CHAPTER

52

Gerbils

Margaret Batchelder[1], Lynn S. Keller[1], Mary Ball Sauer[2], and Wanda L. West[3]

[1]Bristol-Myers Squibb, Department of Veterinary Sciences, Wallingford, CT, USA; [2]Iowa State University, Ames, Iowa, USA; [3]Bristol-Myers Squibb, Department of Veterinary Sciences, Princeton, NJ, USA

OUTLINE

The Laboratory Rabbit, Guinea Pig, Hamster, and Other Rodents
DOI: 10.1016/B978-0-12-380920-9.00052-3

INTRODUCTION

The introduction and development of the Mongolian gerbil, *Meriones unguiculatus*, as a laboratory animal is recent, compared to other rodents. The gerbil is usually non-aggressive and is one of the easiest rodents to maintain and handle. Its disposition, curious nature, relative freedom from naturally occurring infectious diseases, and adaptability to its environment have contributed to its popularity as a laboratory animal (Wagner and Farrar, 1987). It has several interesting anatomical and physiological characteristics that make it a useful model in biomedical research. Several other species of gerbils (e.g. *Meriones libycus, Meriones crassus*) have been used as experimental animals (Belhocine et al., 2010; Khokhlova et al., 2009). However, the Mongolian gerbil (*Meriones unguiculatus),* on which this chapter will focus, is the most common species of gerbil used in biomedical research (Schwentker, 1963).

TAXONOMY AND HISTORY

Taxonomy

It should be noted that mammalian taxonomy is a rapidly changing field. The following description outlines a classification of the Mongolian gerbil based on morphology as well as more recent molecular techniques. Gerbils are in the class Mammalia and order Rodentia. Rodents are divided into five major suborders (Musser and Carleton, 2005). Gerbils are part of the suborder Myomorpha, originally so named because the deep and lateral masseter muscles attach to the front of the muzzle, giving it a forward thrust. Myomorphs also lack premolar teeth (Hurst, 1999). Gerbils belong to the superfamily Muroidea, family Muridae, and subfamily Gerbillinae based on morphology and on evaluation of nuclear protein coding sequences of the Lecithin Cholesterol Acyl Transferase gene and the von Willebrand factor gene (Michaux et al., 2001; Robinson, 1975). The genus *Meriones* was first described by Illiger in 1811, and *Meriones unguiculatus* was first identified in 1867 by Milne-Edwards (Robinson, 1975; Thiessen and Yahr, 1977). Chaworth-Musters and Ellerman (1947) provided a comprehensive description of the genus *Meriones* which was updated by Ellerman and Morrison-Scott (1951), Corbet (1978), and Pavlinov et al. (1990).

The genus name, *Meriones*, was derived from a Greek warrior who wore a battle helmet decorated with boar tusks (Robinson, 1975). The species name, *unguiculatus*, is Latin for clawed or fingernail leading to one of the common names, clawed jird. The name gerbil is from the Arabic word, yarbu, which refers to saltatorial, desert-inhabiting rodents. Yarbu was translated into Latin as gerbo and into English as gerbil (Robinson, 1975).

Origin, Domestication, and Geographical Distribution

Approximately 15 genera and 81 species of gerbils are known (Agren, 1986). Gerbils are found in deserts and semi-arid geographical regions of the world (Field and Sibold, 1999; Thiessen and Yahr, 1977). They are native to northern Africa, India, Mongolia, southwestern and central Asia, northeastern China, and regions of Eastern Europe (Robinson, 1976). Because wild gerbils live in arid habitats they dig burrows that extend between 50 cm and 1.5 m below the surface so the temperature is relatively constant throughout the day and night. The burrows may be small and simple with one entrance or complex with eight to 14 entrances (Agren, 1986; Brain, 1999).

The domestication of the Mongolian gerbil is a relatively recent occurrence. They were found by a French missionary, Father Armand David, who traveled extensively in Mongolia and China in the 1860s. Some wild-caught stock were sent to Japan, where they were bred freely (Alderton, 1986). The Mongolian gerbils that are available today originated from 20 pairs of captured animals that were maintained in 1935 by Dr. C. Kasuga in a closed, random-bred colony at the Kitasato Institute in Japan. In 1949 a sub-colony of gerbils was established at the Central Laboratories for Experimental Animals in Tokyo by M. Nomura. In 1954 Dr. V. Schwentker imported 11 pairs from Japan. Five females and four males from this group were successfully bred and formed a foundation colony which produced gerbils for distribution throughout the United States (Robinson, 1979). This foundation colony was established at Tumblebrook Farm at Brant Lake, NY, founded by Dr. Schwentker. After his retirement in 1971, the Brant Lake facilities were phased out, and the Tumblebrook Farm gerbil production colony was relocated to new facilities in West Brookfield, MA under the ownership of D.G. Robinson. The name "Tumblebrook Farm" was retained (Robinson, 1974). A sub-colony established from seven pairs of animals by Dr. J.H. Marston at the Worcester Foundation for Experimental Biology in Shrewsbury, MA during 1961–62 was the origin of the sub-colony established at the University of Birmingham, England in 1964. This breeding stock produced the animals used in laboratories throughout the United Kingdom and Europe. Charles River Laboratories purchased Tumblebrook Farm in 1996 giving rise to the Crl:(MON)BR strain.

FIGURE 52.1 Size comparison between an adult rat (top), gerbil, and mouse.

FIGURE 52.2 Male and female gerbils are easily differentiated by the male's greater anogenital distance and pigmented scrotum (left, female; right, male).

Genetics

There is a low amount of genetic variability present in laboratory gerbils compared to wild gerbils as a result of their origination from a few founder animals (Razzoli et al., 2003). Recently, Neumann et al. (2001) identified the first polymorphic dinucleotide repeat loci in Mongolian gerbils by a microsatellite technique. These studies demonstrated that there has been minimal genetic variability identified in the Mongolian gerbil used in research, even though there are several different lines or strains. Razzoli et al. (2003) confirmed these results using an amplified fragment length polymorphism technique to characterize and detect strain-specific polymorphisms in gerbils. Prior to these studies, relatively few genetic studies had been performed.

The common agouti or mixed brown Mongolian gerbil stock is used in research and sold as pets. The agouti has given rise to black (Cramlet et al., 1974; Waring and Poole, 1980), albino (Hedges, 1977), piebald, dove, cinnamon, and a "hairless" mutant (Alderton, 1986; Matsuzaki et al., 1989b). An inbred strain (Mon/Tum) is also available (Brain, 1999). There are also seizure-sensitive and seizure-resistant lines of gerbils (Loskota et al., 1974).

At the time of publication, Mongolian gerbils are commercially available in the United States from Charles River Laboratories, Inc., Wilmington, MA and Harlan, Indianapolis, IN.

ANATOMY, PHYSIOLOGY, AND BEHAVIOR

Basic Features

Gerbils have several unique anatomical and physiological features. Mature gerbils are smaller than rats, but larger than mice (Figure 52.1). Adults of both sexes vary between 11.5–14.5 cm in body length with males weighing an average of 100 grams and females weighing an average of 87.5 grams (Kramer, 1964). Body weights vary among colonies and this variation may be a genetic phenomenon as well as a dietary factor (Arrington et al., 1973). In adults, the sexes are easily differentiated by the male's longer anogenital distance, prominent testicles, and pigmented scrotum (Figure 52.2). Females have four pair of mammae, two inguinal and two thoracic, and the urethra is located outside the vagina (Wagner and Farrar, 1987).

External Features

External anatomical features are depicted in Figure 52.3. Cranial characteristics are consistent with saltatorial rodents. They have broad, short heads with prominent ears and large, black, slightly bulging eyes. Most

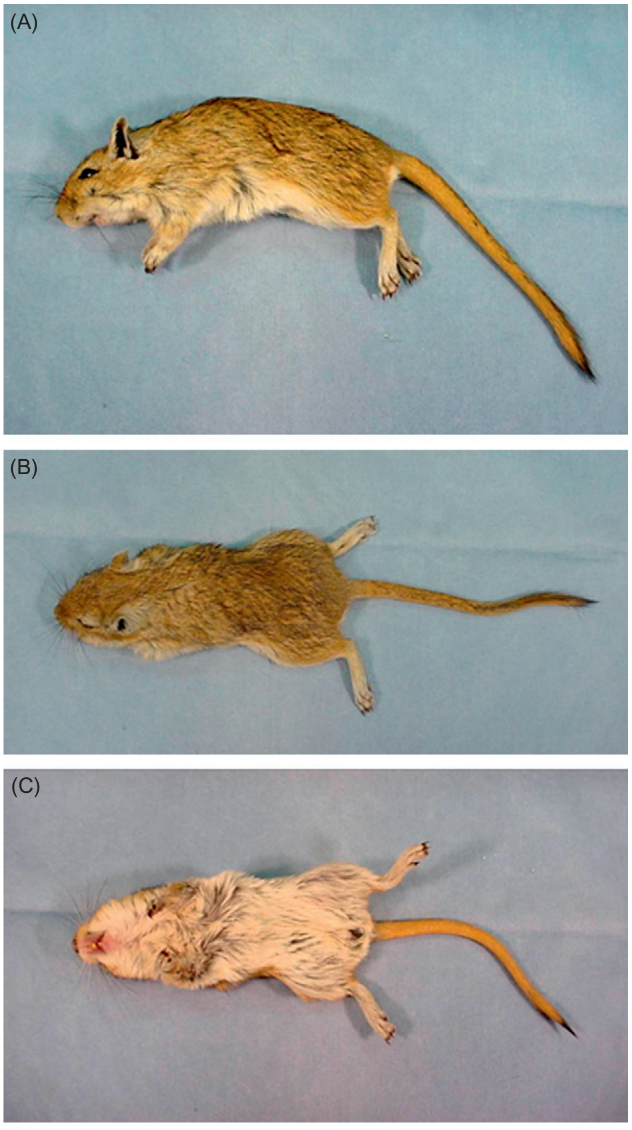

FIGURE 52.3 External anatomy of the gerbil. (A) Lateral view. (B) Dorsal view. (C) Ventral view.

mice and rats have longer, extended faces. The large eyes are an adaptation found in nocturnal animals, and their vision is very well developed (Alderton, 1986). Gerbils show active periods during day and night, and use both rod- and cone-based vision.

Gerbils generally have reddish brown fur with black outer tips on their backs, but coat color can vary from tan to gray, with a gray or creamy white undercoat. The tail is covered with fur that is short at the base and progressively becomes longer and bushy toward the tip of the tail. The tail length ranges from 10.0–19.3cm (Norris and Adams, 1972c).

Musculoskeletal System

The hindlimbs are elongated, and the forefeet are relatively small. The hindlimbs are very muscular, and aid in the gerbil's ability to jump considerable distances in proportion to their size. Gerbils use jumping or hopping as a form of ambulation (Brain, 1999). Gerbils' hind paws are not equipped with friction pads or opposable toes, and the soles are covered with fur; therefore, they cannot climb like mice (Roger and Polioudakis, 1977).

Special Senses

The gerbil's sense of smell is very keen and well developed. Gerbils have been shown to use a variety of odors as discriminative social cues from urine, ventral sebaceous glandular secretions, and Harderian gland secretions (Halpin, 1974; Thiessen et al., 1976; Thiessen and Yahr, 1977). Mongolian gerbils are attracted to saliva and use salivary cues to discriminate between siblings and non-siblings, and females use oral cues in the selection of sociosexual partners (Smith and Block, 1991). The Harderian gland functions as a potential site for immune response, serves as a part of the retinal–pineal axis, acts to cushion the eyeball, secretes lubrication for the eye, and is a source for pheromones and thermoregulatory lipids (Johnston et al., 1983; Sakai, 1981). Harderian gland secretions, comprised of lipids, proteins, and protoporphyrin, are carried by an excretory duct to the medial aspect of the nictitating membrane. These secretions bathe the eye and conjunctival space and are transported down the nasolacrimal duct, exiting at the external nares. The Harderian secretions are mixed with saliva and spread over the pelage during grooming (Thiessen, 1977).

Compared with mice, gerbils possess a much higher proportion of cones to rods. Since the gerbil retina is not exclusively rod-dominated, it is a valuable model for in vitro studies of retinogenesis (Bytyqi and Layer, 2005).

The tympanic bullae are prominent, giving the gerbil remarkable hearing with a high frequency peak of 50kHz (Johnson and Marcotti, 2008).

Digestive System

The dental formula is 2 (incisors 1/1, canines 0/0, premolars 0/0, molars 3/3) = 16. The incisors are hypsodont (long crown) and elodont (continuously growing and erupting teeth that do not develop anatomical roots). The molars in gerbils are brachydont (short crown), rooted, anelodont (limited growth period) and cease to grow in mature animals. They are prone to dental caries, periodontal disease, and can develop incisor malocclusion (Field and Sibold, 1999).

The Mongolian gerbil's liver enzymes which are involved in cholesterol metabolism and hepatic cholesterol ester storage differ from those found in other rodents and make the gerbil an excellent model for hypercholesterolemia research (Norris, 1987; Temmerman et al., 1989). The gerbil's serum cholesterol level is very sensitive to increased dietary cholesterol. Gerbils are resistant to atheromatous changes on high-cholesterol diets, but they can develop hepatic lipidosis and cholesterol gallstones when fed these diets (Vincent et al., 1979).

Circulatory System

Approximately 40% of Mongolian gerbils have an incomplete circle of Willis that allows for a reliable development of focal cerebral ischemia which is used to study the pathophysiology and treatment of ischemic stroke (Başkaya et al., 1999). When one carotid artery is ligated, a cerebral infarct on the side ipsilateral to the ligation is formed (Vincent et al., 1979). Gerbils have less collateral blood supply to the brain compared to mice and rats (Vincent et al., 1979).

Respiratory System

The respiratory system is very similar to other rodents in that gerbils do not appear to have respiratory bronchioles in the lung (Bal and Ghoshal, 1988). The right lung is composed of four lobes, while the left lung has three lobes (Williams, 1974).

Genitourinary System

Since they are desert animals, gerbils have several characteristics that have allowed them to adapt to dry environments. Gerbils have an excellent ability for thermoregulation, and they have a high level of heat tolerance. They have a unique water metabolism in that they require very little water to function (Winkelmann and Getz, 1962). Gerbils can obtain sufficient water from their diet and their kidneys have a highly efficient urine-concentrating capacity to ensure adequate hydration (Goyal et al., 1988). The ratio of long-loop nephrons to short-loop nephrons in gerbils is high. Ninety-six percent of their nephrons are long loop which allows them to efficiently concentrate their urine (Ichii et al., 2006). The digestive system is also very efficient at absorbing and retaining water, and water can be stored in fat cell layers. Gerbils produce and excrete a small amount of concentrated urine and dry feces per day (Alderton, 1986); therefore they require less frequent cage changing than other laboratory rodents.

Other Characteristics

The internal anatomy of Mongolian gerbils was investigated and described in detail by Williams (1974). He demonstrated that the anatomy of the gerbil and the albino laboratory rat is similar except for some minor

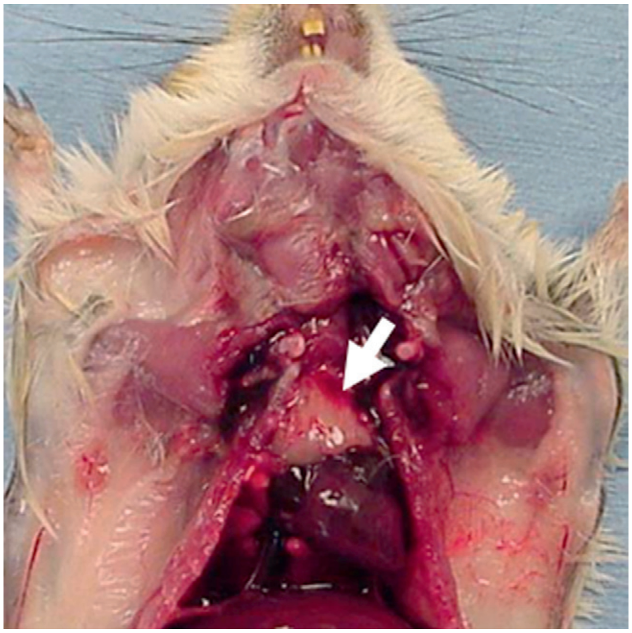

FIGURE 52.4 The thymus persists in adult gerbils (arrow).

