Chapter 2
Bats: A Glimpse on Their Astonishing Morphology and Lifestyle

Volker Walldorf and Heinz Mehlhorn

Abstract Bats (*zool*. Chiroptera) are unique in the zoological group of Mammalia with respect to their morphology, their lifestyle, their capacity to fly and to orientate themselves during the darkest nights and by the fact that they succeeded in extending their biotopes over all continents except for Antarctica and the Northern arctic regions. Due to their nocturnal activity and their resting, respectively, sleeping during daytime at hidden places, information on this group remained scarce compared to other mammalians. Thus this chapter aims to throw some short glimpses on their morphology and on some other astonishing peculiarities.

Keywords Morphology • Megachiroptera • Microchiroptera • Pteropodidae • Echolocating • *Pteropus* • *Acerodon* • *Craseonycteris* • *Desmodus* • Monophyly • Mammalia • Wings • Flying foxes • Vectorship of viruses • *Pterosauria* • Patagium

2.1 Systematic Position

The order Chiroptera is subdivided into the Megachiroptera (Old world fruit bats, Flying foxes, "Megabats") and the Microchiroptera (Echolocating Bats, "Microbats") and is one of the most successful and abundant mammalian groups. The Megachiroptera are represented by only one family, the Pteropodidae, whereas the Microchiroptera comprise 16 families. Within the Pteropodidae, 42 genera and 166 species are described; 16 families of the Microchiroptera include 135 genera with 759 species (Simmons 2005; http://www.ucmp.berkeley.edu/mammal/eutheria/chirolh.html).

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System of Chiroptera	
Class	Mammalia
Subclass	Higher Mammalia (Eutheria)
Order	Chiroptera
1. Suborder	Microchiroptera
Family	Rhinopomatidae
	Natalidae
	Noctilionidae
	Rhinolophidae
	Molossoinidae
	+10 further families
2. Suborder	Megachiroptera (Old world fruit bats, flying foxes)
Family	Pteropodidae

Most of the Microchiroptera do not reach a weight of 30 g and are significantly smaller than the Megachiroptera. Nevertheless, there are some microbats exceeding the dimensions of the smallest Megabats. For example in Australia, the so-called ghost bat (*Macroderma gigas*) reaches a wing span of up to 60 cm and a weight of 200 g at the maximum. The largest bats can weigh up to 1,500 g and may reach a wingspan up to 1.7 m (Megachiroptera, genera *Pteropus* and *Acerodon*), whereas the smallest representative has a wingspan of only 15–17 cm and reaches a weight of 1.5–3 g (Microchiroptera, *Craseonycteris thonglongyai*) (Westheide and Rieger 2010).

The ancestors of the Pteropodidae had apparently been capable of echolocating, too. But this ability was lost in most members of this family during evolution. Simultaneously their efficiency in night vision was improved, as it becomes obvious in formation of bigger eyes compared to those of the majority of the Microchiroptera (Westheide and Rieger 2010).

The monophyly of the group has been doubted and it was supposed that Megachiroptera and Microchiroptera might have developed independently from different ancestors (Jones and Genoways 1970; Pettigrew et al. 1989). This would as well imply the convergent evolution of the active flight as other similarities within the two groups. However, the results of numerous studies now strongly support the monophyly of the members of the order Chiroptera (for detailed bibliography, see Simmons and Conway 1997; Simmons et al. 2008).

However, the systematical belongings of the Chiroptera still are under discussion. There had been established different phylogenetical trees depicting the relationships between the groups of the Chiroptera. Within one tree, the group is subdivided into only five taxa. The Pteropodidae are classified as a sistergroup of the Rhinolophidae, Emballonuridae, Noctilionidae, and Vespertilionidae, which represent the former Microchiroptera (Smith 1976; Westheide and Rieger 2010).

The majority of the established determination keys utilize the subdivision of the Chiroptera into Mega- and Microchiroptera. This classification is therefore used in the present text. The Chiroptera are the only vertebrates besides the formerly existing pterosauria and the recent birds that have evolved the ability of an active

Fig. 2.1 *Pteropus seychellensis* during flight

flight. Furthermore, they are the only actively flying mammalians (Fig. 2.1). Other Mammalia (as for instance the gliders) are only able to fly passively by gliding (Simmons and Conway 1997). In contrast to the gliders, all bats sleep or rest in a head down-under position (Figs. 2.2 and 2.3). The oldest known representative of the group of bats derives from the Eocene (about 50 million years ago) (Lawlor 1979; Carroll 1988).

2.2 Morphology

All bats show the characteristics of mammalians, as for instance, hairs, lactiferous glands, three ossicles, and the ability to maintain their body temperature (Maywald and Pott 1988).

