CHAPTER 1

Rabbit Basic Science

1.1 Biological characteristics of the domestic rabbit (*Oryctolagus cuniculus*)

1.1.1 Origins of the domestic rabbit

Domestic rabbits are descended from the European rabbit, *Oryctolagus cuniculus*. The ancestral form probably evolved in the Iberian Peninsula and spread to other parts of the Mediterranean (Fox, 1974). Fossil records show that the European rabbit was confined to the Iberian peninsula and southern France following the Pleistocene era. While rabbits have been associated with man since Roman times, they have only been truly domesticated for around 200 years. The geographical range of the rabbit has been altered significantly by man, who from Roman times onwards placed rabbits on islands on various shipping routes, to allow them to breed and form a ready source of food. Thus their European range significantly altered, and rabbits proved very successful where the climate and geographical conditions were suitable. More recently rabbits were introduced in Victoria, Australia, where their success, due to rapid breeding and a lack of suitable predators, rapidly became a plague that cost the Australian Government millions of dollars and led to the implementation of myxomatosis virus for biological control. Although European rabbits have been released in North America, the presence of suitable predators, an unsuitable climate and other species filling their ecological niche proved insurmountable. In North America the native wild rabbit is either *Sylvilagus floridanus* (cottontail) or *Sylvilagus bachmani* (brush rabbit). The North American jackrabbit, *Lepus californicus,* is from the hare genus.

It is not clear when the European rabbit was introduced into Great Britain. The Romans brought many food animals with them, such as pheasant and quail, and it is believed that they not only introduced rabbits but also kept them in cages, thereby starting the process of domestication. The modern pet rabbit still retains many of the characteristics of its wild counterparts despite changes in size, colour, coat texture and temperament.

Rabbits belong to the order Lagomorpha, which are characterized by the presence of a second small pair of upper incisors or peg teeth situated behind the central incisors. Lagomorphs were once considered to be a suborder of the Rodentia, which is divided into Sciuromorpha (squirrel-like rodents), Myomorpha (mouse-like rodents) and Hystricomorpha (porcupine-like rodents) that includes guinea pigs and chinchillas. Current opinion suggests that Rodentia and Lagomorpha have no fundamental similarities and on the basis of structural features and serological data, Lagomorpha show more affinity to Artiodactyla (hoofed mammals) (Nowak, 1999). Other lagomorphs include hares and pikas. All members of the Lagomorpha order are terrestrial and eat only vegetation.

1.1.2 Wild rabbits

The behavioural characteristics of lagomorphs differ between species. For example, cottontails *(Sylvilagus* spp.) do not dig burrows, although they may use burrows made by other animals. Females dig holes to make nests and sit over the hole to suckle the young. Vegetation is used to cover the fur-lined nest between feeds. Cottontails are solitary animals, in contrast with *Oryctolagus cuniculus*, which live in groups with a defined social hierarchy (Nowak, 1999).

The European rabbit, *Oryctolagus cuniculus*, prefers a sandy, hilly terrain with shrubs and woody plants and is not found at altitudes above 600 m. It often digs complex burrows or warrens that can be 3 m deep and 45 m long. The tunnels are about 15 cm in diameter and the living chambers 30–60 cm high. The main surface entrances are usually indicated by mounds of earth but there are numerous other small openings that lack these mounds. *Oryctolagus cuniculus* is essentially nocturnal, leaving the burrow in the early evening and returning in the morning, although it can be seen grazing or basking during the day. The home range is rarely larger than 20 hectares (Nowak, 1999).

Wild rabbits live in groups of two to eight adults plus juveniles with a defined social hierarchy (McBride, 1988). The group's territory is defended by the males, while the females dig out deep burrows to nest in. Male rabbits within the group will establish a dominance hierarchy, with the older heavier males at the top. Aged males that have been usurped by younger, fitter rabbits are driven from the group to become solitary satellite males (Lockley, 1978). Young male rabbits are also often driven from the group when they reach puberty either to join another warren or to lead solitary lives in the hedgerows. The females tend to remain within the original group. Female rabbits are less aggressive towards each other than males, but will defend a chosen nesting site ferociously. Territories are scent marked with pheromones from the scent glands on the chin and genital area or by urine marking. Dominant males will continually scent mark their territory by rubbing their chins on branches and bushes and leaving piles of strategically placed faeces. They also mark territory by spraying urine, sometimes on to other individuals.