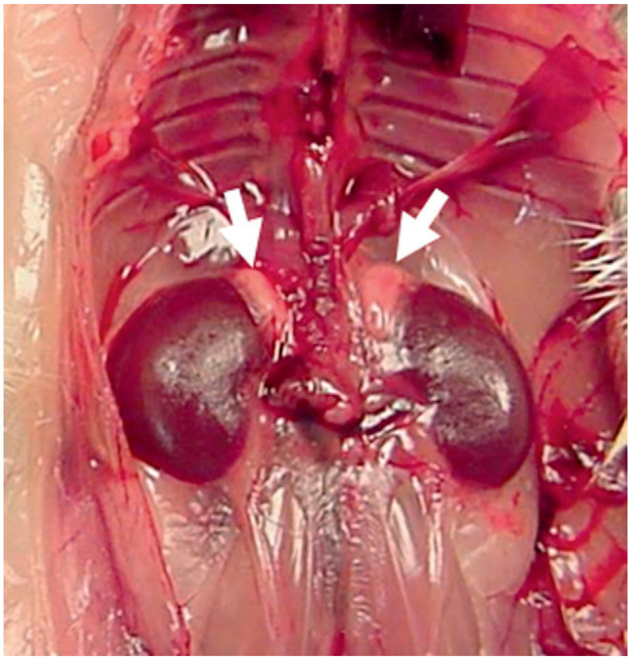

FIGURE 52.5 Gerbils have large adrenal glands for their weight when compared to rats and mice (arrows).

variations. These include a lack of a preputial gland, the presence of a gall bladder, and 12 pairs of ribs in gerbils (Williams, 1974).

Gerbils have an unusually large thymus and adrenal glands compared to other rodents of similar size (Figures 52.4 and 52.5). The thymus is persistent in adults (Wagner and Farrar, 1987). The adrenal gland weight

FIGURE 52.6 There is a significant sex difference in the size of the ventral sebaceous gland, located in the shaved areas of these gerbils (left, female; right, male).

when compared to the body weight is approximately three times the size of the adrenal gland in rats (Cullen et al., 1971; Holmes, 1985). The significance of these anatomically enlarged structures is not known (Schwentker, 1963), although the enlarged adrenal glands are thought to contribute to their unique water conservation ability (Wagner and Farrar, 1987). The adrenal cortex produces equal amounts of corticosterone and 19-hydroxycorticosterone (Drummond et al., 1988). Unlike a rat, an adrenalectomized gerbil cannot be maintained by providing supplemental sodium (Cullen et al., 1971).

Both sexes have distinct mid-ventral abdominal sebaceous glands, which are used for territorial marking. The male sebaceous gland is twice the size of the female gland (Figure 52.6). At puberty in males, the gland becomes orange and produces an oily, musky scented secretion (Clark, 1984).

Physiology

Selective normal mature gerbil physiological parameter and hematological and serum chemistry values are listed in Tables 52.1, 52.2 and 52.3, respectively. The data reported are compiled from literature using average values with sexes combined. There is a limited amount of hematological and clinical chemistry data available in gerbils. Ruhren (1965), Mays (1969), Dillon and Glomski (1975), and Gattermann (1979) conducted studies and reported original data in gerbils. The blood volume of a Mongolian gerbil is approximately 7.7 ml/100 g. The red blood cell half life is approximately 9.9 days, which is short in comparison with that of other rodents (Womack, 1972). Young gerbils can have up to a 40% increase in circulating, stippled red blood cells and reticulocytes compared to adults (Ruhren, 1965; Smith et al., 1976). Gerbils have lower hematocrit values than mice, and have higher blood lipid values than rats (Mays, 1969). Sexual dimorphism in hematocrit, hemoglobin, total leukocyte count, and lymphocytes has been reported (Dillon and Glomski, 1975; Mays, 1969). Mays (1969) demonstrated that there were significant differences between males and females in phosphorus and uric acid levels. Serum cholesterol levels are higher than other rodents, even when gerbils are fed diets containing normal levels of fat (Roscoe and Fahrenbach, 1962).

TABLE 52.1 Basic Biological Parameters of Gerbils

Chromosome number	44
Life span (years)	2–5
Number of mammary glands	4 pairs: 2 thoracic, 2 inguinal
Birth weight (g)	2–4
Mature body weight (g)	65–100 (males)
	55–85 (females)
Body temperature (°C)	37–38.5
Dental formula	2 (1/1, 0/0, 0/0, 3/3)
Food intake (g/day/100 g weight)	5–7
Water intake (ml/day/100 g weight)	4–7
Urine volume (ml/day)	Few drops to 3–4 ml
Heart rate	260–600
Respiratory rate	70–120
Sexual maturity	9–12 weeks for both sexes
Estrous cycle	4–6 days; postpartum estrus is present
Gestation	24–26 days
Number of litters in lifetime	6 or more
Litter size	1–12 (average 5)
Eyes open	16–20 days
Weaning	21–24 days

(Adapted from Clark, 1984; Field and Sibold, 1999; Harkness and Wagner, 1983).

Select Normative Values

Basic biological values are presented in Tables 52.1, 52.2, and 52.3 (adapted from Clark, 1984; Field and Sibold, 1999; Harkness and Wagner, 1983; Wagner and Farrar, 1987). Similar and additional data are presented in the sections on Normative Values; and Clinical Biochemistry and Hematology.

Behavior

Gerbils are quiet animals that are generally docile, easy to handle, and seldom bite. They are quite

TABLE 52.2 Hematological Parameters

Red blood cells (10^6/μl)	7–10
Hemoglobin (g/dl)	13–16
Hematocrit (%)	44–49
MCH (pg)	16–19
MCV (fl)	46.6–60
MCHC (%)	30.6–33.3
Reticulocytes (%)	2.0–5.4
Platelets (10^3/mm^3)	400–600
White blood cells (10^6/μl)	7.3–15.4
Neutrophils (10^6/μl)	1.3–5.2
Lymphocytes (10^6/μl)	5.1–11.8
Eosinophils (10^6/μl)	0.07–0.32
Basophils (10^6/μl)	0.1–0.28
Monocytes (10^6/μl)	0.03–0.25
Blood volume (ml/kg)	60–85
Adult total blood volume (ml)	4.4–8.0

(Adapted from Clark, 1984; Field and Sibold, 1999; Harkness and Wagner, 1983).

TABLE 52.3 Clinical Chemistry Parameters

Albumin (g/dl)	1.8–5.5
Total protein (g/dl)	4.3–12.5
Globulin (g/dl)	1.2–6.0
Blood urea nitrogen (mg/dl)	17–32
Creatinine (mg/dl)	0.64–1.12
Glucose (mg/dl)	50–135
Sodium (meq/L)	143–157
Chloride (meq/L)	105
Calcium (mg/dl)	3.6–6.0
Potassium (meq/dl)	3.9–5.2
Phosphorus (mg/dl)	3.7–7.1
Total bilirubin (mg/dl)	0.2–0.6
Cholesterol (mg/dl)	90–151

(Adapted from Clark, 1984; Field and Sibold, 1999; Harkness and Wagner, 1983).

curious as demonstrated by their increased activity in an open field test and decreased thigmotrophic or "wall hugging" behavior compared to mice (Oldham and Morlock, 1970). In nature, gerbils live in family groups in complex burrows. Their compulsive burrowing behavior extends into the laboratory setting as well, and in many cases they will scratch at the sides and bottoms of cages in their attempts to burrow (Brain, 1999; Field and Sibold, 1999). Other normal activities include gnawing, making nests, and nibbling on food continually to support their bursts of energy (Bradley and Pence, 1995). While primarily nocturnal, they are active during daylight hours, too, alternating periods of intense activity with sleep or rest (Brain, 1999; Thiessen and Yahr, 1977). They do not hibernate, but may exhibit estivation, depending on the species (Bradley and Pence, 1995).

Gerbils are territorial, and will mark almost any object in their environment by depositing a pheromone with their ventral sebaceous gland (Thiessen and Gray, 1971, 1974) (Figure 52.6). This enlarged, specialized gland is under the control of gonadal hormones (Glenn and Gray, 1965). Animals of both sexes which have higher androgen levels are more frequent markers and have an advantage in hostile encounters (Swanson et al., 1978; Thiessen et al., 1968a). In males, the gonadal androgens act on the medial preoptic area of the brain (Commins and Yahr, 1984; Thiessen and Yahr, 1970). In the female there is contradictory information regarding the influence of estrogen and progesterone on marking behavior (Thiessen and Lindzey, 1970; Wallace et al., 1973; Whitsett and Thiessen, 1972). Male gerbils scent mark more frequently than females (Lindzey and Carbonell, 1968) and gerbils with black coat color tend to mark more often than those with brown coat color (Turner and Carbonell, 1984). Marking behavior in males is used for exploration, establishing social dominance, and identifying territory (Thiessen and Yahr, 1970). In females, scent marking is used for exploration and is also important for identification and for the attraction between mother and young (Dagg and Windsor, 1971; Wallace et al., 1973). Males also urinate and defecate to mark their territory. Only groups of males that are raised together are compatible as adults and will defend their territory as a group. Once a family unit (male and female, or parents with a litter) is established, the gerbils will viciously attack intruders.

Pair bonding between male and female gerbils occurs; however, gerbils may not be completely monogamous (Brain, 1999; Robinson, 1978). Mating usually occurs at night, and the male will mate with the female several times. Both males and females will build a nest and care for the young (Elwood, 1975).

Gerbils make a drumming sound by thumping their hindlegs rapidly on the cage floor to signal a warning or excitement, or during courtship by the male (Brain, 1999).

Food hoarding is also a natural behavior in gerbils with females serving as the primary food hoarders. Castration of male gerbils will increase hoarding behavior indicating that hoarding is inversely related to androgen levels. In one experimental setting where a pair of gerbils was provided with a ten foot square room with a closet, the female gerbil gathered and stored approximately 50 pounds of food in the closet (Thiessen and Yahr, 1977).

MANAGEMENT, HUSBANDRY, AND COLONY HEALTH

Maintaining a well-managed gerbil colony requires attention to many aspects of animal care. Animal well-being is dependent on appropriate housing conditions, from the micro-environment (cage) to the macro-environment (holding room and facility). Animals must receive appropriate nutrition, and veterinary oversight must be provided to ensure an effective preventive medicine and health-monitoring program. Finally, documentation is essential to ensure that procedures are being followed as designed and to comply with national regulations.

Housing Systems

Caging designed for other rodents (e.g. hamsters and rats) is generally adequate for gerbils, and solid-bottom, bedded caging is preferred (Brain, 1999; Field and Sibold, 1999; Harkness and Wagner, 1983; Moore, 1995; Olfert and Cross, 1993). Recommended cage dimensions vary and may be subject to national regulations. For example, the Canadian Council on Animal Care (Olfert and Cross, 1993) proposes a floor area per animal of 116 cm^2 and 15 cm cage height, while the Committee for the Purpose of Control and Supervision on Experiments on Animals (CPCSEA) in India recommends a floor area of 64.5 cm^2 (up to 60 g) to 122.5 cm^2 (over 100 g) and a height of 12 cm. Although the gerbil is a United States Department of Agriculture (USDA)-covered species, neither the Animal Welfare Act Regulations (9CFR Part 3 nor the *Guide for the Care and Use of Laboratory Animals* (*Guide*)) (National Research Council, 2011) provide standards for cage sizes for gerbils in the United States. Others have recommended that adult gerbils have 36 in^2/230 cm^2 of floor space per animal and 6 in/15 cm of internal cage height and that breeding pairs with litters should have 180 in^2/1300 cm^2 of floor space (Harkness and Wagner, 1983).

Bedding types used for gerbils are the same as those used for other rodent species. These include chopped corncob, hardwood chips, cellulose fiber, and other commercially available beddings. In addition to absorbing wastes, bedding may be used as a burrowing substrate, or a separate substrate such as sand may be provided. Pine bedding is not recommended as it causes matting and greasiness of the fur (Brain, 1999; Field and Sibold, 1999) as well as the induction of hepatic drug-metabolizing enzymes (Vesell, 1967).

Gerbils do best when housed in groups established prior to puberty. Introducing new cagemates into an established group, or re-introducing former cagemates who have been separated for more than 14 days, may precipitate fighting (Harkness and Wagner, 1983; Moore, 1995; Olfert and Cross, 1993). One method of pairing unfamiliar adults is to allow them to recover from anesthesia in a neutral cage (Harkness and Wagner, 1983). Male gerbils raised in isolation exhibit increases in social sniffing, aggression, and anxiety compared with group-reared males (Shimozuru and Kikusui, 2008).

Environmental Conditions

Recommendations for environmental conditions for gerbils are similar to those for rats and mice. Temperature recommendations range from 64–79°F/18–26°C (typically 72 ± 2°F/22 ± 1°C). A 12-h light: 12-h dark cycle is appropriate for general housing, but a longer 14-h light: 10-h dark cycle is desirable for breeding colonies (Field and Sibold, 1999; Moore, 1995). Cold temperatures and/or short light cycles (e.g. 5°C, 8-h light: 16-h dark) may elicit physiological changes related to winter survival mechanisms such as increased basal metabolic rate and non-shivering thermogenesis (Li and Wang, 2005). Relative humidity should be maintained at 30–70% RH; however, rough hair coats have been reported to occur at humidity levels greater than 50% RH (Field and Sibold, 1999; Harkness and Wagner, 1983; Moore, 1995). Housing areas should be kept quiet, because sudden noises may elicit epileptic seizures. The *Guide* (National Research Council, 2011) recommends 10–15 air changes per hour as a general standard for animal holding rooms.

Cage enrichment devices for gerbils that are not made of a sturdy material will be quickly destroyed by the gerbils' natural chewing activities. Stainless steel and PVC materials have been recommended in the form of "toys", cups, tubes, and other shelters (Field and Sibold, 1999). However, it has been suggested that providing shelters may result in differences in behavior, maturation rate, and adrenal weights (Moore, 1995). Nesting material is used readily but may be chewed and incorporated into the cage bedding. Heavier material such as thick cardboard tubing can provide shelter and a chewing substrate which will last longer than other nesting materials (Batchelder, personal communication). Naturalistic environmental enrichment such as sand and stones has been recommended. Sand or deep bedding allow expression of the animals' burrowing behaviors (Field and Sibold, 1999). Sand bathing is an important part of the gerbil behavioral repertoire (Tortora et al., 1974), but providing sand may not always be practical in the laboratory setting.

Gerbils in solid-bottom caging generally have the bedding replaced once or twice a week, depending on factors such as cage density or the presence of newborn pups. Since gerbils are a desert species, they produce little urine and dry feces, which may allow a decreased frequency of bedding changes relative to other species (Moore, 1995). Typically, bedding is changed and solid-bottom cages are sanitized on the same schedule, while animals in wire-bottom cages may have the cage sanitized less often. The *Guide* recommends that primary enclosures and accessories (including lids and feeders) be sanitized at least every 2 weeks (National Research Council, 2011).