In contrast to the wing of a bird, which is characterized by strong arm bones, two fingers, and feathers, the wings of bats consists of rather thin arm bones and four strongly elongated bones of the hand that strengthen the wing membrane (patagium, Figs. 2.4, 2.5, and 2.6). This organization led to the name of the group: Chiroptera = hand wing (from *greek*: cheir = hand, pteron = wing). The short clawed thumbs are not integrated into the wing membrane but are freely movable and used to grab, to hold, and to climb. The bones of the hand, which comprise four metacarpalia and elongated phalanges, strengthen the wing membrane (Figs. 2.1, 2.4, and 2.5), which stretches between the bones of the arms, the hands, the side of the body, and the bones of the hind limbs. The latter are rotated by nearly 180°. That causes the knees to be directed upwards. There is a chondral spur at both hind limbs, which in some species may be bony (osseous). It is called calcar and serves as support of the rear end of the wing membrane, the uropatagium. All toes are free and provided with laterally flattened claws and a locking mechanism. It consists of tendons and their

Fig. 2.2 *P. seychellensis* just landed at its resting place

Fig. 2.3 *P. seychellensis* in typical sleeping position. The five toes at the feet are clearly visible

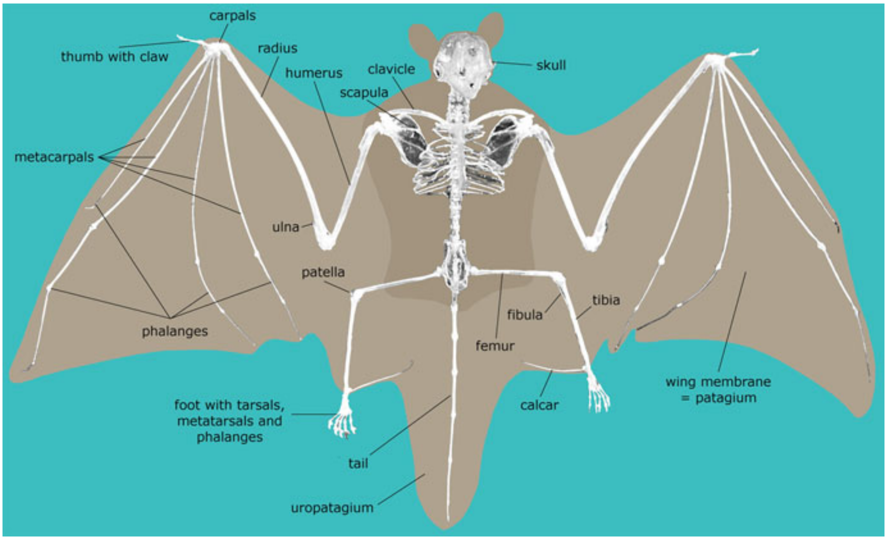


Fig. 2.4 Semiphotographic and diagrammatic representation of the skeleton of a microchiropteran bat to show that the wing bones originate mainly from the hand. The wing membrane and body shape are schematically represented

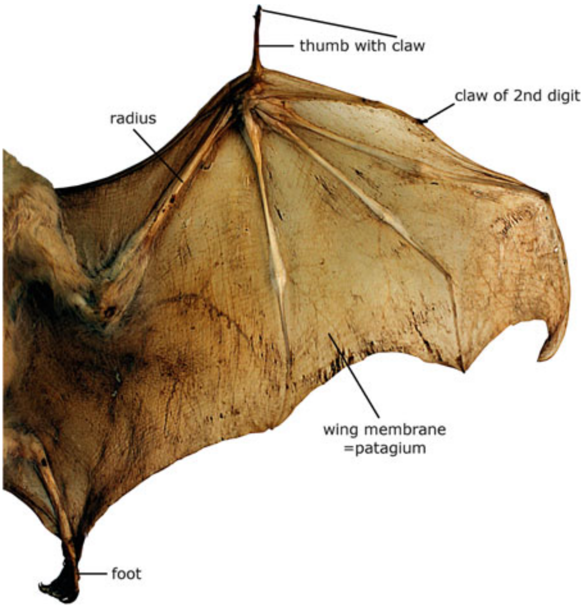


Fig. 2.5 Photograph of the ventral side of the left wing of a megachiropteran bat. This Pteropodidae bat species exhibits besides the clawed thumb, that all microbats have, another claw at the second digit

