 45.7% of elective health examinations, with subsequent action (such as treatment, follow-up or further diagnostics) required in just under half of those animals or 21.1% of health examinations overall (Table 4).

The chance of a problem being identified on health examination differed significantly between taxa (P=0.000). Post-hoc pairwise comparisons indicated that the proportion of animals with an identified health problem was significantly lower for amphibians in comparison to all other taxa (P<0.001). Additionally, the proportion of reptiles with health abnormalities was significantly lower than for birds (P=0.029) and mammals (P=0.001). There was no significant difference between mammals and birds.

When analysed for each age class separately, these trends were significant only for adult (P=0.000) and senile animals (P=0.000), with juvenile animals showing no difference in the prevalence of identified problems between taxa (P=0.248). The most common diagnosis made on avian health examinations was pododermatitis with 98 of 494 birds (19.8%) affected, whereas the most common diagnosis made on mammalian health examinations was dental disease with 112 of 679 mammals (16.5%) affected.

Table 5 shows the ten most common diagnoses per taxon where a specific problem was identified on health examination.

Table 4. Findings from analysis of 1651 elective health exams by taxon.

Taxon	Number of health exams	Problem identified (outcomes 1–3) n (%)	Action required n (% of problems)	Complication caused (outcome 4) n (%)
Mammals	679	341 (50.2%)	167(48.9%)	21 (3.1%)
Birds	494	234 (47.3%)	106 (45.3%)	29 (5.9%)
Reptiles	437	176 (40.2%)	74 (42%)	0
Amphibians	41	3 (7.3%)	2 (66.7%)	0
Total	1651	754 (45.7%)	349 (46.2%)	50 (3%)

Table 5. Most common diagnoses made on health examinations as a percentage of the total number of animals with an identified problem (n).

Diagnosis	Amphibians n=3	Reptiles n=176	Birds n=234	Mammals n=341
Beak abnormality		1.7%	3.0%	
Campylobacter spp. infection			2.1%	4.1%
Cardiac disease				3.5%
Dental disease				32.8%
Gastrointestinal foreign body		3.4%	2.1%	
Hepatic disease			3.8%	
Hypercholesterolaemia				3.5%
Lice			1.7%	
Musculoskeletal abnormality including old fractures, arthritis and spinal spondylosis		7.4%	5.6%	
Mycoplasma spp. infection		2.8%		
Nutritional secondary hyperparathyroidism	66.6%	4.5%		5.3%
Overweight	33.3%	2.8%		23.2%
Osteomyelitis		1.7%		
Pododermatitis			42%	2.3%
Poor body condition			3.8%	8.5%
Respiratory disease		2.8%	5.6%	3.5%
Salmonella spp. infection		32.0%		
Shell abnormality		2.3%		
Wounds		2.3%	4.7%	2.3%

The necessity of an action following a problem identified on health examination was not affected by taxon (P=0.421) or type of examination (P=0.708). However for reptiles only, it was affected by age, with problems identified in senile animals significantly more likely to warrant further action than those identified in juveniles or adults (P<0.002).

A complication occurred during 3% of all health examinations, with problems significantly more likely to have been caused in birds than in mammals (P=0.02) and none at all identified in reptiles and amphibians. However 28 of the 29 (96.6%) problems caused during bird health examinations were minor wounds to the carpal area, cere or beak, sustained during capture of the bird for transport to the veterinary clinic. Treatment to close the wound was only required in one of these cases. The only serious complication as a result of an avian health examination was tracheal stenosis in a scarlet macaw (*Ara macao*), which occurred secondary to tracheal intubation for anaesthesia (Figure 1c). This is a recognised complication of anaesthesia in birds (Sykes et al. 2013). It required emergency placement of an air sac tube as a life-saving measure and subsequent surgical resection of the affected section of trachea. In comparison, 12 of 21 (57.1%) problems caused during mammalian heath examinations were minor wounds or injuries that did not require treatment. However, a red-bellied lemur (*Eulemur rubriventer*) and a Javan langur (*Trachypithecus auratus*) sustained digit injuries requiring treatment in the crush cage used to restrain them. Three mammals died as a result of anaesthetic-related complications. A southern pudu (*Pudu puda*) died four days after anaesthesia from bronchopneumonia, caused by aspiration of rumen content under anaesthesia. An elderly ring-tailed lemur (*Lemur catta*) and a squirrel monkey (*Saimiri sciureus*) both died under anaesthesia. In the former, underlying pathology which contributed to the death was identified on post-mortem examination. No underlying cause was identified in the squirrel monkey.