Sanitization may be performed by hand or in automated equipment. Detergent and hot water (143–180°F/62–82.2°C) are used to remove soil and disinfect the equipment. Care must be taken to rinse all chemical residue from the caging before use (Committee for the Purpose of Control and Supervision on Experiments on Animals, 2010; National Research Council, 2011). Cages, accessories, and bedding may be autoclaved if a sterile environment is desired (Field and Sibold, 1999).

Nutrition

Gerbils are adapted to live in arid conditions in the wild. Their diet is primarily seeds, and a large portion of their water intake is derived from their food. Although they can live for extended periods without supplemental water, provision of fresh water is generally recommended for animals in captivity. Reproduction may be decreased if water is restricted (Yahr and Kessler, 1974). Supplementation with natural feeds such as vegetables and grains is not necessary, but they may be provided as a treat.

Zeman (1967) proposed a semi-purified diet as a basis for research into the nutritional requirements of gerbils. However, very little work has been published since then, and the specific nutritional requirements of gerbils remain largely undetermined. They are generally considered to be similar to those of the rat, and gerbils are usually maintained by ad libitum feeding of commercial diets formulated for rats or mice. Diets should contain at least 16% protein. Harkness and Wagner (1983) recommend 22% protein and 2–5% dietary fat. Gerbils appear to have a higher need for magnesium than rats, as levels below 1 g/kg diet may result in alopecia and increased susceptibility to seizures; 1.5 g/kg diet is recommended. Gerbils are also susceptible to developing elevated blood and liver cholesterol when fed an excess of fat or cholesterol in the diet (Brain, 1999; Subcommittee on Laboratory Animal Nutrition, 1995). Gerbils are not coprophagic when fed a nutritionally complete diet (Field and Sibold, 1999; Otken and Scott, 1984).

Weanling gerbils may have difficulty reaching food provided in a cage-lid feeder. If necessary, food may be placed in a dish on the cage floor.

Breeding

It is relatively easy to determine the sex of adult gerbils. The male is distinguished by its longer anogenital distance, prominent genital papilla, and pigmented scrotum (Figure 52.2). Gerbils become sexually mature at 9–12 weeks of age. Females have a 4–6-day estrous cycle and are spontaneous ovulators. They are sexually receptive for 12–15 hours, and mating often occurs several times. Males thump their feet as a courtship display. A vaginal plug is present after ejaculation, but usually disappears by the following morning (Brain, 1999). Gestation is 24–26 days, and litter size averages five pups (range 1–12). Larger litters may necessitate fostering some of the pups to another lactating female gerbil or even to a lactating rat (Brain, 1999; Moore, 1995). Both parents participate in building a nest and caring for the young, although during post-partum estrus the male may be more interested in mating than in child-rearing (Prates and Guerra, 2005). Arrington et al. (1973) reported that 47% of females become pregnant at this time. As in mice, gestation during lactation may be prolonged due to delayed implantation (Brain, 1999; Norris and Adams, 1981). Pups are about 2.5 g at birth, are altricial, begin eating solid food at about 14 days of age, and are weaned when they reach 21–24 days of age. Handling and cage changing should be minimized during the breeding and peri-partum periods to reduce the chance of females abandoning their pups.

Gerbils may be bred as pairs or as harems with 2–3 females per male. However, they may form monogamous pairs, mating for life. After the loss of one mate, it may be difficult to introduce a new one to the survivor (Norris and Adams, 1972a). Pairs are usually established at about 6–7 weeks of age (Moore, 1995), although Brain (1999) suggests animals reproduce sooner if paired at 2–3 months of age. Animals may fight or fail to mate if they were not previously housed together. Females which mature earlier (vaginal opening before 25 days of age) have been reported to be more productive breeders than later-maturing females (Brain, 1999). Female gerbils housed as a single-sex group show decreased incidence of estrus whereas pairing with a male will result in estrus by day 3 in 44% of females (Meckley and Ginther, 1974). Pseudopregnancy has been known to occur, lasting a shorter period (14–18 days) than pregnancy (Brain, 1999). Gerbils have a relatively high incidence of cystic ovaries which may affect breeding production (Norris and Adams, 1972b). Wu (1974) has described artificial insemination in the gerbil, and Mochida and Wakayama (2005) describe gerbil embryo cryopreservation with subsequent implantation and live births.

Colony Health

Maintaining a healthy gerbil colony is a matter of good husbandry and sanitation, screening of any new animals brought into the colony, and appropriate veterinary medical care and oversight. Routine health monitoring is recommended to detect any unwanted agents that may arise in the colony.

Animals being brought into an established colony should be obtained from a reliable source and have documentation that they do not carry any infectious agents excluded by the institution. Shipping containers should be disinfected before bringing into the facility, in case the outside surfaces were contaminated during transport. Animals should be checked for general health upon receipt, and in some cases – especially if obtained from a non-commercial or untested source – may be subjected to a quarantine period to ensure absence of unwanted infectious agents before introduction into the general population.

Similarly, any tissues or biologicals that will be introduced into the colony should be screened for infectious agents prior to use (Rehbinder et al., 1996). This can be done by Mouse Antibody Production testing or by screening with a panel of polymerase chain reaction (PCR) tests.

Gerbils have not been reported to be susceptible to spontaneous viral diseases. Nevertheless, they can be screened for viruses that may infect other species, including zoonotic viruses. These include lymphocytic choriomeningitis virus (LCMV), pneumonia virus of mice (PVM), minute virus of mice (MVM), parainfluenza virus, hantavirus, coronavirus, reovirus, Sendai virus, and simian virus 5 (Charles River Laboratories, 2009; Rehbinder et al., 1996).

Health monitoring for agents likely to cause disease in gerbils is primarily directed toward bacterial and parasitic agents. It is recommended that gerbil colonies be screened for *Clostridium piliforme* (Tyzzer's disease) and for *Salmonella* spp. They may also be screened for CAR bacillus, *Bordetella bronchiseptica*, *Pasteurella* spp., Beta *Streptococcus* spp., *Streptococcus pneumoniae*, *Pseudomonas* spp., *Klebsiella* spp., *Helicobacter* spp., *Citrobacter rodentium*, and *Corynebacterium kutscheri*, which may less commonly cause disease in gerbils, or be transmitted to other species (de la Puente-Redondo et al., 1999; Glage et al., 2007). Screening for *Staphylococcus aureus* may generate positive results without disease being present, but the organism can be associated with some conditions such as nasal dermatitis (Charles River Laboratories, 2009; Rehbinder et al., 1996; Solomon et al., 1990).

Screening should also be performed for the more common parasites including *Demodex merioni* mites and pinworms such as *Syphacia* spp. or *Dentostomella translucida* (Wightman et al., 1978). Other possible parasitic agents include *Hymenolepis diminuta* and *Hymenolepis nana*, *Giardia* spp., *Entamoeba muris*, *Eimeria* spp., *Encephalitozoon cuniculi*, *Toxoplasma gondii*, *Spironucleus* spp., and intestinal flagellates.

Screening may be performed using colony animals and/or using dedicated sentinel animals, most often animals exposed to soiled bedding and/or caging from colony animals. Mice have been used as sentinels in gerbil colonies as they are susceptible to lymphocytic choriomeningitis virus, coronavirus, Sendai virus, pneumonia virus of mice, and Reovirus 3, as well as to *Syphacia* and bacterial pathogens (Batchelder, personal communication).

Record Keeping

Several types of records are important in the maintenance of a gerbil colony, including animal records, facility records, breeding records, and regulatory records.

Identification records and health records are two types of animal records. Each animal should be able to be identified as to source, birth date, receipt date, sex, animal use protocol, responsible investigator name, and any identifying information such as an ear tag or microchip number. These records help ensure that the appropriate animal, and the correct animal, is used in an experimental procedure. Health records can include examination records at the time of receipt, surgical and experimental procedure records, and records of any individual health issues and treatments the animal may have received.

Facility records consist of documentation that appropriate husbandry and sanitization procedures have been followed. These are commonly kept as a check-off sheet that lists daily, weekly, and other scheduled tasks which are marked off as they are completed. Other facility records include cage wash and autoclave validation, feed receipt and expiration dates, pest control documentation, environmental parameters such as light, temperature, and humidity, etc.

Breeding records are essential to the maintenance of any breeding colony. An animal's genealogy should be able to be traced, and records should be kept on the breeding success of both males and females. Daily records, such as birth and weaning dates, and long-term records such as planned breeder replacement are necessary to keep breeding at top efficiency. Unless inbreeding is desired, careful records will help avoid mating close relatives.

Additional records may be required by regulatory agencies in the country where the animals are being kept. Such records might include animal receipt and transfer records, disposition records, and documentation concerning the research for which the animals were used. Animals which are sick or which die unexpectedly may be expected to have additional documentation such as individual medical or necropsy records. Records may be needed to document research oversight activities such as approval of protocols involving gerbils, facility inspections, and animal care program reviews. Regulations may also stipulate how long such records need to be retained. Those involved with research using gerbils should be familiar with the regulations for their particular location.

BASIC EXPERIMENTAL METHODS

Gerbils have been used as experimental models in a number of areas of biomedical research. They are relatively easy to maintain and to handle. Experimental methods used for gerbils are similar to those used in other rodents such as mice and rats.

Handling and Restraint

Gerbils are generally non-aggressive and can easily be handled with little risk of being bitten. They may be moved using cupped hands, or may be lifted gently by the base of the tail. Care must be taken to grasp the tail base only (Figure 52.7), since the skin on more distal parts of the tail may pull off easily (Donnelly, 1997). If more secure restraint is needed, gerbils may be grasped by the loose skin on the back of the neck (Figure 52.8). With this grasp, they may be oriented in any position; however gerbils dislike being held on their backs and may struggle in this position (Moore, 1995).

Mechanical restraint devices designed for mice or small rats may be used for gerbils. Again, care must be taken to grasp the tail only at the base when placing the animal in the device to prevent a degloving injury.

A number of chemical agents used in other species are also used to sedate gerbils for handling. These include diazepam (5 mg/kg IM or IP), ketamine (100–200 mg/kg IM), medetomidine (100–200 µg/kg IP or SC), midazolam (5 mg/kg IM or IP), or xylazine (2 mg/kg IM) (Flecknell, 2009; Hawk et al., 2005). Acepromazine has been reported to induce convulsions in gerbils (Harkness and Wagner, 1983) and is not recommended in this species. A short-acting inhalant anesthetic such as isoflurane or sevoflurane may also be used to effect for brief chemical restraint. Atropine (0.02–0.05 mg/kg SC, IM, or IV) or glycopyrrolate (0.01–0.02 mg/kg IM or SC) may be used to decrease salivary and bronchial secretions (Hawk et al., 2005).

FIGURE 52.7 When restraining a gerbil by the tail, only the base of the tail should be grasped to avoid degloving injuries.

Identification

Gerbils may be identified by cage cards, ear tags or notches, indelible markers, or microchip implantation. Tattooing is another option, but is less useful in gerbils than in mice and rats due to the presence of hair on the paws and tail.

Sampling Techniques

Several sites may be used for blood collection in the gerbil. Use of the lateral tail vein may be facilitated by warming the tail to promote blood flow and by placing pressure on the vein at the base of the tail. Methods for

FIGURE 52.8 Gerbils may be restrained by the scruff of the neck.

FIGURE 52.9 Blood collection from the retro-orbital sinus.

FIGURE 52.10 Blood collection by cardiac puncture.

FIGURE 52.11 Measuring the gavage needle to the level of the last rib.

bleeding from the lateral saphenous vein and from the submandibular vein have also been reported (Golde and Gollobin, 2005; Hem and Smith, 1998). For a small amount of blood, a toenail may be clipped short, or the tip of the tail (1–2 mm) may be transected. Care should be taken to control hemorrhage, the tail tip should only be used once or twice to avoid damage to the coccygeal vertebrae, and anesthesia is recommended. Larger volumes of blood may be collected by retro-orbital puncture (Figure 52.9), jugular venipuncture (Palm and Hollander, 2007), or cardiac puncture; all of these procedures should be performed under anesthesia, and cardiac puncture (Figure 52.10) should be terminal because of the risk of pericardial hemorrhage and cardiac tamponade. The maximum volume for blood withdrawal which has the least scientific impact on the gerbil's physiologic response is 0.77 ml/100 g body weight (Diehl et al., 2001; Moore, 1995).

Urine collection is difficult due to the very small volume of urine produced by the gerbil, variously reported as a few drops to 3–4 ml/day (Brain, 1999; Moore, 1995). If urine cannot be collected by expressing the bladder or by free catch, a metabolism cage may be used. Care should be taken that the small amount of urine does not evaporate from the collection chamber.

Compound Administration

Oral administration of compounds is most commonly accomplished with the use a ball-tipped gavage needle, as used in other small rodents. The length of the needle should be checked against the side of the animal to the level of the last rib to ensure it is not so long as to bypass the stomach (Figure 52.11). The needle should slide easily into the stomach (Figure 52.12); any resistance may indicate the needle is located in the trachea and it should be withdrawn and redirected. Animals may also be dosed orally by the use of medicated feed or water. If this method is used, the animals' food and water consumption should be monitored to ensure that the drug is not causing the feed or water to be unpalatable. Decreased consumption may lead to underdosing.

The most common site for intravenous (IV) injection in the gerbil is the lateral tail vein (Figure 52.13). Injection may be facilitated by warming the tail to promote blood flow and by placing pressure on the vein at the base of the tail to dilate the vessel. A 23-gauge or smaller needle should be used (Field and Sibold, 1999). Cutdown procedures have been described for intravenous dosing using the jugular vein (Palm and Hollander, 2007) and the femoral vein (Pérez-García et al., 2002).

FIGURE 52.12 Oral gavage using a ball-tipped dosing needle.

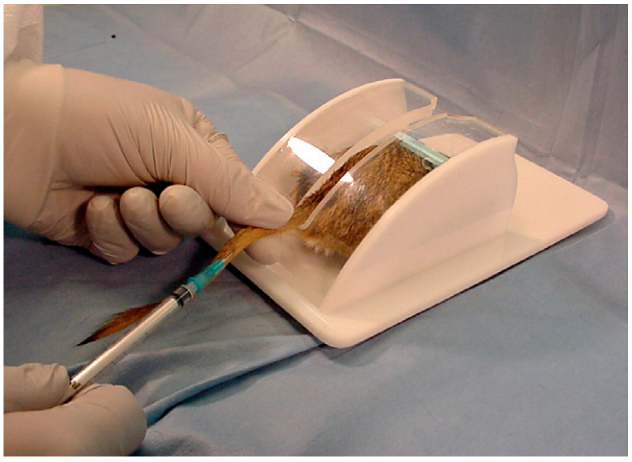

FIGURE 52.13 Intravenous injection in the lateral tail vein.

FIGURE 52.14 Intramuscular injection into the thigh muscles.

FIGURE 52.15 Subcutaneous injections may be given under the loose skin over the gerbil's back by tenting the skin and inserting the needle parallel to the body wall.

Intramuscular (IM) injections are given in the muscles of the thigh (Figure 52.14), with care being taken to avoid the sciatic nerve. The volume of the IM injection should be small enough to avoid muscle damage and pain. Volumes over 0.1 ml should be split between two sites.

Most subcutaneous (SC) injections are given under the loose skin over the neck and shoulders of the gerbil (Figure 52.15). The skin is tented and the needle is inserted parallel to the body wall to avoid injecting into deeper tissues.