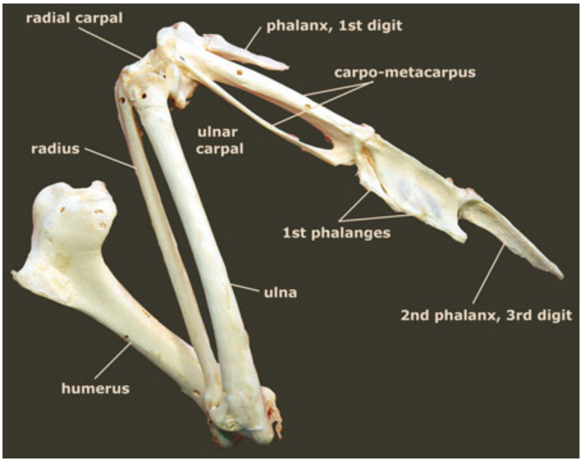


Fig. 2.6 Photograph of a bird wing skeleton with extremely reduced or eradicated hand bones

sheath being locked by the bat's weight, thus allowing the animal to rest at its roost without using a muscle (Maywald and Pott 1988).

The wing membranes consist of connective tissue, elastic filaments, muscles, nerves, and blood vessels (Fig. 2.1). It is covered on either side by a thin epidermal layer. The elastic fibers contract the relaxed wing, thus reducing its surface. During the flight, the muscles keep the wing membrane tightened. Contractile vessels assure the supply of the wing margin with blood. During flight, the wing membrane with its blood vessels serves as cooling surface to control the body temperature (Maywald and Pott 1988).

The flight muscles of birds are located in their chest, whereas the upstroke muscles of bats are located on their back and the downstroking muscles are attached to a keel at the breastbone, similarly as in birds (Fenton 1992). The shape of chiropteran skulls reveals an adaption to their diets (Fig. 2.7). For instance, the skulls of nectar feeding species are slim and elongated, allowing easy access to the nectar in the blossoms. Frugivorous and insectivorous species often have relatively short and blunt skulls (Hill and Smith 1984; Westheide and Rieger 2010) (Fig. 2.7)

The dentition shows adaptation to the diet, too (Fig. 2.7). The dental formula originally contained 38 teeth. However, the dentition of the recent species is extremely variable and the number of teeth has been reduced even to 20 in the vampire bat (*Desmodus rotundus*). There exist altogether about 50 different dental formulas within the Chiroptera (Westheide and Rieger 2010). About 75 % of the Chiroptera are insectivorous feeding mainly on beetles and moths. About 20 % of the species are frugivorous (Pteropodidae and Phyllostomidae) and only a few species feed on nectar and pollen (Pteropodidae and Phyllostomidae). Less than 2 % are predators of small mammals, birds, reptiles, amphibians, and fishes. In addition, there are only three species that feed on blood of vertebrates (see Chap. 7).

Some specializations of the alimentary tract have been developed as adaptation to the kind of food. Nectar feeding bats possess long tongues that can be protruded to ingest food that is deeply hidden in plant blossoms. The esophagus of