When wild rabbits emerge from their burrows at dusk, they begin to feed. Initially, they graze grass and vegetation, raising their heads at intervals to survey the surroundings, perhaps chewing through a long stalk or blade of grass at the same time. After half an hour or so, they will start to look around for other palatable plants to nibble. They are constantly on the lookout for danger and will readily bolt back to their burrow. Hard faecal pellets are always voided above ground, never in the burrow and soft caecotrophs are usually consumed during periods of rest underground, although occasionally rabbits exhibit this behaviour above ground (Lockley, 1978). The only vocal sounds that are made are a loud high-pitched scream of terror or a range of growls and hums that denote pleasure or defence. Apprehensive or frightened rabbits will thump the ground with their hind feet. The loud thumping sounds acts as an alarm signal to other rabbits in the vicinity.

Many of the behavioural characteristics of their wild ancestors are still present in the modern-day pet rabbit. Domestication has resulted in rabbits that are far tamer than their wild counterparts and easy to handle. Although some domestic rabbits still retain the tendency to dig holes and live underground, many do not, with the result that domestic rabbits that escape or are released do not survive for long in the wild. Conversely, wild rabbits seldom become tame in captivity, although the occasional individual will overcome its fear of humans. Hand-reared orphans usually grow into fearful adults. Even rabbits that are born as a result of egg transfer from a wild rabbit to a domesticated tame host retain their shy nature (Adams, 1987).

1.1.3 Breeds of rabbits

Domestication has resulted in a wide range of breeds with different attributes. They can be roughly divided into two groups: fancy breeds and fur breeds (Sandford, 1996). The fur breeds include rex, Angoras and satin rabbits with their beautiful coat textures. Fancy breeds include the Belgian hare, and lop and dwarf rabbits with their varying physical characteristics. Most pet rabbits belong to the smaller breeds such as dwarf lops, Dutch or English. Pedigree rabbit breeders often sell surplus stock to the pet trade and occasionally one of the more obscure breeds may turn up as a pet. Pedigree stock is identified by aluminium rings slipped over the hock when the rabbit is 8–10 weeks old. The rings are supplied by the British Rabbit Council in a range of sizes. Each ring has the year of birth and a unique number from which the rabbit can be identified. Many pet rabbits are the result of interbreeding between pets and are cross-breeds. As with other domestic animals, there are breed predispositions to disease. For example, dwarf rabbits are prone to congenital incisor malocclusion (Fox and Crary, 1971). Dutch, Havana and tan rabbits have a high incidence of uterine neoplasia (Greene, 1941).

1.1.4 Angoras

Angoras have been bred for wool production for hundreds of years. The wool is plucked or sheared and either spun on its own or mixed with sheep's wool. Plucked wool is superior to shorn wool. Commercial Angoras are kept in a specialized manner to prevent staining and matting of the fur. After defleecing, woollen jackets can be worn for 2–3 weeks to reduce heat loss or a strip of fleece can be left along the back (Lebas *et al.*, 1998). Commercial Angoras are not provided with bedding but are kept on wire mesh floors and hay is provided in a rack. The long fine coat is a definite disadvantage for the pet animal as it difficult to keep the rabbit free from knots and mats. It is not surprising that a high number of Angoras arrive at rescue shelters for rehoming. The breed is prone to intestinal obstruction by felts of ingested hair.

1.1.5 Diurnal rhythms

Many behavioural and physiological processes of rabbits show a marked diurnal rhythm. In the late afternoon wild rabbits emerge from their burrows to feed, explore, socialize and mate. Grazing resumes during the early morning before the rabbit returns to the warren. Hard faecal pellets are voided during these periods above ground. During the day, caecotrophy (see Section 1.3.1) takes place while the rabbit is resting in the burrow, typically between 08.00 and 17.00 h. Female rabbits give birth in the morning and feed their young at night (McBride, 1988). Domesticated rabbits also follow a natural daily rhythm. Laboratory rabbits that are fed ad lib consume little food between 06.00 h and midday and increase their intake between 17.00 h and midnight, eating most food during the night. Caecotrophs are expelled during periods of minimal feed intake in the morning and sometimes during the evening. If food is restricted, caecotrophs are excreted approximately 5 h after a meal. If a collar is fitted to prevent the ingestion of caecotrophs, feeding still ceases during caecotroph excretion, suggesting that cessation of food intake is not associated with gastric filling (Hörnicke *et al.*, 1984).