Gerbils may be dosed intraperitoneally (IP) in the caudal left or right abdomen, similar to other small rodent species. However, because gerbils may struggle if held on their backs, they should be restrained in a vertical position while dosing (Figure 52.16). Extra care should be taken to draw back on the syringe to ensure the needle has not entered the bowel or bladder prior to injecting.

Other routes of dosing include topical, intradermal, intranasal, and cerebroventricular. Any substance used for parenteral dosing should be sterile and pyrogen-free (Moore, 1995).

If dosing is performed repeatedly, the animal should be monitored closely for any complications. Depression, dyspnea, hunched posture, abdominal splinting, or signs of pain or irritation at an injection site should be brought to the attention of the veterinary staff.

FIGURE 52.16 An intraperitoneal injection is given while holding the gerbil in a vertical position.

An alternative to repeated parenteral injections is the implantation of an osmotic pump. These devices are designed to be implanted subcutaneously or intraperitoneally, and will subsequently provide a steady-state dose of compound for up to several weeks.

Euthanasia

Methods for euthanasia should be selected based on the recommendations of the AVMA (American Veterinary Medical Association, 2007), the experimental parameters, and operator comfort with the procedure. Common methods include carbon dioxide inhalation, overdose of an anesthetic agent (e.g. pentobarbital 100–150mg/kg IP), use of a commercial injectable euthanasia agent, or physical methods such as decapitation or cervical dislocation. The latter two methods should be performed under anesthesia unless scientifically justified and approved by the Institutional Animal Care and Use Committee. Less commonly used methods include microwave irradiation and exsanguination/perfusion under anesthesia. All methods require training and proper equipment in order to be performed humanely.

VETERINARY CARE AND DISEASES

Veterinary Care

Gerbils are excellent subjects for laboratory animal research as they are susceptible to bacterial, viral, and parasitic pathogens that affect humans and other species, yet they have very few of their own diseases. Some of the most common conditions seen in laboratory gerbils are related to handling, husbandry, or keeping the gerbils until old age. In general, veterinary practices used in providing health care for other laboratory rodents are also appropriate for laboratory gerbils.

Meeting gerbils' specific housing and husbandry needs will help keep them healthy. Gerbils' hind legs are longer than their front legs and they like to stand erect on the hind legs. To accommodate this behavior, the floor to lid height of gerbil cages needs to be sufficient for the gerbil to stand. Gerbils should be housed in solid-bottom caging with bedding at least 3–5cm deep to allow for burrowing behavior. Gerbils also exhibit gnawing behavior and need to have non-toxic, hard materials on which to gnaw.

Gerbils must be picked up by the base of the tail to avoid the skin on the tail degloving. They should have their incisors and claws checked periodically to make sure that both are being worn down. Claws can be clipped if they are too long. A rough-surfaced object such as a stone or a bathroom tile can be placed in the cage for the gerbils to wear down their claws as well as to use for normal marking behaviors. Gerbils exhibit shredding behavior and should be provided with autoclaved cardboard, hay, straw, paper, or tissue. Gerbils are burrowing animals and sometimes will resort to stereotypic digging in the corner of the cage. A man-made burrow may be used in a laboratory setting. One example utilizes clear and opaque sections with an access tunnel (Waiblinger, 2010).

Gerbils need to have a substrate to remove the lipids that they place on their hair coat during self-grooming. In the wild, gerbils use sand baths, and they will use them in the laboratory if provided (Tortora et al., 1974). If gerbils exhibit a dirty, ungroomed hair coat, consider changing the type and amount of bedding, make sure the relative humidity is less than 50% and consider lowering the temperature of the room.

Common Diseases

Epilepsy

Gerbils may have spontaneous seizures secondary to stress such as handling, cage change, abrupt noises, or changes in the environment. Generally, gerbils will recover from these seizures after 30–90 seconds without treatment, and appear to have no long-lasting effects.

Tail Slip

Gerbils that are picked up by the tip or middle of the tail are very susceptible to skin degloving (Donnelly, 1997). Gerbils should always be picked up by the base of the tail or by cupping the hands. Tails that have been degloved can be surgically amputated.

Nasal Dermatitis (Sore Nose, Facial Eczema)

This is a common skin condition of gerbils which likely has a multifactorial etiology. Clinical signs start as erythema at the nares and develop into facial alopecia, dermatitis, and scab formation. Some cases can develop into a moist dermatitis involving the head, forelimbs, and chest. This condition has been reported to be most common in young weanling gerbils (Field and Sibold, 1999).

Gerbils release a complex mixture of pigments and lipids from the Harderian gland during self-grooming. The material is excreted at the nares and is mixed with saliva and spread over the gerbil's hair coat. Harderian exudates are normally removed from the gerbil's pelage by sand bathing (Harriman and Thiessen, 1983; Thiessen, 1988). Two studies have shown that Harderian secretions which act as primary skin irritants are a factor in the development of nasal dermatitis. Removal of Harderian glands or housing animals on sand either prevented lesions or caused improvement in existing lesions, while animals with intact Harderian glands and reduced opportunity to groom or sand bathe developed or maintained existing lesions (Farrar et al., 1988; Thiessen and Pendergrass, 1982).

Staphylococcus spp. have been implicated in the development of this condition. One paper reports *S. aureus* as the bacteria most commonly cultured from the nasal area of affected animals, although *S. aureus* was also cultured from non-affected gerbils (Bresnahan et al., 1983). Another study reported that *S. xylosus* was the predominant species isolated from all gerbils, most commonly from the nasal area, and the only species isolated from the nasal area of gerbils with clinical signs of nasal dermatitis (Solomon et al., 1990).

Cystic Ovaries

Cystic ovaries are seen commonly in female gerbils over 1 year of age (Norris and Adams, 1972b). Clinical signs include symmetrical alopecia, abdominal swelling, lethargy, anorexia, dyspnea, and reduced fertility. In 1982, Norris and Adams showed that female gerbils older than 700 days had a 79% rate of cystic ovaries in gerbils with two ovaries and a 40% rate of cystic ovaries in gerbils with one ovary. They also showed that removing one ovary in a gerbil does little to affect overall reproductive performance (Norris and Adams, 1982).

Less Common Diseases

Bacterial

Although there have been reports of bacterial diseases in laboratory gerbils in the past, animals can be purchased today that are free from antibodies to *Clostridium piliforme* and are culture-negative for *Salmonella* spp., *Bordetella bronchiseptica*, and *Pasteurella pneumotropica*. The most common bacterial threat to a high-quality research colony is helicobacter.

There have been reports of laboratory and pet gerbils infected with *Clostridium piliforme,* the etiologic agent for Tyzzer's disease (Motzel and Gibson, 1990; Port et al., 1971; Vincent et al., 1975). Gerbils usually exhibited diarrhea or sudden death. Necropsy findings included multi-focal hepatic necrosis. In 1984, Waggie et al. experimentally induced Tyzzer's disease in gerbils and showed that they were highly susceptible to the disease. Strittmatter (1972) eliminated the disease in gerbils by cross-fostering gerbil offspring to unaffected mice.

In 2005, Bergin et al. reported a case of two laboratory gerbils with fatal *Clostridium difficile* enteritis. The gerbils were being treated for helicobacter infection with antibiotic wafers containing amoxicillin, metronidazole, and bismuth subsalicylate. There is also one report of a fatal epidemic of *Citrobacter rodentium* affecting nine gerbils (de la Puente-Redondo et al., 1999).

In 2009, Tappe et al. reported a new species of the genus *Streptococcus* which was cultured from the oropharynx of Mongolian gerbils. The new name proposed for these Gram-positive, catalase-negative, chain-forming cocci is *Streptococcus merionis* sp. nov. There were no clinical signs reported in the gerbils.

Gerbils are natural carriers of multiple species of helicobacter (Bergin et al., 2005). Glage et al. (2007) reported rederivation of *Helicobacter hepaticus*-infected gerbils by Caesarean section and cross-fostering on non-infected mice.

Viral

No naturally occurring viral diseases of gerbils have been published.

Parasitic

Parasites rarely cause clinical problems in the laboratory gerbil, and are excluded from major commercial gerbil suppliers. Wightman et al. (1978) reported finding *Syphacia obveleta* and *Dentostomella translucida* in gerbils. They showed that *S. obveleta* can be transmitted from gerbil to mouse, mouse to gerbil, and gerbil to gerbil, while Ross et al. (1980) showed that *Syphacia muris* is similarly easily transmitted between gerbils, rats, hamsters, and mice. Wilkerson et al. (2001) reported that using fenbendazole-medicated feed was the only practical and reliable way to eradicate pinworms in gerbil colonies. In 1970, Lussier and Loew reported a naturally occurring case of *Hymenolepis nana* in Mongolian gerbils, while in 1975, Vincent et al. reported the recovery of *Hymenolepis diminuta* from gerbils. *Demodex merioni* mites have been reported in gerbils with alopecia, dry skin, and ulcerations. Animals who are already debilitated are at most risk for developing mite infestations (Rollin and Kesel, 1995).

Other Diseases

Antibiotic Sensitivity

Gerbils are very sensitive to dihydrostreptomycin. Wightman et al. (1980) reported that an injection of 50 mg caused mortality in 80–100% of gerbils weighing 55–65 grams. Two gerbils given a commercially available treatment to eradicate helicobacter developed a necrohemorrhagic enteritis. It was determined that the amoxicillin component caused an overgrowth of *Clostridium difficile* (Bergin et al., 2005).

Neoplasia

There are a number of surveys about neoplasia in laboratory colonies of Mongolian gerbils (Meckley and Zwicker, 1979; Ringler et al., 1972; Vincent and Ash, 1978; Vincent et al., 1975). Neoplasia has been most often reported in gerbils over 3 years of age (Matsuoka and Suzuki, 1995). Commonly reported tumors are squamous cell carcinoma of the ventral marking gland in males and ovarian granulosa cell tumors in females. In surveys, adrenocortical tumors, cutaneous squamous cell carcinoma, malignant melanoma, and renal and splenic hemangiomas are the next most commonly reported tumors. Other tumors that have been reported include astrocytoma, craniopharyngioma, and systemic mastocytosis (Guzman-Silva, 1997; Guzman-Silva et al., 1988; Kroh et al., 1987; Rembert and Johnson, 2001). In 1997, Campos et al. reported a variety of epithelial-type neoplasias in the ventral prostrate of 18-month-old gerbils. Tumors included prostatic intraepithelial neoplasias, microinvasive carcinomas, and adenocarcinomas.

Chronic Interstitial Nephritis

This condition is considered an old-age change. Gerbils will exhibit clinical signs of polyuria, polydipsia, and weight loss. On gross exam the kidneys will be shrunken and pitted (Bingel, 1995).

Aural Cholesteatoma

Older gerbils can spontaneously develop cholesteatomas in the ear canal which resemble the human condition. Clinical signs include scratching, head tilt, and circling. The incidence appears to be age-related (Fulghum and Cole, 1985; Schiffer et al., 1986).

GERBILS AS EXPERIMENTAL MODELS

Gerbils have unique characteristics which make them appropriate for a number of animal models. Classically, gerbils have been used in research involving stroke, parasitology, infectious diseases, epilepsy, brain development and behavior, and hearing.

Stroke (Cerebral Ischemia)

In mammals the circle of Willis is comprised of a communication of arteries at the bottom of the brain consisting of the internal carotid arteries, anterior cerebral arteries, anterior communicating arteries, posterior communicating arteries, posterior cerebral arteries, and basilar arteries. This structure provides for alternate blood flow to the brain in case one artery becomes occluded. Levine and Payan (1966) first identified gerbils as having an anatomical anomaly of the circle of Willis with no communication between the posterior cerebral arteries. This has been termed an incomplete circle of Willis. Researchers found that ligating the left carotid artery of the gerbil caused acute cerebral ischemia much more consistently than when performing the same ligation in the rat (Wexler, 1972). In 1974, Levy and Brierley performed a study on gerbils to assess the cerebrovascular anatomy and communications in the gerbil brain by injecting colored dye into the aorta. Based on evaluating ten male gerbils from an unspecified source, these authors concluded that each of the gerbil's carotid arteries is divided into an anterior, middle, and posterior cerebral artery. They found that the basilar artery communicated with the carotid artery in all gerbils, that the posterior cerebral artery was a branch of the carotid, and that there was no single posterior communicating artery.

As gerbils were more frequently used for stroke research, more information about their cerebrovascular anatomy became available. It was determined that not all gerbils have an incomplete circle of Willis and that "stroke-prone" and "stroke-resistant" gerbils could be identified (Delbarre et al., 1988; Kitagawa et al., 1989; Pelliccioli et al., 1995). Considerable variability was found both in the extent of damage after bilateral artery occlusion and in the percentage of stroke-prone gerbils in a population. The percentage varied between the sexes (males 42.9% stroke-prone, females 26.7%) (Hall et al., 1991) and by the source of the animals (Breuer and Mayevsky, 1992; Laidley et al., 2005; Seal et al., 2006).

Methods to define stroke-prone gerbils include examination of retinal blood flow after ligation of the carotid artery (Delbarre et al., 1988), measurement of the diameter of the common carotid artery before and after temporary ligation (Kitagawa et al., 1989), survival after unilateral carotid artery occlusion (Pellliccioli et al., 1995), and determination of the presence and diameter of the posterior communicating artery (Seal et al., 2006).

Despite the fact that the anatomy of the gerbils' circles of Willis cannot be considered uniformly lacking in posterior communicating arteries, gerbils continue to be used as a common animal model for stroke, with the two-vessel occlusion being considered the simplest (Small and Buchan, 2000). Laboratory animal veterinarians that work with gerbils as stroke models need to be aware that this difference in cerebral vascular anatomy could lead to variable or conflicting results.

Parasitic Diseases

Gerbils seem to be very well suited to host parasitic infections from other species and are therefore a popular animal model for a wide variety of parasites. Many parasitic genera have been described in experimental studies of infection, susceptibility, pathology, immunology, and chemotherapy.

Cestodes

Gerbils are alternative definitive hosts for *Echinococcus granulosis* (Conchedda et al., 2006). Gerbils have also been used as an animal model for *Echinococcus multilocularis* (Kamiya and Sato, 1990) as well as *Echinococcus vogeli* (Matsuo et al., 2000).

Although the Mongolian gerbil is not a natural host for *Rodentolepsis nana*, it can be experimentally transmitted to gerbils that are given dexamethasone daily (Vianna and deMelo, 2007). Gerbils have also been experimental hosts for *Hymenolepis diminuta*, *Taeniasolium*, *Taenia saginata*, *Taenia asiatica*, and *Taenia crassiceps* (Avila et al., 2005; Chang et al., 2006; Johnson and Condor, 1996; Kamiya and Sato, 1990; Sato et al., 2000).

Nematodes

Gerbils can also serve as experimental hosts for a number of nematode parasites. These include Haemonchus contortus, Toxocara canis, Strongyloides stercoralis, Strongyloides papillosus, Aspiculuris tetraptera, Syphacia obvelata, Dentostomella translucida, and Baylisascaris procyonis (Akao et al., 2003; De Jesús-Gabino et al., 2009; Lok, 2007; Pinto et al., 2003a, 2003b; Zanandréa et al., 2008).

One of the most important uses of gerbils in biomedical research is for the study of filarid nematodes, which include *Brugia malayi*, *Brugia pahangi*, *Loa loa*, and *Litomosoides sigmodontis* (Lim et al., 2004; Mand et al., 2006; Shigeno et al., 2006; Wanji et al., 2002). Gerbils have been experimentally infected with these filarid nematodes to study the immunology, antigenicity, and life cycles of the parasites. Serologic tests and treatment regimens have been developed by using these models (Hübner et al., 2009; Lim et al., 2004; Shigeno et al., 2006).