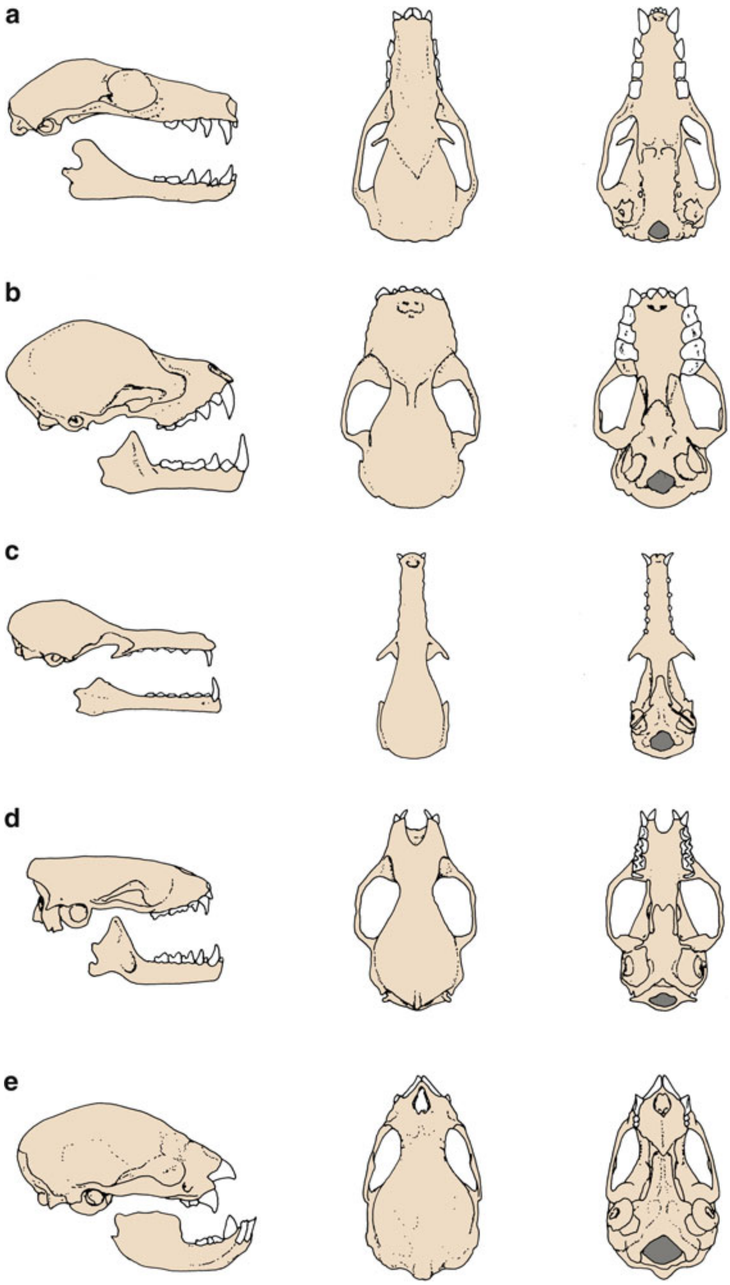


Fig. 2.7 Variety of chiropteran skulls represented in lateral, dorsal, and ventral sight to show the adaptation of skull shape and teeth formula to the diet of the species. (**a**) Megachiroptera, Pteropodidae (flying fox), *Epimorphosis* sp., fruit-feeder. (**b**) Microchiroptera, Phyllostomidae, *Artibeus* sp., fruit-feeder. (**c**) Microchiroptera, Phyllostomidae, *Choeronycteris* sp., nectar-feeder. (**d**) Microchiroptera, Vespertilionidae, *Eptesicus* sp., insectivorous. (**e**) Microchiroptera, Phyllostomidae, *Desmodus rotundus*, hematophagous. The proportions between the skulls do not correspond to the reality (Modified after Lawlor 1979)

insectivorous bats is lined by a horny epithelium. Bloodfeeding species, such as *Desmodus rotundus*, are provided with a long, dilatable blind sac to store great amounts of blood. In general, the intestine of insectivorous bats is shorter compared to the longer ones of frugivorous species (Westheide and Rieger 2010).

The sensory organs of bats are also well adapted to the "way of life" of the different chiropteran groups. As far as known, the olfactory sense is comparatively well developed in fruit-, nectar-, and bloodfeeding bats but is less good in insectivorous species. The eyes of the members of the Megachiroptera are essential for orientation and foraging of most species and therefore are in general very large and thus efficient even in dim light. Orientation of flying foxes in the night is accomplished by optical and olfactory senses. In contrast, the eyes of the echolocating Chiroptera (Microchiroptera) are mostly small but help to catch the prey, too. Other microchiropteran bats, such as Megadermatidae (False vampire bats), Phyllostomidae (Leaf-nosed bats, e.g., the hematophagous *Desmodus rotundus*), and several members of the Vespertilionidae (Vesper bats; Vespertilio= bat, *latin* from vesper = evening), have developed larger eyes (Hill and Smith 1984; Westheide and Rieger 2010).

The ears of flying foxes (Old world fruit bats) do not possess special features. However, ears of echolocating bats are often characterized by striking and variable formations of the morphology of the outer ear as well as of the middle and inner ear. Large auricles are found in Microchiroptera producing sounds at lower frequencies, while the smaller auricles of some species send out higher frequencies. Sounds—especially in the ultrasonic range—are produced within the larynx and are emitted through the openings of mouth and nose. The echos are recorded by help of the ears. The used frequencies range from 8 to 220 kHz and the sending lasts 2 ms to more than 100. The phonetic pattern can be modified and adjusted to the prevalent conditions. The nose and lips of bats can be modified extremely for instance by noseleafs, folds, and wrinkles. Function and purpose of most of those modifications are not understood. The nose of the vampire bat (*Desmodus rotundus*) is surrounded by so-called pit organs, which are sensitive for infrared radiation and allows the vampire bat to detect its bloodsource by the emitted body heat (Gracheva et al. 2011; Westheide and Rieger 2010).

2.3 Food of Bats

The Old world fruit bats (Megachiroptera and Pteropodidae) mainly feed on fruits. Some live on blossoms, pollen, or nectar. Especially the fruit feeding species definitely can introduce severe damages in fruit plantations. On the other hand, several plants need to be pollinated by other fruit bats (Grzimek 1975). At least 289 plant species worldwide (e.g., the African Baobab tree and the Australian Iron tree) depend on propagation by flying foxes. This can only be brought about by large populations of these animals (Fujita and Tuttle 1991). Besides fertilization of plants they play an important role in spreading and transporting the seeds of plants into new areas. Many of the Microchiroptera act in the same manner as flying foxes as transporters and pollinators for many plant species, for instance, guavas, avocados, mangos, agaves, bananas, etc. (Grzimek 1975; Hill and Smith 1984; Fujita and Tuttle 1991; Nowak 1991).