The diurnal feeding pattern affects digestive processes and caecal motility, which also follow a circadian rhythm. Ingestion of food is associated with increased caecal motility and the excretion of hard faeces. Caecotrophy is associated with a decline in caecal contractions, so caecal contractions are at a maximum when the animal is feeding. If food is withheld completely, the circadian rhythm of caecal contractions is maintained, but at a lower frequency that does not correlate with soft or hard faeces production (Hörnicke *et al.*, 1984). Absorption of volatile fatty acids and their metabolism in the liver shows a circadian rhythm parallel to the activity of the adrenal gland. Volatile fatty acid absorption into the portal circulation is greatest during the hard faeces phase of digestion, although arterial levels remain remarkably constant (Vernay, 1987). Bile acid production shows a circadian rhythm (Fekete, 1989). There is a diurnal variation in haematological values (Fox and Laird, 1970), with lowest total white blood cell and lymphocyte counts occurring in the late afternoon and evening in association with increased neutrophil counts. Eosinophil counts peak during the afternoon, with the lowest values occurring in the morning. Blood urea nitrogen shows a diurnal variation that is linked with feeding patterns. Even body temperature follows a 24-h cycle (Lazarus-Barlow, 1928).

1.2 Housing and husbandry

1.2.1 Housing

The quiet docile nature of the rabbit combined with its fertility and rapid growth rate has led to its intensive production for commercial and laboratory purposes. Units housing several thousand does are found in countries such as China, Hungary and the USA. At the other end of the scale, in the developing world, a few rabbits are often kept as 'biological refrigerators', i.e. a source of small quantities of meat that is fresh and readily available and which can be eaten before it goes off (Cheeke *et al.*, 1982). The social and behavioural needs of such animals are ignored when they are housed individually in small, wire mesh cages or confined to tiny hutches. The Royal Society for the Prevention of Cruelty to Animals (RSPCA), the Department for Environment, Food and Rural Affairs (DEFRA) and other animal health and welfare associations promote the 'Five Freedoms' of animal welfare:

- Freedom from hunger and thirst
- Freedom from discomfort
- Freedom from pain injury and disease
- Freedom to behave normally
- Freedom from fear and distress

in order that guidelines for animal husbandry and nutrition as far as possible advance the welfare of pet and production animals. There are many welfare implications associated with keeping rabbits in cages, as they are not able to follow their natural instincts. Abnormal behaviour patterns such as stereotypies and restlessness have been recorded. Perpetual wire biting and pawing behaviour has been described in rabbits confined to small cages and does provided with an open nesting box and no bedding material to cover the young (Stauffacher, 1992). A proven link has been established between small cage size and painful conditions such as skeletal disorders or ulcerative pododermatitis in intensively reared rabbits (Drescher, 1993; Drescher and Loeffler, 1996). Morphological differences have been observed in the adrenal glands of rabbits kept in wire cages and those kept in group housing conditions on solid floors (Drescher and Breig, 1993).

In recent years, conditions have improved for many laboratory rabbits. They can be kept in social groups of four to eight animals with no detriment to their health (Turner *et al.*, 1997). It has been proven that rabbits prefer to be in proximity with each other as they are a social species with a defined hierarchy. They also 'interact with enrichment objects' such as wooden sticks, parrot toys or balls designed for cats (Huls *et al.*, 1991). Keeping rabbits in this way not only benefits the rabbits but also the people looking after them. Love (1994) described the response of animal technicians to group housing by saying they 'found it more agreeable to work with rabbits that came to the front of the cage when they heard the sounds of people, rather than cowering away' and 'it was a pleasure to see the rabbits interact with each other'. Stauffacher (1992) describes in detail many ways in which housing for rabbits can be constructed to permit natural behaviour patterns. Despite these advances, most breeding and exhibition rabbits still live their entire life confined to small cages. Some breeders still insist that rabbits should be kept singly in small cages and that large hutches and runs lead to aggression and behaviour problems (Sandford, 1996). At last, the pet-owning fraternity is becoming aware of the rabbit's social nature and need for exercise. There has been a steady increase in the number of house rabbits and the status of the rabbit has shifted from the child's pet to a member of the family. A rabbit can be a satisfactory companion for adults that are out at work all day and find the needs of a dog or cat too demanding. Hopefully the days of keeping pet rabbits in solitary confinement in a barren hutch at the bottom of the garden are now coming to an end. There is legislation governing the welfare of rabbits that is summarized in Box 1.1.