Trematodes

Gerbils have been used to study all aspects of the trematode life cycle including infectivity and immunology as well as to study potential treatments. These trematodes include *Schistosoma mansoni*, *Schistosoma japonicum*, *Schistosoma haemotobium*, *Schistosoma magreboweie*, *Echinostoma caproni*, and *Opisthorcis viverinni* (Adam et al., 1993; Boonmars et al., 2009; Chisty et al., 2002; Mahler et al., 1995; Ogbe, 1983; Sato and Kamiya, 2001). Gerbils are also a good host for the avian schistosome, *Austrobilharzia variglandis* (Bacha et al., 1982).

Protozoa

Gerbils are good animal models for intestinal *Cryptosporidium parvum* infection and for gastric infection with *Cryptosporidium andersoni* and *muris* (Kvác et al., 2009). Immunosuppressed gerbils have been reported to be infected with *Cryptosporidium hominis* (Baishanbo et al., 2005).

Gerbils have been identified as a model for infection with *Giardia lamblia* (Belosevic et al., 1984; Faubert et al., 1983). Gerbils were used to develop the fecal antigen test for giardiasis (Moss et al., 1990). Gerbils can also be experimentally infected with *Giardia duodenalis* (Araújo et al., 2008).

Viral Diseases

Borna Disease

This is caused by a negative-strand RNA neurotropic virus which causes acute or subacute encephalitis in horses and sheep. This virus has been linked with schizophrenia and other affective disorders in humans (Rott et al., 1985). Borna disease is considered a model for studying neuronal plasticity, as the virus can persist in the CNS and cause changes in brain cell function (Gonzalez-Dunia et al., 2005). The gerbil is the definitive animal model for Borna disease. Newborn gerbils are very susceptible to intracranial infection with Borna virus resulting in inflammatory reactions in the brain as well as evidence of viral persistence in the brain (Nakamura et al., 1999).

Swine Hepatitis Virus

In 2009, gerbils were identified as the first animal model for swine hepatitis virus. Gerbils inoculated intraperitoneally with hepatitis E virus became infected, with viremia and virus shedding in the feces for 4 weeks. Additionally, the virus could be found in the liver of the infected gerbils (Li et al., 2009).

La Crosse Virus

This is an arbovirus that is one of the most common causes of pediatric arboviral infection in the US (Haddow and Odoi, 2009). In 1996, researchers at the University of Wisconsin discovered that Mongolian gerbils were an ideal animal model for La Crosse virus studies. Gerbils were susceptible to infection, survived, and developed viremia and neutralizing antibody titers following exposure by intramuscular injection and by the bite of infected mosquitoes. Moreover, they are attractive to mosquito vectors (Osorio et al., 1996).

Other Viruses

Gerbils are able to be infected with encephalomyocarditis virus, with viral replication evident in the heart and pancreas (Matsuzaki et al., 1989a). The young gerbil has also been identified as the first animal model of Rift Valley fever encephalitis that was uniformly fatal without causing lesions outside of the CNS (Anderson et al., 1988). During the summer of 2003, three gerbils were shown to be infected with monkey pox virus after being exposed to the virus from an infected Gambian giant rat (Kulesh et al., 2004). Newborn gerbils have been shown to be a better model for Puumula virus transmission than rats or mice (Lokugamage et al., 2003). Newborn gerbils can also be experimentally infected with reovirus 3 with histopathologic lesions noted in the brain and pancreas (Yukawa et al., 1993).

Bacterial Diseases

Helicobacteriosis

The gerbil is favored by many researchers as an animal model for *Helicobacter pylori* research because, when infected, the gerbil develops severe gastritis and gastric ulcers. These ulcers do not heal spontaneously but do respond to therapeutic treatment. This is similar to human infection with *Helicobacter pylori* (Peek, 2008). Gerbils also can develop gastric adenocarcinoma secondary to chronic helicobacter infection (Franco et al., 2008; Tsukamoto et al., 2007; Watanabe et al., 1998).

Listeriosis

The Mongolian gerbil is an animal model for listeriosis, the disease resulting from infection with *Listeria monocytogenes* (Blanot et al., 1997). The gerbil has two cell receptors which are similar to the human, InlA-E-cadherin and InlB-Met. These cell receptors work with *L. monocytogenes* surface proteins to facilitate entry into the cells (Disson et al., 2009).

Leptospirosis

The gerbil has been identified as a good animal model to study pulmonary hemorrhage as a consequence of severe leptospirosis infection. More importantly, the gerbil mimics the human in its response to the infection by producing increased amounts of platelet-activating factor acetylhydrolase (Yang et al., 2009).

Borreliosis

Gerbils have been used in research on vaccines for *Borrelia burgdorferi,* the etiologic agent for Lyme disease (Preac-Mursic et al., 1992).

Epilepsy (Seizures)

Gerbils are considered a good model for inherited epilepsy. Gerbils will display spontaneous, recurrent generalized seizures beginning at about 6 weeks of age (Buckmaster and Wong, 2002; Loskota and Lomax, 1975). Mongolian gerbils were first identified as a new animal model of inherited seizures in 1968 (Thiessen et al., 1968b). Immediately thereafter a number of papers were published regarding gerbils and seizures (Kaplan and Miezejeskic, 1972; Loskota et al., 1974, 1975).

In the 1970s Loskota started a selective breeding program at UCLA to develop seizure-sensitive and seizure-resistant gerbils. Selective breeding of three pairs of seizure-sensitive gerbils, originating from Tumblebrook Farm in Massachusetts, for 18 generations resulted in the creation of the seizure-sensitive gerbil. The seizure-sensitive gerbils were identified as WJL/UC and seizure-resistant gerbils as STR/UC (Loskota et al., 1974).

Mongolian gerbils continue to be used as a model of inherited epilepsy. It is now known that the seizure-sensitive gerbils have abnormalities that involve the GABAergic synaptic transmission in the brain (Hwang et al., 2004; Kang et al., 2001; Kwak et al., 2005). The entire mechanism of how and why seizures occur continues to be under investigation.

Brain Development and Behavior

Since the 1980s, the gerbil has been widely used in studies of brain growth and development, neural plasticity, behavior, and normal and pathological aspects of aging (Cheal, 1986). Examples include studies of changes in the muscarinic receptors in the gerbil thalamus from age 6–36 months (Pilar-Cuéllar et al., 2008), effects of periadolescent sensory stimulation on neural development (Lehmann et al., 2009), and ontogeny of the dopamine innervations in the nucleus accumbens (Lesting et al., 2005). Behavioral studies include reports of neonatal separation that results in behavioral and biochemical differences in adult gerbils (Jaworska et al., 2008) and studies of the effects of the father in gerbil developmental behavior (Piovanotti and Vieira, 2004). Lee et al. (2009, 2010a, 2010b) have studied neurochemical changes in the gerbil brain, especially the hippocampus, as it relates to aging. As gerbils are an important model for hearing research there is also interest in the development of specific parts of the brain that relate to hearing, such as age-related changes in the medial nucleus of the trapezoid body and in the lateral superior olive (Gleich and Strutz, 2002; Gleich et al., 2004).

General Neuroscience

Gerbils have been used extensively in neuroscience research. It has been found that gerbils are more homologous to humans in the tachykinin NK-1, 2, 3, receptor activity and affinity as compared to rats and mice (Griffante et al., 2006; Leffler et al., 2009). A new model, gerbil foot tapping, has been developed as a fear-related response. Gerbils injected with NK-1 agonists in the brain develop a fear-related foot-tapping behavior (Bristow and Young, 1994; Sundqvist et al., 2007). Gerbils have also been used as animal models of anxiety in the elevated plus maze and Black/White Box tests (Bridges and Starkey, 2004; Heldt et al., 2009), and to evaluate the anxiolytic properties of rose odor inhalation (Bradley et al., 2007). Gerbils have been used in the forced swim test which has predictive validity for the evaluation of novel anti-depressants (Wallace-Boone et al., 2008). In 2009, Gaese et al. published a report using Mongolian gerbils for acoustic startle and prepulse inhibition studies.

Auditory Research

Mongolian gerbils are a common animal model in auditory research as gerbils have human-like low-frequency hearing (Engel, 2008; Wetzel et al., 2008). Gerbils have been used as an animal model of auditory neuropathy and it has been shown that there is the potential for use of stem cells to cure some hearing loss (Matsuoka et al., 2007).

Miscellaneous Disease Models and Research Uses

Iron Overload

The gerbil is the first animal model found for the human disease hemochromatosis. In the experimental gerbil model histopathologic lesions in the heart and liver are very similar to the human disease. The model is created by once- or twice-daily injections with iron dextran (Carthew et al., 1993). The gerbil iron-overload model continues to be used to further elucidate the mechanisms of the disease as well as to explore potential therapies (Al-Rousan et al., 2009; Kaiser et al., 2003; Otto-Duessel et al., 2008).

Cholesteatoma and Otitis Media

Just as gerbils have been used widely in acoustic and auditory basic research, they have also been found to be an animal model for cholesteatoma, a benign tumor of the middle ear. The animal model is most commonly created by surgical ligation of the gerbil's auditory duct (Choufani et al., 2007; Kim and Chole, 1998). Gerbils are also commonly used for studies of infectious otitis media. In the induced model the gerbils are usually infected with *Streptococcus pneumoniae* (Soriano et al., 2000), although *Haemophilus influenza* (Ponte et al., 1999) and *Moraxella catarrhallis* (Fulghum and Marrow, 1996) have also been used.

Prostate Gland Biology

Gerbils have been used as an animal model for the study of androgen receptors in the prostate gland (Campos et al., 1997; Cordeiro et al., 2008).

Dental Research

Gerbils are used as experimental models to correlate the periodontium's biological response to various mechanical stresses, as the periodontal ligament was shown to be highly sensitive to occlusal alterations (Iyomasa et al., 2008). Gerbils have also been used as animal models for dental caries (Fitzgerald and Fitzgerald, 1966).

References

9CFR Part 3. Office of the Federal Register, Washington, D.C.

Adam, R., Hinz, E., Sithithaworn, P., Pipitgool, V., Storch, V., 1993. Ultrastructural hepatic alterations in hamsters and jirds after experimental infection with the liver fluke *Opisthorchis viverrini*. Parasitol. Res. 79, 357–364.

Agren, G., 1986. Gerbils. In: MacDonald, D. (Ed.), All the World's Animals-Rodents (pp. 90–93). Torstar Books, New York.

Akao, N., Tomoda, M., Hayashi, E., Suzuki, R., Shimizu-Suganuma, M., Shichinohe, K., et al. 2003. Cerebellar ataxia due to *Toxocara* infection in Mongolian gerbils, *Meriones unguiculatus*. Vet. Parasitol. 113, 229–237.

Alderton, D., 1986. A Petkeeper's Guide to Hamsters and Gerbils. Tetra Press, United Kingdom.

Al-Rousan, R.M., Paturi, S., Laurino, J.P., Kakarla, S.K., Gutta, A.K., Walker, E.M., et al. 2009. Deferasirox removes cardiac iron and attenuates oxidative stress in the iron-overloaded gerbil. Am. J. Hematol. 84, 565–570.

Anderson G.W., Jr., Slone T.W., Jr., Peters, C.J., 1988. The gerbil, *Meriones unguiculatus*, a model for Rift Valley fever viral encephalitis. Arch. Virol. 102, 187–196.

Araújo, N.S., Mundim, M.J, Gomes, M.A., Amorim, R.M., Viana, J.C., Queiroz, R.P., et al. 2008. *Giardia duodenalis*: pathological alterations in gerbils, *Meriones unguiculatus*, infected with different dosages of trophozoites. Exp. Parasitol. 118, 449–457.

Arrington, L.R., Beaty, T.C., Kelley, K.C., 1973. Growth, longevity, and reproductive life of the Mongolian gerbil. Lab. Anim. Sci. 23, 262–265.

American Veterinary Medical Association, 2007. AVMA Guidelines on Euthanasia. Retrieved on October 29, 2009, from <http://www.avma.org/issues/animal_welfare/euthanasia.pdf/>.

Avila, G., Teran, N., Aguilar-Vega, L., Maravilla, P., Mata-Miranda, P., Flisser, A., 2005. Laboratory animal models for human *Taenia solium*. Parasitol. Int. 55 (Suppl.), S99–S103.

Bacha Jr., W.J., Roush Jr., R., Icardi, S., 1982. Infection of the gerbil by the avian schistosome *Austrobilharzia variglandis* (Miller and Northrup 1926, Penner 1953). J. Parasitol. 68, 505–507.

Baishanbo, A., Gargala, G., Delaunay, A., François, A., Ballet, J.J., Favennec, L., 2005. Infectivity of *Cryptosporidium hominis* and *Cryptosporidium parvum* genotype 2 isolates in immuno-suppressed Mongolian gerbils. Infect. Immun. 73, 5252–5255.

Bal, H.S., Ghoshal, N.G., 1988. Morphology of the terminal bronchiolar region of common laboratory mammals. Lab. Anim. 22, 76–82.

Başkaya, M.K., Doğan, A., Dempsey, R.J., 1999. Application of endovascular suture occlusion of middle cerebral artery in gerbils to obtain consistent infarction. Neurol. Res. 21, 574–578.

Belosevic, M., Faubert, G.M., Guy, R., MacLean, J.D., 1984. Observations on natural and experimental infections with Giardia isolated from cats. Can. J. Comp. Med. 48, 241–244.

Belhocine, M., Gernigon-Spychalowicz, T., Jacob, M.P., Benazzoug, Y., Exbrayat, J.M., 2010. Immunoexpression of gelatinase (MMP-2 and MMP-9) in the seminal vesicles and ventral prostate of Libyan jird (*Meriones libycus*) during the seasonal cycle of reproduction. Histol. Histopathol. 25, 619–636.

Bergin, I.L., Taylor, N.S., Nambiar, P.R., Fox, J.G., 2005. Eradication of enteric helicobacters in Mongolian gerbils is complicated by the occurrence of *Clostridium difficile* enterotoxemia. Comp. Med. 55, 265–268.

Bingel, S.A., 1995. Pathologic lesions in an aging Mongolian gerbil. (*Meriones unguiculatus*) colony. Lab. Anim. Sci. 45, 597–600.

Blanot, S., Joly, M.M., Vilde, F., Jaubert, F., Clement, O., Frija, G., et al. 1997. A gerbil model for rhombencephalitis due to *Listeria monocytogenes*. Microb. Pathog. 23, 39–48.

Boonmars, T., Boonjaraspinyo, S., Kaewsamut, B., 2009. Animal models for *Opisthorchis viverrini* infection. Parasitol. Res. 104, 701–703.

Bradley, B.F., Starkey, N.J., Brown, S.L., Lea, R.W., 2007. The effects of prolonged rose odor inhalation in two animal models of anxiety. Physiol. Behav. 92, 931–938.

Bradley, P., Pence, H., 1995. A Step-by-Step Book about Gerbils. T.F.H. Publications, Inc., Neptune City, NJ.

Brain, P.F., 1999. The laboratory gerbil. In: Poole, T. (Ed.), The UFAW Handbook on the Care and Management of Laboratory Animals, vol. 1. Terrestrial Vertebrates, seventh ed. Blackwell Science, Malden, MA, pp. 345–355

Bresnahan, J.F., Smith, G.D., Lentsch, R.H., Barnes, W.G., Wagner, J.E., 1983. Nasal dermatitis in the Mongolian gerbil. Lab. Anim. Sci. 33, 258–263.

Breuer, Z., Mayevsky, A., 1992. Brain vasculature and mitochondrial responses to ischemia in gerbils. II. Strain differences and statistical evaluation. Brain Res. 598, 251–256.