Microchiroptera have made accessible very different food sources. Most of them feed on insects. In turn, others feed on fruits, blossoms, pollen, or nectar as do the Megachiroptera, others catch little frogs or even fish (e.g., bats of the genus *Myotis*).

Microbats play a fundamental role within the ecosystems, since the insectivorous species control certain insect populations. The abundance of certain insects would be much higher without this regulation. Some bat species for instance feed especially on mosquitoes, which are known to be able to transmit the agents of severe diseases in animals and humans. One single bat as the Little brown bat can catch up to 600 mosquitoes per hour (Grzimek 1975). Extrapolation of a quantity of 500 mosquitoes per bat per day by 7 days and a total population of 1,000 bats adds up to five million mosquitoes per night (Callisher et al. 2006). The latter example demonstrates the fundamental role of bats in pest control. Some few species in South and Central America feed on blood. After scratching the skin by help of their pointed and sharp teeth they lick the flowing blood (see Chap. 7).

2.4 Social Behavior and Reproduction

Bats are socially highly developed mammals. Many of them live in groups. Some species may create giant groups with up to one million of individuals. Species like the so-called Mexican free-tailed bat can aggregate up to 300 individuals per square meter (Constantine 1967). In contrast, there are other species, which live solitary most of the time (Wund and Myers 2005).

On daytime the bats rest in trees, caves, buildings, etc. (Figs. 2.2 and 2.3). Some bats of the temperate regions can fall in torpor daily and hibernate in cold seasons (Lyman 1970). Other species may migrate yearly over long distances (up to 800 miles) to the sites, where they overwinter (Cockrum 1969).

A highly developed social behavior has been observed in the common vampire bat (*Desmodus rotundus*) in South America. As this bat dies of starvation after only two nights without a blood meal, regurgitation and sharing of blood with other starving individuals regularly takes place (Wilkinson 1990).

Most bats are polygyn, so that males establish a harem. For several bat species, courtship behavior has been observed and female bats may aggregate on nursery roosts. The bats of the temperate zones breed only once per year, but in warmer climates some species can give birth to several babies, but at each time only one. Chiroptera may reach an extraordinarily long life span of often 20 years. For a *Myotis* species, even a life span of 40 years had been reported (Westheide and Rieger 2010).

2.5 Geographic Range

Bats belong to the most widely distributed land mammals, only humans and rodents have reached a higher prevalence rates (Wimsatt 1970). The 170 species of Megachiroptera (being included in the single family Pteropodidae) are found exclusively in the tropical zones of the Old world. That is Africa, Indochina, East Indies, Australia including the islands north and east of the continent. However, they do not occur in the Americas. On the other hand, the members of the second suborder Microchiroptera have spread all over the whole world with the exception of mountain peaks, Arctic and Antarctic regions, and some isolated islands. Therefore, it is understandable that the different groups of the Chiroptera have attained the highest diversity of species in the tropical regions.

2.6 Parasites

Bats are hosts for a large number of endo- and ectoparasites. Endoparasites are protozoans such as instance *Plasmodium* and *Trypanosoma* species. For platyhelminthes (trematodes and cestodes) as well as for nematodes, bats may serve either as intermediate or as final host. Ectoparasites that live on bats belong to the groups of ticks and mites. Other parasites are insects. Especially the groups of bugs (Hemiptera), fleas (Siphonaptera), and flies (Diptera) are very common. One family of flies (Streblidae) is extremely specialized as some of their members have lost their ability to fly during evolution and live now as “bat lice” in the fur of bats (Wund and Myers 2005).

2.7 Bats as Victims and Vectors of Diseases

More than 70 viruses have been isolated from bats (Callisher et al. 2006). They can be transmitted within the large populations of bats between the individuals of one species. Since often several different bat species roost in the same habitat, intraspecific transmission takes place too. In addition, these viruses can be exchanged easily between bat species living relatively constant in their habitat and other species, which migrate as groups. Viruses as for instance the rabies virus group can cause serious illness in some bats and often lead to death (Boxes 2.1, 2.2, and 2.3). However, other bats may overcome the infection and seem to store the virus in their body. Field studies revealed that bats when infected with rabies may become aggressive against other bats or against other animals in their surroundings. Thus, bites become a possible way of interspecific transmission of the virus (Bell 1980). Several of these “bat”-viruses are known to be transmitted to other mammals including humans as it is shown in the following examples.