1.2.2 Hutches for pet rabbits

Traditionally, pet rabbits are kept in hutches in the garden, shed or garage. Hutches are a convenient method of housing rabbits; however, most hutches on sale today do not provide sufficient space for rabbits to display their natural behaviours. It is important to provide time outside their hutch for exercise each day. At least 4 h daily exercise is required (Richardson, 2000a). Longer periods or unrestricted exercise are preferable.

The hutch should be as big as possible, especially if two rabbits are housed together. It needs to be situated in a dry, cool, well-ventilated site protected from wind and rain. The minimum recommended size is sufficient space to hop three times in any direction, and high enough for the rabbit to stand up on its hind legs without its ears touching the roof. This space should be available in both the dark, covered portion of the hutch and the open living space. This space

Box 1.1 Legislation governing the welfare of rabbits

There is legislation governing the welfare of farmed rabbits in the UK. The advice also applies to pet rabbits kept in hutches although they are not technically covered by the legislation. Separate legislation governs the transport and slaughter of rabbits. A guide to the legal requirements for farmed rabbits has been produced by UFAW (Universities Federation for Animal Welfare) and can be summarized as follows:

Rabbits must be provided with:

- Adequate lighting to enable the inspection of the animals at any time.
- Wholesome food that is appropriate and in sufficient quantity to maintain good health and satisfy nutritional needs.
- A daily supply of fresh drinking water.
- Suitable accommodation with a suitably bedded floor for the isolation of a sick or injured rabbit.
- Cages of sufficient size to allow the rabbits to move around, feed and drink without difficulty, and allow all the rabbits kept in them to be able to lie on their sides at the same time.
- Cages of sufficient height to allow rabbits to sit upright on all four feet without their ears touching the top of the cage.
- Shelter from bad weather including direct sunlight.
- Daily inspection of all automatic equipment, such as drinkers, by a competent person.
- An alarm on automatic ventilation systems that is independent of the mains electricity and will give warning when the system fails to function properly.
- Daily inspection of stock and the prevention of unnecessary suffering or distress.
- Veterinary care. Prescription-only medicines (POM) including antibiotics and vaccines can only be supplied by the veterinary surgeon that has the rabbits in his/her care.

In 2006 section 14 of the Animal Welfare Act made provision for Codes of Practice relating to petkeeping to be formulated and subsequently enforced in Wales, Scotland and England. Currently only Wales has these Codes of Practice in use. The Codes of Practice detail the care and maintenance of rabbits and closely follow the concept of the 'Five Freedoms', and make it an offence to fail to achieve the required standard of care. Currently (2012) there is no similar legislation in force in England. However, the RSPCA has produced some guidelines for rabbit care, which may be found at http://www.rspca.org.uk.

There are other national rabbit awareness campaigns ongoing, for example Rabbit Awareness Week, 'A hutch is not enough' and 'Make Mine a Chocolate One', all sponsored by the Rabbit Welfare Association, a national welfare agency dedicated to promoting the health and welfare of rabbits in the UK.

requirement should not include the outdoor run. The RSPCA spatial requirements are somewhat greater, the minimum being 1 m (3 ft) wide × 2 m (6 ft) long × 1 m (3 ft) high for both the enclosed and open portions of the living area. In any case where two adult rabbits live together, the space must be increased proportionally and suitable hide areas provided so that each rabbit can get away from the other if they want. The optimum temperature range for rabbits is 15–20°C, which can be checked with a maximum and minimum thermometer. Above this temperature rabbits can suffer from heat stress. Poor ventilation and ammonia build-up predispose to conjunctivitis and respiratory tract infections. It is preferable to situate the hutch against a sheltered wall outside, rather than in an enclosed garage with potential exposure to toxic car fumes. Placing the hutch in a large airy shed can be a good option as shelter is provided with the option of protected exercise space. Many rabbit owners are now using a whole garden shed as a kind of 'super-hutch' for housing two or more rabbits, providing ample indoor space. These sheds are then often attached to large aviary type runs to allow outside access (See Figure 1.1). Rabbits are tolerant of cold conditions and can withstand winter weather provided they have shelter and plenty of bedding material. Thin rabbits with no body fat are more susceptible to the effects of cold and need extra

Figure 1.1 Example of outdoor rabbit housing.