Bridges, N.J., Starkey, N.J., 2004. Sex differences in Mongolian gerbils in four tests of anxiety. Physiol. Behav. 83, 119–127.

Bristow, L.J., Young, L., 1994. Chromodacryorrhea and repetitive hind paw tapping: models of peripheral and central tachykinin NK1 receptor activation in gerbils. Eur. J. Pharmacol. 253, 245–252.

Buckmaster, P.S., Wong, E.H., 2002. Evoked responses of the dentate gyrus during seizures in developing gerbils with inherited epilepsy. J. Neurophysiol. 88, 783–793.

Bytyqi, A.H., Layer, P.G., 2005. Lamina formation in the Mongolian gerbil retina *Meriones unguiculatus*. Anat. Embryol. 209, 217–225.

Campos, S.G.P., Zanetoni, C., Scarano, W.R., Vilamaior, P.S.L., Taboga, S.R., 1997. Age-related histopathological lesions in the Mongolian gerbil ventral prostate as a good model for studies of spontaneous hormonal related disorders. Int. J. Exp. Path. 89, 13–24.

Carthew, P., Dorman, B.M., Edwards, R.E., Francis, J.E., Smith, A.G., 1993. A unique rodent model for both the cardiotoxic and hepatotoxic effects of prolonged iron overload. Lab. Invest. 69 (2), 217–222.

Chang, S.L., Ooi, H.K., Nonaka, N., Kamiya, M., Oku, Y., 2006. Development of *Taenia asiatica* cysticerci to infective stage and adult stage in Mongolian gerbils. J. Helminthol. 80, 219–223.

Cheal, M.L., 1986. The gerbil: a unique model for research on aging. Exp. Aging Res. 12, 3–21.

Charles River Laboratories, 2009. Health Monitoring Protocols. Retrieved on October 11, 2009, from <http://www.criver.com/SiteCollectionDocuments/rm_ld_c_health_monitoring.pdf/>.

Chaworth-Musters, J.L., Ellerman, J.R., 1947. A revision of the genus Meriones. Proc. Zool. Soc. Lond. 117, 478–504.

Chisty, M.M., Nargis, M., Sato, H., Inaba, T., Takahashi, G., Kamiya, H., 2002. *Schistosoma mansoni*: kinetics of glomerulonephritis in Mongolian gerbils and its correlation with intensity and duration of infection. Parasite 9, 143–151.

Choufani, G., Roper, N., Delbrouck, C., Hassid, S., Gabius, H.J., 2007. Animal model for cholesteatoma induced in the gerbil: will the profiles of differentiation/growth-regulatory markers be similar to the clinical situation? Laryngoscope 117, 706–711.

Clark, J.D., 1984. Biology and diseases of other rodents. In: Fox, J.G., Cohen, B.J., Loew, F.M. (Eds.), Laboratory Animal Medicine (pp. 183–206). Academic Press, Orlando.

Commins, D., Yahr, P., 1984. Adult testosterone levels influence the morphology of a sexually dimorphic area in the Mongolian gerbil brain. J. Comp. Neurol. 224, 132–140.

Committee for the Purpose of Control and Supervision on Experiments on Animals (CPCSEA), 2010. CPCSEA Guidelines for Laboratory Animal Facility. Retrieved on May 25, 2010, from <http://envfor.nic.in/divisions/awd/cpcsea_laboratory.pdf/>.

Conchedda, M., Gabriele, F., Bortoletti, G., 2006. Development and sexual maturation of *Echinococcus granulosus* adult worms in the alternative definitive host. Acta Tropica 97, 119–125.

Corbet, G.B., 1978. The Mammals of the Palaearctic Region: A Taxonomic Review. British Museum (Natural History), London.

Cordeiro, R.S., Scarano, W.R., Campos, S.G., Santos, F.C., Vilamaior, P.S., Góes, R.M., et al. 2008. Androgen receptor in the Mongolian gerbil ventral prostate: evaluation during different phases of post-natal development and following androgen blockage. Micron 39, 1312–1322.

Cramlet, S.H., Toft, J.D., Olsen, N.W., 1974. Malignant melanoma in a black gerbil (*Meriones unguiculatus*). Lab. Anim. Sci. 24, 545–547.

Cullen, J.W., Pare, W.P., Modney, A.L., 1971. Adrenal weight ratios in the Mongolian gerbil (*Meriones unguiculatus*). Growth 35, 169–176.

Dagg, A.I., Windsor, D.E., 1971. Olfactory discrimination limits in gerbils. Can. J. Zool. 49, 138–140.

De Jesús-Gabino, A.F., Mendoza-de Gives, P., Salinas-Sánchez, D.O., López-Arellano, M.E., Liébano-Hernández, E., Hernández-Velázquez, V.M., et al. 2009. Anthelmintic effects of *Prosopis laevigata* n-hexanic extract against *Haemonchus contortus* in artificially infected gerbils (*Meriones unguiculatus*). J. Helminthol. 21, 1–5.

de la Puente-Redondo, V.A., Gutiérrez-Martín, C.B., Pérez-Martínez, C., del Blanco, N.G., García-Iglesias, M.J., Pérez-García, C.C., et al. 1999. Epidemic infection caused by *Citrobacter rodentium* in a gerbil colony. Vet. Rec. 145, 400–403.

Delbarre, G., Delbarre, B., Barrau, Y., 1988. A suitable method to select gerbils with incomplete circle of Willis. Stroke 19, 126.

Diehl, K.H., Hull, R., Morton, D., Pfister, R., Rabemampianina, Y., Smith, D., et al. 2001. A good practice guide to the administration of substances and removal of blood, including routes and volumes. J. Appl. Toxicol. 21, 15–23.

Dillon, W.G., Glomski, C.A., 1975. The Mongolian gerbil: qualitative and quantitative aspects of the cellular blood picture. Lab. Anim. 9, 283–287.

Disson, O., Nikitas, G., Grayo, S., Dussurget, O., Cossart, P., Lecuit, M., 2009. Modeling human listeriosis in natural and genetically engineered animals. Nat. Protoc. 4, 799–810.

Donnelly, T.M., 1997. Disease problems of small rodents. In: Hillyer, E.V., Quesenberry, K.E. (Eds.), Ferrets, Rabbits and Rodents: Clinical Medicine and Surgery (pp. 307–327). W.B. Saunders, Philadelphia.

Drummond, T.D., Mason, J.L., McCarthy, J.L., 1988. Gerbils' adrenal 11 beta- and 19-hydroxylating activities respond similarly to inhibitory or stimulatory agents: two activities of a single enzyme. J. Steroid Biochem. 29, 641–648.

Ellerman, J.R., Morrison-Scott, T.C.S., 1951. Checklist of Palaearctic and Indian Mammals 1758 to 1946. British Museum (Natural History), London.

Elwood, R.W., 1975. Paternal and maternal behavior in the Mongolian gerbil. Anim. Behav. 23, 766–772.

Engel, J., 2008. Gerbils can tune in. J. Physiol. 586 (4), 919.

Farrar, P.L., Opsomer, M.J., Kocen, J.A., Wagner, J.E., 1988. Experimental nasal dermatitis in the Mongolian gerbil: effect of bilateral Harderian gland adenectomy on development of facial lesions. Lab. Anim. Sci. 38, 72–76.

Faubert, G.M., Belosevic, M., Walker, T.S., MacLean, J.D., Meerovitch, E., 1983. Comparative studies on the pattern of infection with *Giardia* spp. in Mongolian gerbils. J. Parasitol. 69, 802–805.

Field, K.J., Sibold, A.L., 1999. The Laboratory Hamster and Gerbil. CRC Press, Boca Raton.

Fitzgerald, D.B., Fitzgerald, R.J., 1966. Induction of dental caries in gerbils. Arch. Oral Biol. 11, 139–140.

Flecknell, P., 2009. Laboratory Animal Anaesthesia, third ed.. Academic Press, London.

Franco, A.T., Johnston, E., Krishna, U., Yamaoka, Y., Israel, D.A., Nagy, T.A., et al. 2008. Regulation of gastric carcinogenesis by *Helicobacter pylori* virulence factors. Cancer Res. 68, 379–387.

Fulghum, R.S., Chole, R.A., 1985. Bacterial flora in spontaneously occurring aural cholesteatomas in Mongolian gerbils. Infect. Immun. 50, 678–681.

Fulghum, R.S., Marrow, H.G., 1996. Experimental otitis media with *Moraxella* (*Branhamella*) *catarrhalis*. Ann. Otol. Rhinol. Laryngol. 105, 234–241.

Gaese, B.H., Nowotny, M., Pilz, P.K., 2009. Acoustic startle and prepulse inhibition in the Mongolian gerbil. Physiol. Behav. 98, 460–466.

Gattermann, R., 1979. Hematologic and clinical chemical normal ranges of the Mongolian gerbil. Z. Versuchstierkd. 21, 273–275.

Glage, S., Dorsch, M., Hedrich, H.J., Bleich, A., 2007. Rederivation of *Helicobacter hepaticus*-infected Mongolian gerbils by Caesarean section and cross-fostering to rats and mice. Lab. Anim. 41, 103–110.

Gleich, O., Strutz, J., 2002. Age dependent changes in the medial nucleus of the trapezoid body in gerbils. Hear Res. 164 (1-2), 166–178.

Gleich, O., Weiss, M., Strutz, J., 2004. Age-dependent changes in the lateral superior olive of the gerbil (*Meriones unguiculatus*). Hear Res. 194, 47–59.

Glenn, E.M., Gray, J., 1965. Effects of various hormones on the growth and histology of the gerbil (*Meriones unguiculatus*) abdominal sebaceous gland pad. Endocrinology 76, 1115–1123.

Golde, W.T., Gollobin, P., 2005. A rapid, simple, and humane method for submandibular bleeding of mice using a lancet. Lab. Anim. (N.Y.) 34, 39–43.

Gonzalez-Dunia, D., Volmer, R., Mayer, D., Schwemmle, M., 2005. Borna disease virus interference with neuronal plasticity. Virus Res. 111, 224–234.

Goyal, S.P., Ghosh, P.K., Sasidharan, T.O., Chand, P., 1988. Body water relations in two species of gerbil (*Tatera indica indica* and *Meriones hurrianae*) of the Indian desert. J. Comp. Physiol. B 158, 127–134.

Griffante, C., Carletti, R., Andreetta, F., Corsi, M., 2006. [3H]GR205171 displays similar NK1 receptor binding profile in gerbil and human brain. Br. J. Pharmacol. 148, 39–45.

Guzman-Silva, M.A., 1997. Systemic mast cell disease in the Mongolian gerbil, *Meriones unguiculatus*. Lab. Anim. 31, 373–378.

Guzman-Silva, M.A., Rossi, M.I.D., Guimaraes, J.S.P., 1988. Craniopharyngioma in the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. 22, 365–368.

Haddow, A.D., Odoi, A., 2009. The incidence risk, clustering, and clinical presentation of La Crosse virus infections in the eastern United States, 2003–2007. PLoS One 4 (7), e6145.

Hall, E.D., Pazara, K.E., Linseman, K.L., 1991. Sex differences in postischemic neuronal necrosis in gerbils. J. Cereb. Blood Flow Metab. 11, 292–298.

Halpin, Z.T., 1974. Individual differences in the biological odors of the Mongolian gerbil (*Meriones unguiculatus*). Behav. Biol. 11, 253–259.

Harkness, J.E., Wagner, J.E., 1983. The Biology and Medicine of Rabbits and Rodents. Lea & Febiger, Philadelphia.

Harriman, A.E., Thiessen, D., 1983. Removal of Harderian exudates by sandbathing contributes to osmotic balance in Mongolian gerbils. Physiol. Behav. 31, 317–323.

Hawk, C.T., Leary, S.L., Morris, T.H., 2005. Formulary for Laboratory Animals, third ed.. Blackwell Publishing, Ames.

Hedges, A., 1977. The albino gerbil. J. Inst. Anim. Tech. 28, 91–95.

Heldt, S.A., Davis, M., Ratti, E., Corsi, M., Trist, D., Ressler, K.J., 2009. Anxiolytic-like effects of the neurokinin 1 receptor antagonist GR-205171 in the elevated plus maze and contextual fear-potentiated startle model of anxiety in gerbils. Behav. Pharmacol. 20, 584–595.

Hem, A., Smith, A.J., 1998. Saphenous vein puncture for blood sampling of the mouse, rat, hamster, gerbil, guinea pig, ferret and mink. Lab. Anim. 32, 364–368.

Holmes, D.D., 1985. The Mongolian gerbil in biomedical research. Lab. Anim. (N.Y.) 14, 23–28.

Hübner, M.P., Torrero, M.N., McCall, J.W., Mitre, E., 2009. *Litomosoides sigmodontis*: a simple method to infect mice with L3 larvae obtained from the pleural space of recently infected jirds (*Meriones unguiculatus*). Exp. Parasitol. 123, 95–98.

Hurst, J.L., 1999. Introduction to rodents. In: Poole, T. (Ed.), The UFAW Handbook on the Care and Management of Laboratory Animals, vol. 1. Terrestrial Vertebrates, seventh ed., Blackwell Science, Malden, pp. 262–265.

Hwang, I.K., Park, S.K., An, S.J., Yoo, K.Y., Kim, D.S., Jung, J.Y., et al. 2004. GABA A, not GABA B, receptor shows subunit- and spatial-specific alterations in the hippocampus of seizure prone gerbils. Brain 1003, 98–107.

Ichii, O., Yabuki, A., Ojima, T., Matsumoto, M., Suzuki, S., 2006. Species specific differences in the ratio of short to long loop nephrons in the kidneys of laboratory rodents. Exp. Anim. 55, 473–476.

Iyomasa, M.M., Issa, J.P., De Moura Leite Naves, Regalo, S.C., Siéssere, S., Pitol, D.L., et al. 2008. Histological and histomorphometrical alterations of the periodontal ligament in gerbils submitted to teeth extraction. Anat. Histol. Embryol. 37, 257–262.

Jaworska, N., Dwyer, S.M., Rusak, B., 2008. Repeated neonatal separation results in different neurochemical and behavioral changes in adult male and female Mongolian gerbils. Pharmacol. Biochem. Behav. 88, 533–541.

Johnson, S.L., Marcotti, W., 2008. Biophysical properties of CaV1.3 calcium channels in gerbil inner hair cells. J. Physiol. 4, 1029–1042.

Johnson, S.S., Conder, G.A., 1996. Infectivity of *Hymenolepis diminuta* for the jird (*Meriones unguiculatus*), and utility of this model for anthelmintic studies. J. Parasitol. 82, 492–495.

Johnston, H.S., McGadey, J., Thompson, G.G., 1983. The Harderian gland, its secretory duct and porphyrin content in the Mongolian gerbil (*Meriones unguiculatus*). J. Anat. 137, 615–630.

Kaiser, L., Davis, J.M., Schwartz, K.A., Brittenham, G.M., Kuryshev, Y.A., Objero-Paz, C.A., et al. 2003. Does the gerbil model mimic human iron overload? J. Lab. Clin. Med. 141, 419–422.

Kamiya, M., Sato, H., 1990. Complete life cycle of the canid tapeworm, *Echinococcus multilocularis*, in laboratory rodents. FASEB J. 4, 3334–3339.

Kang, T.C., Park, S.K., Bahn, J.H., Jeon, S.G., Jo, S.M., Cho, S.W., et al. 2001. The alteration of gamma-aminobutyric acid-transaminase expression in the gerbil hippocampus induced by seizure. Neurochem. Int. 38, 609–614.