Several representatives of the family of Rhabdoviridae (genus *Lyssavirus*) have been found in tissues and salivary glands of bats and had been grouped as "bat *Lyssa* viruses." Furthermore exist strains of *Lyssa* viruses, which are known to induce the typical Rabies disease in humans and many animals (see Box 2.1). Bat *Lyssa* disease and typical rabies can be transmitted within the populations as well as from bats to other mammals by biting, scratching, and by aerosols as has been documented in bat populations roosting in caves (Callisher et al. 2006; Constantine 1967; Winkler 1968).

Talking of rabies often associates the vampire bats and transmission of rabies during their blood uptake. The saliva of the vampire *Desmodus rotundus* has been demonstrated to contain rabies viruses, after the bat has overcome the illness. There are reports on several death cases of humans living or temporarily staying in Latin America—where this bat is to be found. They obviously had been infected by the bites of *Desmodus rotundus* (MMWR 2011; Callisher et al. 2006). Of the three known vampire bat species only *Desmodus rotundus* has been witnessed to feed on mammalian blood (Belotto et al. 2005) besides numerous other hosts inclusive non mammalians. Rabies within populations of the vampire bat *Desmodus rotundus* is a potential danger to livestock (particularly for cattle) in Latin America (Batfacts, http://www.si.edu, 1980). Rabies virus is transmitted from bat to bat by saliva during bites (Tuttle 1990; Brass 1994). In several countries of Latin America, vaccination campaigns are carried out to protect the cattle. The vaccination together with efforts to lessen the vampire populations led to a significant reduction of rabies infection in some countries (Arellano-Sota 1988). Not only vampire bats but also other bat species can transmit rabies to various other mammals, which then may infect other mammals including humans (Callisher et al. 2006).

As is outlined in a review of human rabies cases in Latin America transmitted by vampire bats, the outbreaks of this disease are obviously strongly influenced by several factors—biological and nonbiological ones (Schneider et al. 2009).

Biological factors amongst others are the presence of:

1. Vampire bats
2. Shelter and roosting sites for the bats
3. Food sources
4. Reservoir of rabies virus

Nonbiological factors for example are:

1. Type of human activities in the area
2. Changes in activities of animals in the area
3. Changes of the environment caused by activities such as productive processes, working and live style, etc.

These factors altogether for instance could lead to the situation that vampire bats, which lost their food sources by human activities, start to attack people and try to use them as blood source.

Another representative of this virus group is the Australian-bat-*Lyssa*-Virus (ABLV). It can persist in populations of flying foxes namely in several *Pteropus* species and several Australian species of the Microchiroptera (Callisher et al. 2006). Up to now, this virus has caused three human death cases in Australia. In 1996, the *Lyssa*-virus was detected in a black flying fox (*Pteropus alecto*). Within the same year, a woman in Queensland became ill and died. Investigations of samples confirmed that she was infected by *Lyssa*-virus. The same occurred in 1998, when a woman in Northern Queensland became ill and died. She was infected with *Lyssa*-virus, too. Research showed that some bats had *Lyssa*-viruses inside their salivary or in their saliva glands. This virus can be transmitted to humans by bites or scratches of infected fruit bats. (http://www.csiro.au/en/Organisation-Structure/Divisions/Animal-Food-and-Health-Sciences/Infectious-diseases-overview/Australian-bat-lyssavirus.aspx; Constantine 1962).

In 2013, the third fatal case of death by infection with the ABLV virus-type (Box 2.1) occurred in Australia. A 8-year-old boy died, who obviously had been bitten by a bat 3 months before during holiday on the White Sunday Islands—a surfer's paradise along the Barrier Reef (Francis et al. 2013).

The Hendra virus belongs to Paramyxoviridae, genus *Henipavirus*. It was detected in Australia in 1994 for the first time. Horses and humans became infected and died. However, humans were not infected directly by infected bats but had close contact to infected horses. In the years 1994–2010, several humans were infected and died after infection with the Hendra virus, while 14 clusters of virus infections were recorded in horses. In 2011, in the East Australian states of Queensland and New South Wales, 18 outbreaks and 24 cases in horses were recorded. In this year, the first infection of a dog was documented. This virus is apparently able to infect different animal species. Fruit bats are believed to be the natural "host" of this virus. They carry the virus, but the virus does not affect them severely (Callisher et al. 2006; http://www.csiro.au/Outcomes/Food-and-Agriculture/Hendra-Virus/Research-findings.aspx). Both a pre- and a postexposure vaccination are available against the typical rabies virus and ABLV-type as well. There is still no vaccination against the hendra virus, although research is underway since long (Hendra Virus Infection 2012; Rabies 2012; Australian Bat Lyssavirus 2013).