The proportion of animals with identified problems differed significantly between examination types (P<0.001). Health problems were identified significantly more frequently on import examinations compared to pre-export examinations (Table 6) and also on routine examinations compared to first health examinations (Table 7). However, when analysed for each taxon separately, this was not the case for all of them. The trend for an increased number of problems identified on routine as opposed to first health examination, was significant only for mammals (P=0.000) and birds (P=0.000). The trend for an increased number of health problems identified at import as opposed to pre-export examinations was significant for birds (P=0.016) and reptiles (P=0.000), but not for mammals (P=0.653). The type of health examination did not affect the chance of a problem being identified in amphibians (P=1.000). It is worth noting that age distribution was not significantly different between import and pre-export examinations (P=0.541).

Problems were significantly less likely to be identified on health examinations carried out on juvenile (i.e. during the first quartile of an animal's expected lifespan) compared to adult and senile animals (i.e. the subsequent three quartiles) (P<0.001) (Table 8). However, no significant difference was seen in the proportion of animals with an identified problem between adult and senile animals (P=0.521). When broken down by taxon, however, the above trends held true only for birds (P=0.021). There was a significant difference between all age groups for mammals (P=0.000), with problems significantly more likely to be identified as age increased; juveniles < adults (P=0.000) < senile (P=0.004). Age did not appear to affect the chance of a problem being identified in reptiles (P=0.227). No data for amphibian age quartiles existed

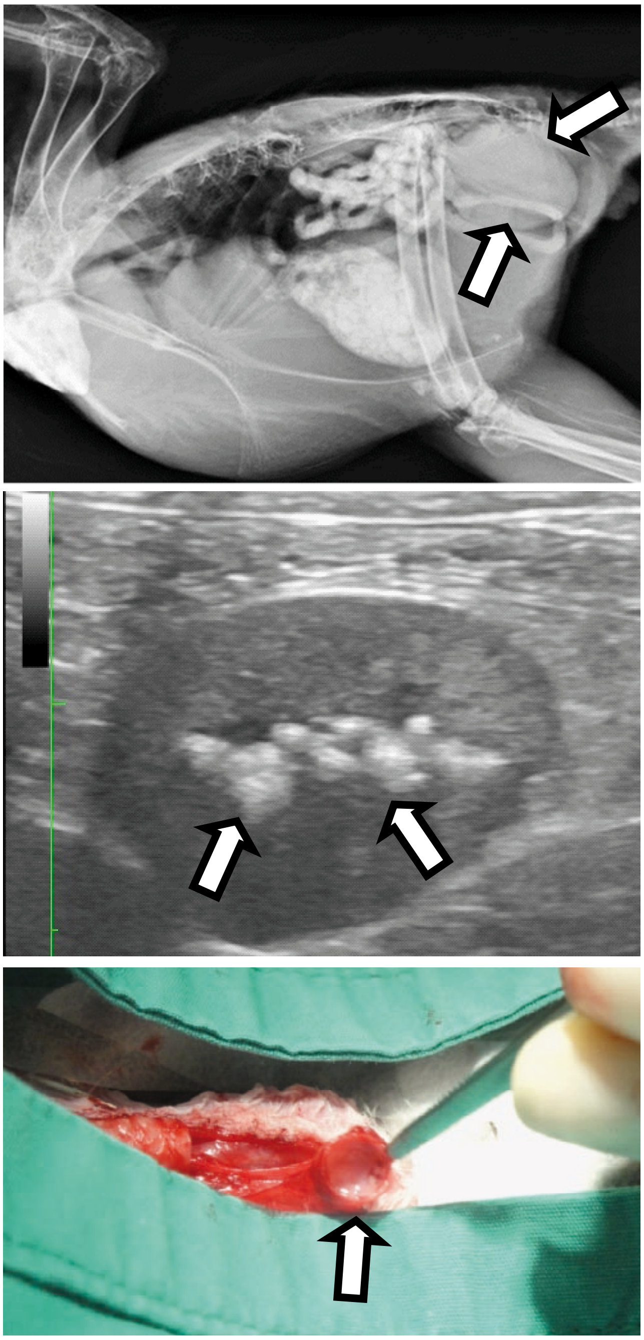

Figure 1. Conditions diagnosed during (top and middle) and caused by (bottom) elective health examinations. (Top) Barium contrast radiograph showing unshelled eggs in caudal coelom (white arrows) displacing intestines in satyr tragopan (*Tragopan satyra*) with chronic coelomitis. (Middle) Ultrasonographic image showing multiple calculi (white arrows) in the kidney of a gentle lemur (*Hapalemur alaotrensis*). (Bottom) Surgical resection of tracheal stenosis (white arrow) in a scarlet macaw.

and so this taxon was excluded from further analysis.