protection on cold nights. Hot conditions and direct sunlight with no shade are distressing for rabbits. These conditions are potentially fatal as rabbits cannot sweat or pant effectively, and are far more damaging than cold conditions. The ability to get out of direct sunlight is of paramount importance, and needs to be considered when providing rabbit accommodation. Rabbits are far more capable of coping with cold and even wet conditions, as long as they have the opportunity to shelter and access to enough food and bedding. When planning rabbit accommodation, allowing the rabbit a choice of positions and therefore ambient temperatures, access to sunlight and shelter is a major benefit. Rabbits produce copious quantities of urine and faeces, which are usually deposited in one part of the hutch that should be cleaned once or twice daily. Bedding that is not fouled and remains clean and dry can be left in the hutch; however, with any deep litter system, a full clean should be done at least weekly, or more often if the bedding is wet or smells. Many types of material can be used as bedding. Any bedding material should be non-toxic, free from dust, comfortable to lie on and good insulation. Garden peat has been recommended to neutralize ammonia and reduce irritation to the eyes and respiratory tract (Malley, 1995). An economical bedding material is a layer of newspaper covered in hay. This can be rolled up for disposal. The hay provides ad lib high fibre food in addition to a soft bed that is kind to the hocks. Other options include straw of various types. The advantage to straw is that it is cheap, easily available and very good at allowing fluid to drain away from the surface of the bedding, reducing potential contact with rabbit skin. Straw can be fairly sharp, depending on what type of crop it is made from, and can in some circumstances cause skin and ocular irritation. Rabbits will sometimes eat straw, which can cause oral trauma if it is sharp. Oat straw is an ideal option as it is soft as well as encouraging fluid drainage. Commercial forms of bedding are also available. These are often recycled paper products, and are well accepted by rabbits, although they are not the most economical bedding. Woodshavings and chips are not recommended because of the potential for dust to cause ocular and respiratory irritation and the possibility of sharp edges causing skin/mouth/eye wounds. Wood products containing aromatic oils may cause respiratory irritation and have been reported to cause hepatotoxicity.

1.2.3 Exercise

Exercise is of paramount importance for the physical and mental health of rabbits. Immobile rabbits are at increased risk of ulcerative pododermatitis, osteoporosis, urine sludging and spinal fractures. There is a proven association between confinement and the development of spinal deformities (Drescher and Loeffler, 1996). Exercise improves blood circulation and prevents pressure sores. The opportunity to explore is mentally beneficial. All methods of providing exercise should be escape proof, although escapees instinctively remain close to their home territory and can usually be found providing they have not been carried off by a predator or are in search of a receptive mate. Any outside exercise area should be as large as possible and allow the rabbit sufficient space to run rather than just hop.

Grass and natural vegetation is the ideal diet for rabbits. Access to a garden, enclosure or pen outside provides nutrition as well as environmental enrichment. Natural daylight is the best way of providing the correct amount of vitamin D for the animal's needs. Rabbits enjoy basking in the sun. However, their destructive and burrowing instincts, along with a taste for bedding plants, means free access to the garden should be supervised. Free rabbits are also prey to neighbours' dogs, cats and other animals such as foxes, so supervision or a well-fenced area or mesh pen is required. Ideally this should be a permanent structure that allows the rabbit to establish a familiar territory and feel secure. An area of approximately 3 m^2 (10 sq. ft) is sufficient, although larger areas are preferable. Branches, drainpipes, boxes and other enrichment objects can be placed in the enclosure to provide cover and recreation. Planting of suitable weeds/plants inside the enclosure is also a good idea.

It is possible to train rabbits to return to their hutch at specified times of the day by rewarding them with food. Many pet rabbits are tame enough to be picked up, especially if they have been handled daily from an early age. These animals can be given free access to a garden during the day, perhaps under supervision, and returned to the hutch at night. Alternatively, portable wire mesh runs can be used, the familiar territory being sacrificed for the ability to provide a fresh area of forage regularly. There are many designs, some of which can be moved around the lawn, allowing the rabbits to keep the grass down. Enclosed yards are an acceptable alternative to a garden. Rabbits can also be allowed to exercise in the house. In either situation tomato trays planted with edible vegetation (seed packages of suitable plants are available) can provide environmental enrichment.

1.2.4 Burrowing

The opportunity to dig their own burrow is appreciated by many rabbits but not by their owners. Once they have dug out and established a burrow, most rabbits appear satisfied and do not start another. Females are more likely to dig burrows than males as their instinct is to dig out new nesting sites, especially during the spring. Pregnant or pseudopregnant does exhibit marked burrowing behaviour, although it can still be exhibited by spayed females. Burrowing can be accommodated in an outside run with a little imagination, attention to escape potential and buried wire walls. Despite the potential inconvenience, allowing rabbits to perform natural behaviours such as burrowing can make a significant difference to perceived well-being in pet rabbits.