Kaplan, H., Miezejeski, C., 1972. Development of seizures in the Mongolian gerbil (*Meriones unguiculatus*). J. Comp. Physiol. Psychol. 81, 267–273.

Khokhlova, I.S., Serobyan, V., Krasnov, B.R., Degan, A.A., 2009. Is the feeding and reproductive performance of the flea, *Xenopsylla ramesis*, affected by the gender of its rodent host, *Meriones crassus*?. J. Exp. Biol. 212, 1429–1435.

Kim, H.J., Chole, R.A., 1998. Experimental models of aural cholesteatomas in Mongolian gerbils. Ann. Otol. Rhinol. Laryngol. 107, 129–134.

Kitagawa, K., Matsumoto, M., Handa, N., Fukunaga, R., Ueda, H., Isaka, Y., et al. 1989. Prediction of stroke-prone gerbils and their cerebral circulation. Brain Res. 479, 263–269.

Kramer Jr., A.W., 1964. Body and organ weights and linear measurements of the adult Mongolian gerbil. Anat. Rec. 150, 343–347.

Kroh, H., Walencik, S., Mossakowski, M.J., Weinrauder, H., 1987. Spontaneous astrocytoma in the Mongolian gerbil (*Meriones unguiculatus*). Neuropatologia Polska 25, 329–336.

Kulesh, D.A., Loveless, B.M., Norwood, D., Garrison, J., Whitehouse, C.A., et al. 2004. Monkeypox virus detection in rodents using real-time 3'-minor groove binder TaqMan assays on the Roche LightCycler. Lab. Invest. 84, 1200–1208.

Kvác, M., Sak, B., Kvetonová, D., Secor, W.E., 2009. Infectivity of gastric and intestinal *Cryptosporidium* species in immunocompetent Mongolian gerbils (*Meriones unguiculatus*). Vet. Parasitol. 163, 33–38.

Kwak, S.E., Kim, J.E., Kim, D.S., Jung, J.Y., Won, M.H., Kwon, O.S., et al. 2005. Effects of GABAergic transmissions on the immunoreactivities of calcium binding proteins in the gerbil hippocampus. J. Comp. Neurol. 485, 153–164.

Laidley, D.T., Colbourne, F., Corbett, D., 2005. Increased behavioral and histological variability arising from changes in cerebrovascular anatomy of the Mongolian gerbil. Curr. Neurovasc. Res. 2, 401–407.

Lee, C.H., Hwang, I.K., Choi, J.H., Yoo, K.Y., Park, O.K., Huh, S.O., et al. 2010a. Age-dependent changes in calretinin immunoreactivity and its protein level in the gerbil hippocampus. Neurochem. Res. 35, 122–129.

Lee, C.H., Hwang, I.K., Yoo, K.Y., Choi, J.H., Park, O.K., Lee, J.C., et al. 2009. Calbindin d-28k immunoreactivity and its protein level in hippocampal subregions during normal aging in gerbils. Cell Mol. Neurobiol. 5, 665–672.

Lee, C.H., Yoo, K.Y., Choi, J.H., Park, O.K., Hwang, I.K., Kang, I.J., et al. 2010b. Cyclooxygenase-2 immunoreactivity and protein level in the gerbil hippocampus during normal aging. Neurochem. Res. 35, 99–106.

Leffler, A., Ahlstedt, I., Engberg, S., Svensson, A., Billger, M., Oberg, L., et al. 2009. Characterization of species-related differences in the pharmacology of tachykinin NK receptors 1, 2 and 3. Biochem. Pharmacol. 77, 1522–1530.

Lehmann, K., Grund, T., Bagorda, A., Bagorda, F., Grafen, K., Winter, Y., et al. 2009. Developmental effects on dopamine projections and hippocampal cell proliferation in the rodent model of postweaning social and physical deprivation can be triggered by brief changes of environmental contex. Behav. Brain Res. 205, 26–31.

Lesting, J., Neddens, J., Teuchert-Noodt, G., 2005. Ontogeny of the dopamine innervation in the nucleus accumbens of gerbils. Brain Res. 1066, 16–23.

Levine, S., Payan, H., 1966. Effects of ischemia and other procedures on the brain and retina of the gerbil (Meriones unguiculatus). Exp. Neurol. 16, 255–262.

Levy, D.E., Brierley, J.B., 1974. Communications between vertebrobasilar and carotid arterial circulations in the gerbil. Exp. Neurol. 45, 503–508.

Li, W., Sun, Q., She, R., Wang, D., Duan, X., Yin, J., et al. 2009. Experimental infection of Mongolian gerbils by a genotype 4 strain of swine hepatitis E virus. J. Med. Virol. 81, 1591–1596.

Li, X.S., Wang, D.H., 2005. Seasonal adjustments in body mass and thermogenesis in Mongolian gerbils (*Meriones unguiculatus*): the roles of short photoperiod and cold. J. Comp. Physiol. 175, 593–600.

Lim, B.H., Noordin, R., Nor, Z.M., Rahman, R.A., Abdullah, K.A., Sinnadurai, S., 2004. *Brugia malayi* infection in *Meriones unguiculatus*: antibody response to recombinant BmR1. Exp. Parasitol. 108, 1–6.

Lindzey, G., Thiessen, D.D., Tucker, A., 1968. Development and hormonal control of territorial marking in the male Mongolian gerbil (*Meriones unguiculatus*). Develop. Psychobiol. 1, 97–99.

Lok, J.B., 2007. *Strongyloides stercoralis*: a model for translational research on parasitic nematode biology. WormBook: Online Rev. *C. elegans* Biol. 17, 1–18.

Lokugamage, N., Kariwa, H., Lokugamage, K., Hagiya, T., Miyamoto, H., Iwasa, M.A., et al. 2003. Development of an efficient method for recovery of Puumala and Puumala-related viruses by inoculation of Mongolian gerbils. J. Vet. Med. Sci. 65, 1189–1194.

Loskota, W.J., Lomax, P., 1975. The Mongolian gerbil (*Meriones unguiculatus*) as a model for the study of the epilepsies: EEG records of seizures. Electroencephalogr. Clin. Neurophysiol. 38, 597–604.

Loskota, W.J., Lomax, P., Rich, S.T., 1974. The gerbil as a model for the study of the epilepsies. Seizure patterns and ontogenesis. Epilepsia 15, 109–119.

Lussier, G., Loew, F.M., 1970. Case report. Natural *Hymenolepis nana* infection in Mongolian gerbils (*Meriones unguiculatus*). Can. Vet. J. 11, 105–107.

Mahler, H., Christensen, N.O., Hindsbo, O., 1995. Studies on the reproductive capacity of *Echinostoma caproni* (Trematoda) in hamsters and jirds. Int. J. Parasitol. 25, 705–710.

Mand, S., Specht, S., Zahner, H., Hoerauf, A., 2006. Ultrasonography in filaria-infected rodents: detection of adult *Litomosoides sigmodontis* and *Brugia malayi* filariae. Trop. Med. Int. Health 11, 1382–1387.

Matsuo, K., Shimizu, M., Nonaka, N., Oku, Y., Kamiya, M., 2000. Development and sexual maturation of *Echinococcus vogeli* in an alternative definitive host, Mongolian gerbil (*Meriones unguiculatus*). Acta Tropica 75, 323–330.

Matsuoka, A.J., Kondo, T., Miyamoto, R.T., Hashino, E., 2007. Enhanced survival of bone-marrow-derived pluripotent stem cells in an animal model of auditory neuropathy. Laryngoscope 117, 1629–1635.

Matsuoka, K., Suzuki, J., 1995. Spontaneous tumors in the Mongolian gerbil (*Meriones unguiculatus*). Exp. Anim. 43, 755–760.

Matsuzaki, H., Doi, K., Mitsuoka, T., Tsuda, T., Onodera, T., 1989a. Experimental encephalomyocarditis virus infection in Mongolian gerbils (*Meriones unguiculatus*). Vet. Pathol. 26, 11–17.

Matsuzaki, T., Yasuda, Y., Nonaka, S., 1989b. The genetics of coat colors in the Mongolian gerbil (*Meriones unguiculatus*). Exp. Anim. 38, 337–341.

Mays A., Jr., 1969. Baseline hematological and blood biochemical parameters of the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. Sci. 19, 838–842.

Meckley, P.E., Ginther, O.J., 1974. Occurence of oestrus in the Mongolian gerbil after pairing with a male. Lab. Anim. 8, 93–97.

Meckley, P.E., Zwicker, G.M., 1979. Naturally-occurring neoplasms in the Mongolian gerbil, *Meriones unguiculatus*. Lab. Anim. 13, 203–206.

Michaux, J., Reyes, A., Catzeflis, F., 2001. Evolutionary history of the most speciose mammals: molecular phylogeny of Muroid rodents. Mol. Biol. Evol. 18, 2017–2031.

Mochida, K., Wakayama, T., 2005. Birth of offspring after transfer of Mongolian gerbil (*Meriones unguiculatus*) embryos cryopreserved by vitrification. Mol. Reprod. Dev. 70, 464–470.

Moore, D.M., 1995. Hamsters and gerbils. In: Rollin, B.E., Kesel, M.L. (Eds.), The Experimental Animal in Biomedical Research (pp. 309–333). CRC Press, Boca Raton.

Moss, D.M., Mathews, H.M., Visvesvara, G.S., Dickerson, J.W., Walker, E.M., 1990. Antigenic variation of *Giardia lamblia* in the feces of Mongolian gerbils. J. Clin. Microbiol. 28, 254–257.

Motzel, S.L., Gibson, S.V., 1990. Tyzzer's disease in hamsters and gerbils from a pet store supplier. J. Am. Vet. Med. Assoc. 197, 1176–1178.

Musser, M., Carleton, M.D., 2005. Rodentia: Myomorpha: Muroidea: Muridae: Gerbillinae. In: Wilson, D.E., Reeder, D.M. (Eds.), Mammal Species of the World, A Taxonomic and Geographic Reference (pp. 1210–1239). The Johns Hopkins University Press, Baltimore.

Nakamura, Y., Nakaya, T., Hagiwara, K., Momiyama, N., Kagawa, Y., Taniyama, H., et al. 1999. High susceptibility of Mongolian gerbil (*Meriones unguiculatus*) to Borna disease virus. Vaccine 17, 480–489.

National Research Council, 2011. Guide for The Care and Use of Laboratory Animals, eighth ed. National Academies Press, Washington, D. C.

Neumann, K., Maak, S., Stuermer, I.W., von Lengerken, G., Gattermann, R., 2001. Low microsatellite variation in laboratory gerbils. J. Hered. 92, 71–74.

Norris, M.L., 1987. Gerbils. In: Poole, T.B. (Ed.), The UFAW Handbook on the Care and Management of Laboratory Animals (pp. 360–376). Blackwell Science, Malden.

Norris, M.L., Adams, C.E., 1972a. Aggressive behaviour and reproduction in the Mongolian gerbil, *Meriones unguiculatus*, relative to age and sexual experience at pairing. J. Reprod. Fert. 31, 447–450.

Norris, M.L., Adams, C.E., 1972b. Incidence of cystic ovaries and reproductive performance in the Mongolian gerbil, *Meriones unguiculatus*. Lab. Anim. 6, 337–342.

Norris, M.L., Adams, C.E., 1972c. The growth of the Mongolian gerbil, *Meriones unguiculatus*, from birth to maturity. J. Zool. 166, 277–282.

Norris, M.L., Adams, C.E., 1981. Mating post partum and length of gestation in the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. 15, 189–191.

Norris, M.L., Adams, C.E., 1982. Lifetime reproductive performance of Mongolian gerbils (*Meriones unguiculatus*). Lab. Anim. 15, 21–23.

Ogbe, M.G., 1983. In vivo and in vitro development of *Schistosoma margrebowiei*. J. Helminthol. 57, 231–235.

Oldham, J., Morlock, H., 1970. The effects of openfield size on activity in the Mongolian gerbil. Psychon. Sci. 20, 290–293.

Olfert, E.D., Cross, B.M., 1993. Guide to the Care and Use of Experimental Animals. Canadian Council on Animal Care, Ottawa.

Osorio, J.E., Schoepp, R.J., Yuill, T.M., 1996. Effects of La Crosse virus infection on pregnant domestic rabbits and Mongolian gerbils. Am. J. Trop. Med. Hyg. 55, 384–390.

Otken, C.C., Scott, C.E., 1984. Feeding characteristics of Mongolian gerbils (*Meriones unguiculatus*). Lab. Anim. Sci. 34, 181–184.

Otto-Duessel, M., Brewer, C., Gonzalez, I., Nick, H., Wood, J.C., 2008. Safety and efficacy of combined chelation therapy with deferasirox and deferoxamine in a gerbil model of iron overload. Acta Haematol. 120, 123–128.

Palm, D.K., Hollander, P., 2007. A procedure for intravenous injection using external jugular vein in Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. 41, 403–405.

Pavlinov, I.Y., Dubrovsky, Y.A., Rossolimo, O.L., Potapova, E.G., 1990. Gerbils of the World. Nauka, Moscow.

Peek, R.M., 2008. *Helicobacter pylori* infection and disease: from humans to animal models. Dis. Model Mech. 1, 50–55.

Pellicciolì, G.P., Gambelunghe, C., Ottaviano, P.F., Iannaccone, S., Ambrosini, M.V., 1995. Variable response of the Mongolian gerbil to unilateral carotid occlusion: magnetic resonance imaging and neuropathological characterization. Ital. J. Neurol. Sci. 16, 517–526.

Pérez-García, C.C., Pena-Penabad, M., Cano-Rabano, M.J., Garcia-Rodriguez, M.B., Gallego-Morales, D., Rios-Granja, M.A., et al. 2002. A simple procedure to perform intravenous injections in the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. 37, 68–71.

Pilar-Cuéllar, F., Paniagua, M.A., Díez-Alarcia, R., Dos Anjos, S., Montori, S., Pérez, C.C., et al. 2008. Muscarinic receptor changes in the gerbil thalamus during aging. Brain Res. 1243, 38–46.

Pinto, R.M., Gomes, D.C., Menezes, R.C., Muniz-Pereira, L.C., Noronha, D., 2003. First natural helminth infection in the Mongolian gerbil (*Meriones unguiculatus*), parasitized with *Dentostomella translucida* in the neotropical region. Braz. J. Biol. 63, 173–175.

Pinto, R.M., Gomes, D.C., Noronha, D., 2003. Evaluation of co-infection with pinworms (*Aspiculuris tetraptera, Dentostomella translucida, and Syphacia obvelata*) in gerbils and mice. Contemp. Top. Lab. Anim. Sci. 42, 46–48.

Piovanotti, M.R., Vieira, M.L., 2004. Presence of the father and parental experience have differentiated effects on pup development in Mongolian gerbils (Meriones unguiculatus). Behav. Processes 66, 107–117.

Ponte, C., Cenjor, C., Parra, A., Nieto, E., García-Calvo, G., Giménez, M.J., et al. 1999. Antimicrobial treatment of an experimental otitis media caused by a beta-lactamase positive isolate of *Haemophilus influenzae*. J. Antimicrob. Chemother. 44, 85–90.

Port, C.D., Richter, W.R., Moize, S.M., 1971. An ultrastructural study of Tyzzer's disease in the Mongolian gerbil (*Meriones unguiculatus*). Lab. Invest. 25, 81–87.

Prates, E.J., Guerra, R.F., 2005. Parental care and sexual interactions in Mongolian gerbils (*Meriones unguiculatus*) during the postpartum estrus. Behav. Processes 70, 104–112.

Preac-Mursic, V., Wilske, B., Patsouris, E., Jauris, S., Will, G., Soutschek, E., et al. 1992. Active immunization with pC protein of *Borrelia burgdorferi* protects gerbils against *B. burgdorferi* infection. Infection 20, 342–349.