Discussion

Preventative medicine is considered a cornerstone of good practice in zoological medicine. There have been multiple studies evaluating vaccine efficacy in zoo animals (Harrenstien et al. 1997; Peters et al. 2004; Wolf et al. 2008; Jessup et al. 2009; Glavis et al. 2011; Connolly et al. 2015) and some assessing anthelmintic treatments or regimes (Young et al. 2000; Oossensd et al. 2006). However, attempts to objectively evaluate the benefits of elective health examinations are rare and from the authors' experience, protocols vary widely between collections. Some prospective health screening studies have been carried out on domestic dogs and cats and give data on prevalence of previously unrecognised problems or disorders (Banyard 1998; Davies 2012; Diez et al. 2015; Willems et al. 2016). For zoo animals, a few reports have been published discussing individual clinical cases, diagnosed on elective health examinations (Pye et al. 2010; Wynne et al. 2012; Perrin et al. 2013; Marrow et al. 2014) and more recently Marinkovich et al. (2016) and Wallace et al. (2016) have argued that a risk-based approach to pre-shipment testing and quarantine isolation and testing respectively, may reduce the necessity of testing and benefit animal welfare. They make the point that if incoming animals have detailed medical histories and come from collections with comprehensive post-mortem screening procedures, then diagnostic testing for at least some transmissible diseases may be obsolete, even if recommended by authorities such as taxon advisory groups.

We hypothesised that import examinations would be more likely to identify a problem than pre-export examinations and that routine examinations would be more likely to identify a problem than first health examinations, when the animals were younger. This was indeed the case, with a problem identified in 52.1% of import examinations, compared to 32.5% of export examinations and 52.2% of routine examinations, compared to 33.6% of first examinations. However, when analysed for each taxon separately, the difference between import and pre-export examinations was significant for birds and reptiles, but not for mammals. This could imply that in the collections from which the animals were transferred, standards of health care were generally higher for mammals than for birds and reptiles. Perhaps zoos are more likely to spend veterinary resources and time on mammals than on other taxa. For example, mammals may have been more likely to have had pre-export health checks to pick up any problems before transfer, than were birds or reptiles. This could be as a result of differences in animal health legislation or simply the fact that in general, mammals have a higher profile than other taxa and may be considered to have a higher commercial value.

It is expected that more health problems would be identified as animals increase in age, with geriatric problems such as arthritis

Table 6. Findings from analysis of 525 import and export health examinations.

		Problem identified (outcomes 1-3)				
Type of health exam	Number of health exams	All taxa n (%)	Mammals n (%)	Birds n (%)	Reptiles n (%)	Amphibians n (%)
Import	301	157 (52.1%)	52 (52.5%)	52 (52%)	52 (60.5%)	1 (6.3%)
Export	224	73 (32.5%)	26 (56.5%)	25 (33.8%)	21 (24.7%)	1 (5.3%)

Table 7. Findings from analysis of 1126 first and routine health examinations.

Type of health exam	Number of health exams	Problem identified (outcomes 1-3)				
		All taxa n (%)	Mammals n (%)	Birds n (%)	Reptiles n (%)	Amphibians n (%)
First check	345	116 (36.6%)	45 (48%)	57 (36.5%)	14 (50%)	0
Routine	781	408 (52.2%)	218 (58.5%)	100 (61%)	89 (37.4%)	1 (16.7%)

and neoplasia common in elderly zoo animals that live longer than their counterparts in the wild. In domestic pets, Banyard (1998) found the prevalence of intercurrent disease in 500 apparently healthy dogs and cats presented for vaccination to be age-related, although this trend was more pronounced in dogs than cats. Willems et al. (2016) reported an increased frequency of orthopaedic problems and subcutaneous masses in geriatric compared with senior dogs.