1.2.5 Companionship

Rabbits are social creatures that benefit from companionship, preferably from another rabbit. A bonded pair becomes inseparable (see Figure 1.2). They spend time grooming each other and there are many benefits to mutual grooming, such as reducing parasite numbers in the fur and cleaning inaccessible places such as the face or back of the neck. Occasionally, a dominant rabbit will barber the fur of its companion. Neutering rabbits that are kept together is necessary to prevent fighting and unwanted pregnancies. Guinea pigs are sometimes kept as companions for rabbits, although this arrangement is not as satisfactory as two rabbits together. There is a small risk of the guinea pig contracting *Bordetella bronchiseptica*, which is asymptomatic in rabbits but can cause pneumonia in guinea pigs. Neutering is required to prevent bullying and constant sexual harassment of the guinea pig. Regardless, some rabbits will still bully their guinea pig companion, and hide boxes small enough to allow the pig in but exclude the rabbit should be provided. If the bullying is severe the welfare of the guinea pig is better served by breaking up the pair. Choosing to pair a rabbit with a guinea pig should not be advocated; however, where a stable pair exists, then the bond is similar to that between two rabbits and should not be broken unless the welfare of the guinea pig is suffering.

Figure 1.2 A bonded pair of rabbits can become inseparable.

Key Points 1.1 Bonding

- Rabbits gain benefit from living in pairs. It reduces boredom and increases contentment.
- In the wild, rabbits are a social species with a defined social hierarchy.
- Not every pair of rabbits will bond successfully. Compatible pairings are more likely to bond; several potential partners may need to be tried.
- The recommended pairing is a neutered female with a neutered male; however, other pairings are possible, depending on the individual rabbit.
- Both rabbits should be neutered prior to attempting bonding, and ideally should also be tested for *E. cuniculi,* so seropositive animals are paired with seropositive, and negative with negative.
- Rabbits that are going to be bonded should be housed next to each other, so that they can see and smell the other rabbit.
- It is sensible to place food items near to the barrier between the two rabbits, as eating is a social activity in rabbits, and this should be encouraged.
- Either bedding should be moved from each enclosure and placed into the other every day, to allow the scent of the potential partner to become familiar, or the rabbits themselves should be moved into the other enclosure for the same reason, but also to reduce territoriality.
- Once the rabbits have become familiar with each other, they can be physically introduced. This should take place in a neutral area. Placing rabbits into a bath tub has been suggested; however, a rabbit pen in an unfamiliar room works just as well.
- Injury and direct fighting should be avoided; rabbits displaying aggression should be separated. Care is needed as this is where owners can get bitten.
- Aggressive signs:
  1. Ears held back
  2. Tail raised
  3. Tension in haunches.
- Dominance sign:

  Mounting (either sex).
- Positive signs:
  1. Initial indifference
  2. Laying down calmly but separately
  3. Licking the other rabbit's face
  4. Mutual grooming
  5. Lying side by side.
- Once the rabbits are comfortable with each other, the time spent together can be increased. Ten to 15 minutes daily is long enough to start with, but this can be increased to several short sessions daily, or longer sessions depending on the behaviour of the rabbits.
- The next step is to feed the rabbits together.
- Once the rabbits are spending time and eating together, then they can be allowed to use the same sleeping area and be left together permanently.
- Some workers advocate 'stress bonding'. This is not necessary if the bonding process is going well; however, for two individuals that are proving difficult it may overcome the obstacles to allow a successful bond. It involves the use of a stressful situation to get the rabbits to take comfort from each other. It must be recognized that this is a means to achieve a long-term bond. In the short term it is an adverse experience to create a long-term benefit.
- Stressful situations could include taking both rabbits on a car ride, placing them together in a carrier on top of the washing machine (that is switched on) or next to a switched-on vacuum cleaner. Once the rabbits are snuggling close to each other for comfort, they can then be placed into an enclosure in a neutral area to continue to interact in the same way as regular bonding. Eventually the rabbits can be allowed to interact in the neutral area without being stressed first.
- Remember that bonding is a difficult process and many rehoming charities provide specialist help to bond compatible animals.