Razzoli, M., Papa, R., Valsecchi, P., Marzano, F.N., 2003. AFLP to assess genetic variation in laboratory gerbils (*Meriones unguiculatus*). J. Hered. 94, 507–511.

Rehbinder, C., Baneux, P., Forbes, D., VanHerck, H., Nicklas, W., Rugaya, Z., et al. 1996. FELASA recommendations for the health monitoring of mouse, rat, hamster, gerbil, guinea pig and rabbit experimental units. Report of the Federation of European Laboratory Animal Science Associations (FELASA) Working Group on Animal Health accepted by the FELASA Board of Management, November 1995. Lab. Anim. 30, 193–208.

Rembert, M.S., Johnson, A.J., 2001. What's your diagnosis? Pigmented mass in an experimental gerbil. Spontaneous malignant melanoma. Lab. Anim. (N.Y.) 30, 22–25.

Ringler, D.H., Lay, D.M., Abrams, G.D., 1972. Spontaneous neoplasms in aging gerbillinae. Lab. Anim. Sci. 22, 407–414.

Robinson, D.G., 1974. 20th Anniversary of Tumblebrook gerbils: some historical notes. Gerbil Digest 1 (1), 1–4.

Robinson, D.G., 1975b. Gerbil classification and nomenclature. Gerbil Digest 2 (1), 1–4.

Robinson, D.G., 1975. Gerbil care and maintenance. Gerbil Digest 2 (2), 1–4.
Robinson, D.G., 1976. Ecology of the Mongolian gerbil. Gerbil Digest 3 (2), 1–2.
Robinson, D.G., 1978. Reproduction in the Mongolian gerbil. Gerbil Digest 5 (1), 1–4.
Robinson, D.G., 1979. Tumblebrook Gerbils: 25th Anniversary. Gerbil Digest 6 (3), 1–4.
Roger, T.J., Polioudakis, E., 1977. The behavior of Mongolian gerbils in a semi-natural environment, with special references to ventral marking, dominance and sociability. Behavior 61, 205–237.
Rollin, B.E., Kesel, M.L., 1995. The Experimental Animal in Biomedical Research. vol. II: Care, Husbandry and Wellbeing. An Overview by Species. CRC Press, Boca Raton.
Roscoe, H.G., Fahrenbach, M.J., 1962. Cholesterol metabolism in the gerbil. Proc. Soc. Exptl. Biol. Med. 110, 51–55.
Ross, C.R., Wagner, J.E., Wightman, S.W., Dill, S.E., 1980. Experimental transmission of *Syphacia muris* among rats, mice, hamsters and gerbils. Lab. Anim. Sci. 30, 35–37.
Rott, R., Herzog, S., Fleischer, B., Winokur, A., Amsterdam, J., Dyson, W., et al. 1985. Detection of serum antibodies to Borna disease virus in patients with psychiatric disorders. Science 228, 755–756.
Ruhren, R., 1965. Normal values for hemoglobin concentration and cellular elements in the blood of Mongolian gerbils. Lab. Anim. Care 15, 313–320.
Sakai, T., 1981. The mammalian Harderian gland: morphology, biochemistry function and phylogeny. Arch. Histol. Jpn. 44, 299–333.
Sato, H., Kamiya, H., 2001. Defect of protective immunity to *Schistosoma mansoni* infection in Mongolian gerbils involves limited recruitment of dendritic cells in the vaccinated skin. Parasite Immunol. 23, 627–632.
Sato, H., Ihama, Y., Kamiya, H., 2000. Survival of destrobilated adults of *Taenia crassiceps* in T-cell-depleted Mongolian gerbils. Parasitol. Res. 86, 284–289.
Schiffer, S.P., Lukas, V.S., Chrisp, C.E., 1986. Diagnostic Exercise: Head Tilt in a Gerbil. Lab. Anim. Sci. 36, 176–177.
Schwentker, V., 1963. The gerbil, a new laboratory animal. Ill. Vet. 6 (4), 5–9.
Seal, J.B., Buchh, B.N., Marks, J.D., 2006. New variability in cerebrovascular anatomy determines severity of hippocampal injury following forebrain ischemia in the Mongolian gerbil. Brain Res. 16, 451–459.
Shigeno, S., Fujimaki, Y., Toriyama, K., Ichinose, A., Mitsui, Y., Aoki, Y., et al. 2006. Temporary shift of microfilariae of *Brugia pahangi* from the lungs to muscles in Mongolian jirds, *Meriones unguiculatus*, after a single injection of diethylcarbamazine. J. Parasitol. 92, 1075–1080.
Shimozuru, M., Kikusui, T., 2008. Effects of isolation-rearing on the development of social behaviors in male Mongolian gerbils (*Meriones unguiculatus*). Physiol. Behav. 94, 491–500.
Small, D.L., Buchan, A.M., 2000. Animal models. Br. Med. Bull. 56, 307–317.
Smith, B.A., Block, M.L., 1991. Male saliva cues and female social choice in Mongolian gerbils. Physiol. Behav. 50, 379–384.
Smith, R.A., Termer, E.A., Glomski, C.A., 1976. Erythrocyte basophilic stippling in the Mongolian gerbil. Lab. Anim. 10, 379–383.
Solomon, H.F., Dixon, D.M., Pouch, W., 1990. A survey of staphylococci isolated from the laboratory gerbil. Lab. Anim. Sci. 40, 316–318.
Soriano, F., Parra, A., Cenjor, C., Nieto, E., García-Calvo, G., Giménez, M.J., et al. 2000. Role of *Streptococcus pneumoniae* and *Haemophilus influenzae* in the development of acute otitis media and otitis media with effusion in a gerbil model. J. Infect. Dis. 181, 646–652.
Strittmatter, J., 1972. Elimination of Tyzzer's Disease in the Mongolian gerbil (*Meriones unguiculatus*) by fostering to mice. Z. Versuchtierskd. 14, 209–214.
Subcommittee on Laboratory Animal Nutrition, 1995. Nutrient requirements of the gerbil. In: Nutrient Requirements of Laboratory Animals, fourth revised ed. National Academy Press, Washington, D.C., pp. 140–143.
Sundqvist, M., Kristensson, E., Adolfsson, R., Leffler, A., Ahlstedt, I., Engberg, S., et al. 2007. Senktide-induced gerbil foot tapping behaviour is blocked by selective tachykinin NK1 and NK3 receptor antagonists. Eur. J. Pharmacol. 577, 78–86.
Swanson, H.H., Lockley, M.R., 1978. Population growth and social structure of confined colonies of Mongolian gerbils: scent gland size and marking behaviour as indices of social status. Aggress. Behav 4, 57–89.
Tappe, D., Pukall, R., Schumann, P., Gronow, S., Spiliotis, M., Claus, H., et al. 2009. *Streptococcus merionis* sp. nov., isolated from Mongolian jirds (*Meriones unguiculatus*). Int. J. Syst. Evol. Microbiol. 59, 766–770.
Temmerman, A.M., Vonk, R.J., Niezen-Koning, K., Berger, R., Fernandes, J., 1989. Effects of dietary cholesterol in the Mongolian gerbil and the rat: a comparative study. Lab. Anim. 23, 30–35.
Thiessen, D.D., 1977. Thermoenergetics and the evolution of pheromone communications. In: Sprague, J.M., Epstein, A.N. (Eds). Progess in Psychobiology and Physiological Psychology, vol. 7. Academic Press, New York.
Thiessen, D.D., 1988. Body temperature and grooming in the Mongolian gerbil. Ann. N.Y. Acad. Sci 525, 27–39.
Thiessen, D.D., Lindzey, G., 1970. Territorial marking in the female Mongolian gerbil: short term reaction to hormones. Horm. Behav. 1, 157–160.
Thiessen, D.D., Pendergrass, M., 1982. Harderian gland involvement in facial lesions in the Mongolian gerbil. J. Am. Vet. Med. Assoc. 181, 1375–1377.
Thiessen, D.D., Yahr, P., 1970. Central control of territorial marking in the Mongolian gerbil. Physiol. Behav. 5, 275–278.
Thiessen, D.D., Yahr, P., 1977. The Gerbil in Behavioral Investigations. University of Texas Press, Austin.
Thiessen, D., Clancy, A., Goodwin, M., 1976. Harderian gland pheromone in the Mongolian gerbil (*Meriones unguiculatus*). J. Chem. Ecol. 2, 231–238.
Thiessen, D.D., Friend, H.C., Lindzey, G., 1968a. Androgen control of territorial marking in the Mongolian gerbil. Science 160, 26–30.
Thiessen, D.D., Lindzey, G., Friend, H.C., 1968b. Spontaneous seizures in the Mongolian gerbil. Psychon. Sci 11, 227–228.
Thiessen, D.D., Owen, K., Lindzey, G., 1971. Mechanisms of territorial marking in the male and female Mongolian gerbil (*Meriones unguiculatus*). J. Comp. Physiol. Psychol. 77, 38–47.
Thiessen, D.D., Regnier, F.E., Rice, M., Goodwin, M., Isaacks, N., Lawson, N., 1974. Identification of a ventral scent marking pheromone in the male Mongolian gerbil (*Meriones unguiculatus*). Science 184, 83–85.
Tortora, D.F., Eyer, J.C., Overmann, S.R., 1974. The effect of sand deprivation on sandbathing and marking in Mongolian gerbils (*Meriones unguiculatus*). Behav. Biol. 11, 403–407.
Tsukamoto, T., Mizoshita, T., Tatematsu, M., 2007. Animal models of stomach carcinogenesis. Toxicol. Pathol. 35, 636–648.
Turner, J.W., Carbonell, C., 1984. A relationship between frequency of display of territorial marking behavior and coat color in the Mongolian gerbil. Lab. Anim. Sci. 34, 488–490.
Vesell, E.S., 1967. Induction of drug-metabolizing enzymes in liver microsomes of mice and rats by softwood bedding. Science 157, 1057–1058.
Vianna, G.J., de Melo, A.L., 2007. Experimental infection and adaptation of *Rodentolepis nana* to the Mongolian jird (*Meriones unguiculatus*). J. Helminthol. 81, 345–349.
Vincent, A.L., Ash, L.R., 1978. Further observations on spontaneous neoplasms in the Mongolian gerbil, *Meriones unguiculatus*. Lab. Anim. Sci. 28, 297–300.
Vincent, A.L., Porter, D.D., Ash, L.R., 1975. Spontaneous lesions and parasites of the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. Sci. 25, 711–722.

Vincent, A.L., Rodflick, G.E., Sodeman, W.A., 1979. The pathology of the Mongolian gerbil (*Meriones unguiculatus*): a review. Lab. Anim. Sci. 29, 645–651.

Waggie, K.S., Thornburg, L.P., Wagner, J.E., 1984. Experimentally induced Tyzzer's disease in Mongolian gerbils (*Meriones unguiculatus*). Lab. Anim. Sci. 34, 53–57.

Wagner, J.E., Farrar, L., 1987. Husbandry and medicine of small rodents. Vet. Clin. North Am. Small Anim. Pract. 17, 1061–1087.

Waiblinger, E., 2010. Comfortable Quarters for Gerbils in Research Institutions. Retrieved on January 25, 2010, from <http://www.awionline.org/www.awionline.org/pubs/cq02/Cq-gerb.html/>.

Wallace, P., Owen, K., Thiessen, D.D., 1973. The control and function of maternal scent marking in the Mongolian gerbil. Physiol. Behav. 10, 463–466.

Wallace-Boone, T.L., Newton, A.E., Wright, R.N., Lodge, N.J., McElroy, J.F., 2008. Behavioral and pharmacological validation of the gerbil forced-swim test: effects of neurokinin-1 receptor antagonists. Neuropsychopharmacology 33, 1919–1928.

Wanji, S., Tendongfor, N., Vuong, P.N., Enyong, P., Bain, O., 2002. The migration and localization of *Loa loa* infective and fourth-stage larvae in normal and immuno-suppressed rodents. Ann. Trop. Med. Parasitol. 96, 823–830.

Waring, A.D., Poole, T.W., 1980. Genetic analysis of the black pigment mutation in the Mongolian gerbil. J. Hered. 71, 428–429.

Watanabe, T., Tada, M., Nagai, H., Sasaki, S., Nakao, M., 1998. *Helicobacter pylori* infection induces gastric cancer in Mongolian gerbils. Gastroenterology 115, 642–648.

Wetzel, W., Ohl, F.W., Scheich, H., 2008. Global versus local processing of frequency-modulated tones in gerbils: an animal model of lateralized auditory cortex functions. Proc. Natl. Acad. Sci. U.S.A. 105, 6753–6758.

Wexler, B.C., 1972. Pathophysiological responses to acute cerebral ischemia in the gerbil. Stroke 3, 71–78.

Whitsett, J.M., Thiessen, D.D., 1972. Sex differences in the control of scent marking behavior in the Mongolian gerbil (*Meriones unguiculatus*). J. Comp. Physiol. Psychol. 78, 381–385.

Wightman, S.R., Mann, P.C., Wagner, J.E., 1980. Dihydrostreptomycin toxicity in the Mongolian gerbil, *Meriones unguiculatus*. Lab. Anim. Sci. 30, 71–75.

Wightman, S.R., Pilitt, P.A., Wagner, J.E., 1978. *Dentostomella translucida* in the Mongolian gerbil (*Meriones unguiculatus*). Lab. Anim. Sci. 28, 290–296.

Wilkerson, J.D., Brooks, D.L., Derby, M., Griffey, S.M., 2001. Comparison of practical treatment methods to eradicate pinworm (*Dentostomella translucida*) infections from Mongolian gerbils (*Meriones unguiculatus*). Contemp. Top. Lab. Anim. Sci. 40, 31–36.

Williams, W.M., 1974. The anatomy of the Mongolian gerbil (*Meriones ungiculatus*). Tumblebrook Farm, Inc., West Brookfield, MA.

Winkelmann, J.R., Getz, L.L., 1962. Water balance in the Mongolian gerbil. J. Mammal. 43, 150–154.

Womack, J.E., 1972. Red cell survival in the gerbil (*Meriones unguiculatus*). Comp. Biochem. Physiol. A Comp. Physiol. 43, 801–804.

Wu, J.T., 1974. Artificial insemination and induction of pregnancy in the Mongolian gerbil (*Meriones unguiculatus*). J. Reprod. Fert. 37, 139–140.

Yang, J., Zhang, Y., Xu, J., Geng, Y., Chen, X., Yang, H., et al. 2009. Serum activity of platelet-activating factor acetylhydrolase is a potential clinical marker for leptospirosis pulmonary hemorrhage. PLoS One 4, e4181.

Yahr, P., Kessler, S., 1974. Suppression of reproduction in water-deprived Mongolian gerbils (*Meriones unguiculatus*). Biol. Repro. 12, 249–254.

Yukawa, M., Takeuchi, T., Mochizuki, K., Inaba, Y., Kamata, H., Onodera, T., 1993. Infection of reovirus type 3 in Mongolian gerbils (*Meriones unguiculatus*) – lesions in pancreas and brain. J. Basic Microbiol. 33, 147–152.

Zanandréa, L.I., Oliveira, G.M., Abreu, A.S., Pereira, F.E., 2008. Ocular lesions in gerbils (*Meriones unguiculatus*) infected with low larval burden of *Toxocara canis*: observations using indirect binocular ophthalmoscopy. Rev. Soc. Bras. Med. Trop. 41, 570–574.

Zeman, F.J., 1967. A semipurified diet for the Mongolian gerbil (*Meriones unguiculatus*). J. Nutr. 91, 415–420.