Box 2.1: Classification of *Lyssa*-Viruses (According to Neumeister et al. 2009)

Genotypes	Virus	Potential/real hosts
1	Rabies (RABV)	Carnivores, bats
2	Lagos-Bat (LBV)	Fruit feeding bats
3	Mokola (MOKV)	Unknown
4	Duvenhage (DUVV)	Insect feeding bats
5	European bat-*Lyssa* (EBLV 1)	Insect feeding bats
6	European bat-*Lyssa* (EBLV 2)	Insect feeding bats
7	Australian bat-*Lyssa* (ABLV)	Fruit and insect feeding bats
Not yet classified	Aravan virus (ARAV)	Insect feeding bats
	Khujand virus (KHUV)	
	Irkut virus (IRKV)	
	West Caucasian bat virus (WLBV)	

Box 2.2: Description of the Viruses

Rabies viruses belong to the family of **Rhabdoviridae**

Size	100–300 nm in length and 75 in diameter
Shape	Bullet-like
Cover	G-proteins with spikes
Contents	Helically arranged nucleocapsid containing single stranded RNA of about 12,000 nucleotides with a negative polarity coding for 5 viral proteins

Box 2.3: Symptoms of Human *Lyssa*-Disease

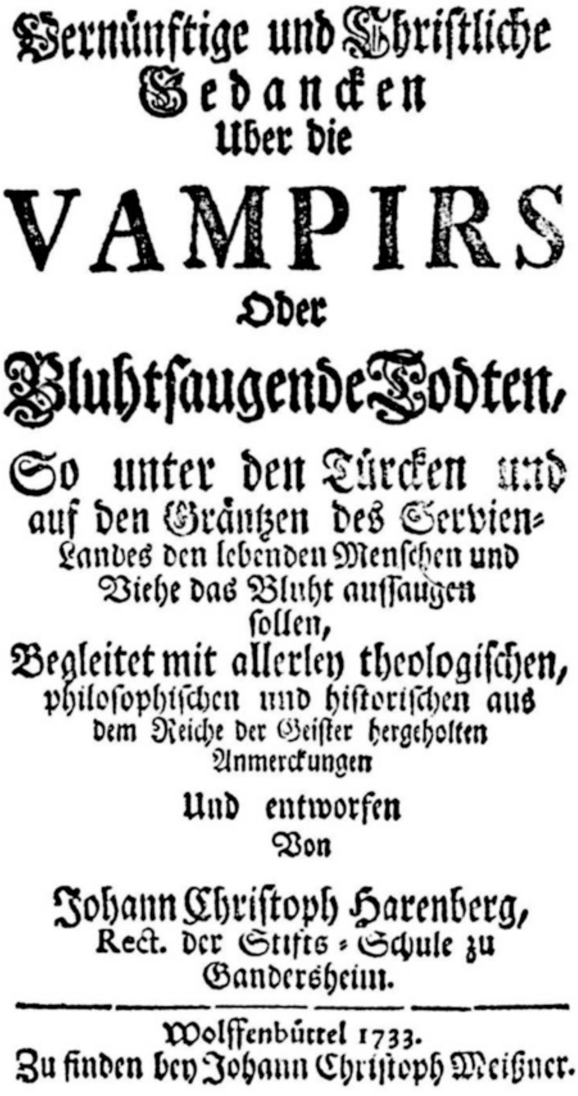
Incubation period	Variable, mostly below 30 days up to 90 days or even years
Prodromal stage	Headache, vomiting, fever for 2–7 days
Neurological phase	So-called “wild wrath,” aggressivity, confusion, delusions, aero-, hydrophobia and hypersalivation, paralytic phases, death due to circulatory collapse
Diagnostic measurements	Immunofluorescence test, immunochemical methods, virus isolation; primers are available for amplification of all genotypes

2.8 Bats and Men

Many myths and misunderstandings are linked to the bats (Fig. 2.8). Their silent flight frightened people and was thought to be a portent in the ancient world (Harenberg 1733). Especially the ability to fly in the darkness was a mystery. It was inapprehensible that a creature half mouse, half bird could fly in the night, when the eyes of humans and other diurnal living beings lost totally their efficiency (Figs. 2.9 and 2.10). Thus it was believed that bats must possess magical powers or to be in league with the devil. Possibly this was one reason to illustrate the devil and his cronies with the wings of bats, whereas the angels got white bird wings (Maywald and Pott 1988).

The imagination of so-called vampires—dead humans who suck blood at night—existed long before the “real” vampire bat (*Desmodus rotundus*) had been discovered and was first described as *Phyllostomus rotundus* (Geoffroy 1810) (see Chap. 8).