In this study, the trend for an increased number of problems identified on routine as opposed to first health examination, was significant only for mammals and birds. Only for mammals was there a significant difference between all age groups, with problems significantly more likely to be identified as age increased. The same pattern was seen as birds aged, but the differences between all age groups were not statistically significant. This was probably because the most commonly identified problem in birds was pododermatitis which, as a husbandry related condition, would not be expected to be age-related (Nielsen et al. 2012; Backues 2015; Wallace 2015).

These findings show that for mammals at least, and particularly where veterinary resources are limited, the frequency of health checks should increase as mammals age. Our data shows that, in particular, the benefit of first health examinations can be questioned. However, the rationale behind first health examinations, carried out on young animals, may differ from that of routine checks in older animals. First health examinations are often used as opportunities for confirming an animal's sex, implanting microchips, placing contraceptive implants or surgically neutering an animal that is not required for breeding. In addition, health examinations in young, healthy animals are often used as an opportunity to establish baseline reference ranges for blood parameters and radiographic measurements for that individual, which can prove valuable in diagnosing disease in the future. Subject-based reference values are more sensitive than population-based values for detecting pathological change in an individual (Walton 2012). Age did not appear to affect the chance of a problem being identified in reptiles.

Wynne et al.(2012), describing diagnosis and treatment of a fungal nasal granuloma in a koala (*Phascolarctos cinereus*), state that "although the majority of pre-shipment examinations produce negative or normal results, the exceptions prove the importance of the process". Amongst the 1651 health examinations analysed in this study were relatively few in which a potentially immediately life-threatening condition was diagnosed. Examples included pyometras in an Asiatic lioness (*Panthera leo persica*) and a mongoose lemur (*Eulemur mongoz*), adrenal carcinoma in a ferret (*Mustela putorius furo*), cardiomyopathy and heart failure in two Livingstone's fruit bats (*Pteropus livingstonii*), mandibular osteomyelitis in a Meller's chameleon (*Chamaeleo melleri*) and egg yolk coelomitis in a satyr tragopan (Figure 1). *Chlamydia psittaci* infection was a significant finding in a sun bittern (*Eurypyga helias*); although the bird was not clinically ill, the zoonotic potential and risk of spread to more susceptible avian species make this an important infection to identify and treat. Similarly, identifying the zoonotic condition salmonellosis in reptiles may be more important from a human health and safety point of view, than from the likelihood that it will cause disease in the reptile host (Gray 2011; Goupil et al. 2012; Lukac et al. 2015). Some might argue that all reptiles should be considered positive, negating the point of testing.

More significant from an overall animal welfare perspective is the identification of progressive conditions which, if caught early, can be prevented from getting worse. The most common findings in birds and mammals were pododermatitis and dental disease respectively. These are both progressive conditions that can vary in severity from mild disease that has minimal impact on welfare to potentially life-threatening conditions (van Foreest 1995; DeBowes 1998; Backues 2015; Wallace 2015). By identifying pododermatitis at an early stage, husbandry changes, such as the provision of more appropriate perches or substrates, can be implemented in order to reduce the risk of disease progression. Similarly, identifying and treating early periodontal disease and perhaps implementing a diet change can have a significant impact on an animal's future welfare and can help to prevent serious sequelae

Table 8. Findings from analysis of 1450 elective health examinations by age of animal.

Age group	Number of health exams	Problem identified (outcomes 1-3)			
		All taxa n (%)	Mammals n (%)	Birds n (%)	Reptiles n (%)
Juvenile	802	319 (39.7%)	121 (37%)	136 (43.3%)	62 (38.5%)
Adult	505	285 (56.4%)	156 (62.7%)	53 (60.2%)	76 (45.2%)
Senile	143	85 (59.4%)	57 (80.3%)	7 (70%)	21 (33.9%)
Total	1450				

such as endocarditis (Semedo-Lemsaddek 2016). Although many animals can be trained to walk onto weighing scales, visual assessment of body condition can be difficult in birds or mammals with thick coats; health examinations provide useful opportunities to thoroughly palpate and physically assess body condition. By identifying animals that are significantly under-conditioned or overweight but with no obvious underlying medical cause, diets can be adjusted or husbandry measures put in place to improve body condition before there is an impact on health and welfare. Other than changes in body condition, the most commonly identified indications of suboptimal nutrition in this study were hypercholesterolaemia in meerkats (*Suricata suricatta*), which can predispose to cholesterol granulomas (Sladky et al. 2000) and nutritional secondary hyperparathyroidism (NSHP) in several species. Most of the cases of NSHP were subclinical, with the condition identified on the basis of suboptimal bone density on radiographs or low ionized calcium levels on blood samples.