Rabbits have distinctive personalities and strong individual likes and dislikes of other rabbits. It is not possible to predict accurately whether newly introduced rabbits will form an instant rapport or attack each other. Neutered rabbits of the opposite sex are most likely to bond, although it is possible to keep same sex pairs together. Pairs of male rabbits need to be castrated to prevent fighting. Ideally, rabbits should be introduced on neutral territory with plenty of room for escape and hiding places to retreat into. If this is not possible, introducing the female to the male on his territory is more likely to be successful than the reverse. When they are first introduced, most rabbits spend a period chasing each other around and pulling some hair out, but will settle down eventually. A rabbit that has spent its entire life confined to a hutch may not realize that it can run around and is daunted by both the great outdoors and its new companion. It is not unusual for such rabbits to remain quiet and immobile for several days before they gain confidence and start to explore. If possible, a period of separated proximity is advisable to allow rabbits to become accustomed to each other's presence before they are introduced. Adjacent pens separated by wire mesh allow rabbits to sniff each other; also change around the bedding to get the rabbits used to the scent of the proposed companion in their own territory. It is a promising sign when the two are found lying side by side on either side of the mesh. Some rabbits never bond; others accept any new companion readily.

1.2.6 Winter housing

The advice is often given that rabbits should be given shelter from the winter weather by bringing the hutch into a shed or garage. As a result, many rabbits do not come out of their hutch for 6 months of the year because owners fear their pet will 'catch a chill'. It is important to provide exercise during the winter as well as the summer. Free-range rabbits that are kept outside all year round often choose to sit in the rain and snow despite having a hutch full of warm bedding to go into if required. They seem impervious to cold and as long as they have access to shelter, plenty of food and protection from predators, rabbits can be kept outside during the winter. Thin or ill rabbits or those that have not been acclimatized should not be kept in this fashion and need to be given extra protection indoors or in a hutch or shed during inclement weather. They can be allowed outside if the weather is good. If rabbits are not exposed to natural daylight during the winter months, vitamin D deficiency can occur. Undetectable vitamin D levels have been found in blood samples taken in spring from pet rabbits housed in hutches over winter (see Figure 1.5) (Fairham and Harcourt-Brown, 1999).

1.2.7 Free-range rabbits

Stauffacher (1992) described the behaviour of rabbits under 'near-to-nature' or free-range conditions. The rabbits were kept in an open-air turfed enclosure with several trees and bushes. They were kept in groups of up to 30 animals and their daily activities followed a double diurnal rhythm with periods of rest alternating with periods of activity around dusk and dawn. During periods of rest, the rabbits sought out places with a good overview of the enclosure under bushes or near trees where they would huddle together and engage in mutual grooming. This method of husbandry permits natural behaviour patterns, encourages grazing and normal caecotrophy and allows animals to groom themselves and each other thoroughly, thereby removing skin debris, dead hair and parasites from the coat. In a study by Harcourt-Brown and Baker (2001) blood samples from rabbits kept under free-range conditions had higher red cell and lymphocyte counts than rabbits kept in hutches, suggesting that they were healthier (see Figure 2.1).

1.2.8 House rabbits

In recent years, there has been a trend to give pet rabbits the run of the house. House rabbits make good companions and can be trained to use a litter tray. They are usually provided with some sort of sleeping accommodation to which they can retreat and can be confined while their owners are out at work. Many house rabbits have their own room that contains an open hutch or childs 'wendy-house' for sleeping. Most house rabbits are neutered, especially males, to reduce territory marking by spraying or defecating outside the litter tray. Rabbits can bond closely with human owners and make entertaining responsive pets. They will play with toys, beg for treats and follow their human companion around the house. Dogs and cats can learn to tolerate rabbits as companions. Rabbits can also learn not to view dogs and cats as predators.

1.2.9 Litter trays

Large cat litter trays or gravel trays from the garden centre can be used for rabbits to urinate and defecate in. Hay, straw, cat litter, peat, soil or 'natural' litters made from hemp, corn cobs or reclaimed wood pulp are all used as litter, materials for rabbits. Clay litters are not advisable as some rabbits will eat the litter, which can then impact the caecum (Brown, 1997).

Key Points 1.2 Litter training

- Rabbits are clean animals and can often be easily litter trained.
- Most rabbits will have specified areas within their living area that they use to urinate.
- Place a litter tray lined with newspaper and filled with hay or straw in these areas and positively reward rabbits when they urinate/defecate in the correct area.
- With newly acquired rabbits (where latrine areas have not been established), placing litter trays in each corner can be successful.
- While using hay in the litter tray is controversial (because rabbits will often eat this and it can be one way that encephalitozoonosis can be spread) sometimes it will make the difference in successfully litter training a rabbit. This is because rabbits will often eat when using their latrine areas in the wild, and having a food source in the litter tray reinforces the use of the litter tray.