For long the important role bats that they play within the ecosystems was completely misunderstood or even completely unknown. The threat that they could transmit rabies disease as well that they accomplish damages in fruit plantations led to attempts to eradicate or to reduce bat populations. Especially eradicating campaigns against vampire bats killed numerous other bats species, which only looked similar like vampires or lived in the same caves. These efforts, however, did not really reduce the transmission of rabies (Callisher et al. 2006) but



Vernünfftige und Christliche
Gedancken
Uber die
VAMPIRS
Oder
Bluhtsaugende Todten,
So unter den Türcken und
auf den Gräntzen des Servien-
Landes den lebenden Menschen und
Viehe das Bluht aussaugen
sollen,
Begleitet mit allerley theologischen,
philosophischen und historischen aus
dem Reiche der Geister hergeholten
Anmerckungen
Und entworfen
Von
Johann Christoph Harenberg,
Rect. der Stifts-Schule zu
Gandersheim.
Wolffenbüttel 1733.
Zu finden bey Johann Christoph Meißner.

Fig. 2.8 Title page of Harenberg's book on vampires (1733). The German text says: Reasonable and Christian thoughts on the vampires or bloodsucking dead humans, which are said to suck off the blood of living humans and cattle resident in countries at the Turkish border and at the borders of Serbia, accompanied by several theological, philosophical and historical comments, which have been taken out of the kingdom of ghosts and composed by Johann Christoph Harenberg, rector of the monastery-school at Gandersheim. Wolfenbüttel 1733. To be found at Johann Christoph Meißner

introduced bad effects on biotopes and on plantations. In addition, other bat populations suffered severely from these measurements and their number was diminished by the extensive use of insecticides amongst others DDT. In particular DDT affected the bats and their offspring in Europe and the USA in the 1960s (http://www.earthlife.net/mammals/chiroptera.html).

From the human point of view, bats may exhibit a potential danger as a reservoir of numerous viruses. But the number of human death cases due to bat-derived fatal diseases is very small compared to those caused by other infectious diseases (mosquito- or tick transmitted ones). As for infections of cattle with rabies virus,

Fig. 2.9 Gray-headed flying foxes, *Pteropus poliocephalus*, resting in trees in the Botanical Garden Sydney, Australia

Fig. 2.10 Gray-headed flying foxes, *Pteropus poliocephalus*, resting in trees in the Botanical Garden Sydney, Australia – note the large numbers crow-wing together

it has to be considered, that obviously high numbers of infection and death cases eventually have been created—at least in part—by the dramatic changes of the environment. Forest clearings in order to get grasslands drew off the habitats of bat populations together with their food resources and therefore the bats entered the environment of cattle and humans. These large numbers of cattle offered large amounts of food for bats and thus increased the growth and denseness of vampire populations. The latter abets a higher infection level of bats directly with rabies and thus brought about the increase of rabies cases in cattle—a constantly running "circulus vitiosus."

Destruction of bat habitats followed by reclaiming land and settlement of people could raise the number and closeliness of contacts between bats and humans, too. Especially in cases when bats used buildings as new shelter and resting places. Trials to eradicate bats—especially vampire bats—by destruction of their roosting places and by deployment of agents such as coumarin being applied on cattle limited the numbers of all bats.

Vaccination of cattle as well as downsizing the droves appears to be a better attempt in controlling rabies. In Europe, vaccination of red foxes against rabies was successfully started in Switzerland 1978. In 1983, Germany succeeded with its vaccination program and stopped rabies practically everywhere in recent times. In the following years, many other European countries did the same and in 2008 rabies was eradicated or controlled in most countries of Western and Central Europe (http://www.who-rabies-bulletin.org/about_rabies/Control.aspx). Lyssa viruses within the reservoir host bats, however, were not affected by this campaign.

Although it is utopian with respect to the increasing world population, that it will be possible to reduce the livestock breeding sites and to renaturalize grassland, efforts are needed to offer space to bats, too, since these animals are important members of the ecosystem—e.g., by reducing the number of pest insects.

And at last, it should be mentioned that the studies on the saliva of the vampire bat *Desmodus rotundus* led to a new and effective enzymatic therapy of aplexia by suspending blood clots (Schleunig 1993; Reddrop et al. 2005; Steiner et al. 2007).

Today bats are protected completely or in part in several countries. In Europe and Russia, all species are protected by law. More and more, the beneficial role of these animals has been recognized in the public. This resulted in increasing efforts to help bats by gates open for bats in caves and buildings, as well as providing special bat houses as roosting sites (Wund and Myers 2005).

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