Unexpectedly, the chance of a problem being identified on health examination differed significantly between taxa, although not for juveniles. It was significantly lower for amphibians compared to all other taxa and was lower for reptiles than for birds and mammals. The reasons for this are unclear, although with amphibians at least, it probably relates to the relatively low number of amphibian health examinations included in the study, as well as the fact that the number of different diagnostic tests carried out on amphibians was usually lower than in other taxa (data not shown).

Overall, the results show that in 45.7% of elective health examinations, a problem was identified and in 21.1% of examinations, an identified problem required subsequent action. In mammals, a problem was identified in 50.2% of health examinations. This is very similar to the results of Banyard (1998), who reported the prevalence of intercurrent disease in apparently healthy domestic dogs and cats presented for routine vaccination. 52% were found to suffer from intercurrent disease and 3% from severe, debilitating disease. Davies (2012) identified at least one previously unrecognized problem in 80% of 45 geriatric domestic dogs after prospective health screening. In our study, dental disease and being overweight were the most common abnormal findings in mammals. This is similar to reports on domestic cats and dogs. Willems et al.(2016) identified severe calculus in 21% of apparently healthy senior and geriatric domestic dogs and found 39% to be overweight. Davies (2012) identified dental disease in 22% of geriatric dogs and found 24% to be overweight. Diez et al.(2015) found 34 and 36% of domestic dogs and cats respectively to be overweight and 31% of dogs and 21% of cats to have dental calculus.

The kind of data analysed in this study can be used to make evidence-based decisions on the necessity and frequency of elective health exams in a particular collection. It must be weighed against the risk of complications occurring during the procedure itself and will vary between taxa and even from species to species. Complication rates for many veterinary diagnostic procedures are not available, but as an example, in humans, the minor complication rate after diagnostic venepuncture is 12.3% and the serious complication rate is 3.4% (Galena 1992). The need for anaesthesia increases the risk for many zoo animals undergoing elective health examinations. In great apes, the risk of death under anaesthesia has been shown to increase with age, with animals aged over 30 showing a 30-fold increased risk of anaesthetic-related mortality, compared with adults aged from 10 to 30 years (Masters et al. 2007).

In this study a complication was recorded during 3% of total health examinations, with problems significantly more likely to have occurred in birds than in mammals and none at all identified in reptiles and amphibians. However, 96.6% of the complications arising from bird health examinations were minor wounds caused during capture for the procedure. In theory these could be prevented by training birds to enter small capture boxes or carriers to avoid chasing and netting them within larger enclosures, as is frequently done within this collection for small mammals, primates in particular. In practice though, this is likely to be impractical for many birds and the risk of iatrogenic trauma must be considered when planning avian health examinations. Another important consideration is that for some species of mammal in particular, individuals taken out of the group for veterinary or other procedures may prove difficult or impossible to reintegrate safely back into the group afterwards. An example of this in the study collection is the naked-mole rat (*Heterocephalus glaber*); no routine health examinations are carried out in this species for this reason (Wood and Mendez, no date).

There were several limitations to this study. One is that there is inevitably a degree of subjectivity on the part of the veterinarian when examining an animal and analysing diagnostic results. Several different veterinarians carried out the health examinations in this collection. Medicine is sometimes described as “as much an art as a science”. In particular in zoo animals, where the veterinarian may be dealing with hundreds of different species, diagnosis is not always easy. Consequently a finding considered significant by one veterinarian, such as poor body condition or an elevated white cell count, may not be considered as significant (and therefore recorded as such) by another. Pododermatitis in birds was always included as a significant finding, even if described as mild, or grade 1–2, due to the potentially serious consequences of progression and the fact that prevention, by improving substrate for example, is crucial given the difficulty of treating more advanced cases that have been allowed to progress. On the other hand, existing conditions were excluded as significant findings, even though ongoing monitoring of known chronic conditions such as arthritis, spinal spondylosis or cardiac disease are justifiable reasons for routine health examinations.

Acknowledgements

We thank Prof. Dr Marcus Clauss for insight into the statistical methods used.

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