Organic solvents in litter materials derived from preserved pine wood shavings or cedar chips have been reported to cause hepatotoxicity and are therefore inadvisable (*Rabbit Health News*, 1991b). Hay or clean, chopped straw can be used in rabbit litter trays.

Key Points 1.3 Environmental requirements

- Hutches are not suitable for rabbits to be kept in all the time.
- Daily exercise is vital for physical and mental health of rabbits. At least 4 h exercise daily is recommended, including during the winter months.
- Rabbits benefit from companionship and form close bonds. The ideal companion is another rabbit, preferably of the opposite sex. Neutering is required.
- Rabbits can be destructive, so they should be either restricted or supervised when out for exercise in the house or garden.
- All rabbits must have access to ad lib hay and fresh water at all times. In winter water bottle nozzles can freeze, so if rabbits are housed outdoors, this should be checked regularly.
- Most rabbits naturally use a litter tray (see Key Points 1.2). Spot cleaning of the environment should be undertaken at least daily and a thorough clean done weekly.
- Rabbits benefit from somewhere to hide in the face of potentially stressful situations. One hide area per rabbit, plus one so that they can run from one to another, is ideal. It is also worth having a variety of sizes of hide boxes, so that some will fit both rabbits but others will fit only one.

1.2.10 Thermoregulation

Rabbits are unable to sweat or pant effectively to dissipate body heat. The main thermoregulatory mechanism is by heat exchange in the ears, which have a large arteriovenous anastomotic system. In the nose, the nasal glands moisten inspired air, which also has a role in thermoregulation. Rabbits are unable to tolerate high ambient temperatures, which can prove fatal.

1.3 Digestive anatomy, physiology and nutrition

1.3.1 Digestive physiology

The alimentary tract of the rabbit is adapted for the digestion of large quantities of fibrous food (Figure 1.3). Rabbits have developed a strategy of high feed intake and rapid food transit through the gut to meet their nutritional needs from a nutrient dilute diet. Rabbits are hindgut fermenters and rely on microbial fermentation of food within the caecum to provide nutrients. In the stomach and small intestine, digestion and absorption of nutrients is similar to monogastric mammals. The end-products of the digestive processes are separated in the colon into indigestible material and substances that can be metabolized by caecal micro-organisms. Separation of the ingesta depends on particle size. The proximal colon of the rabbit is specially adapted for the separation of large particles of indigestible fibre from smaller particles that can be degraded and used as a substrate for bacterial fermentation in the caecum. The two components are simultaneously sent in opposite directions.

Indigestible fibre passes down the colon to be rapidly eliminated as hard, dry faecal pellets. Smaller particles and fluids pass into the caecum where bacterial fermentation releases volatile fatty acids and synthesizes proteins and vitamins. Pellets of soft caecal contents (caecotrophs) are periodically expelled from the anus and re-ingested as a source of nutrients. This digestive strategy utilizes bacterial fermentation to synthesize nutrients and avoids the need to store large volumes of food in the digestive tract. Vegetation can be efficiently digested below ground without the need to spend long periods grazing and exposed to predators.

The rabbit's characteristic of consuming caecotrophs directly from the anus is known as *caecotrophy*, although the term coprophagia is still used in some texts. Coprophagia is defined as 'the ingestion of dung or faeces' (Blood and Studdert, 1999). Faeces are defined as 'body waste discharged from the intestine' and so, strictly speaking, faecal material is not the substance that is ingested by rabbits as it is not waste material but nutritionally rich caecal contents. The terms *soft faeces* and *night faeces* are sometimes used to describe the capsules of caecal material known as caecotrophs. The term *night faeces* is misleading. Caecotrophs are produced during the day in wild rabbits. They are produced 4 to 8 h after feeding during a quiet undisturbed period, which is during the day for a wild rabbit in its burrow but can be during the night or early morning for a domestic or laboratory rabbit in its cage or hutch.

1.3.2 Ingestion of food

The rabbit has a wide visual field that allows it to watch for predators while it is grazing. The visual field does not include the area immediately under the nose. Food selection and ingestion is based on smell and from tactile information gained from the sensitive vibrissae around the nose and lips.

The teeth are adapted for the ingestion of a fibrous diet. All the teeth are open rooted and grow continuously. The incisors are adapted to cut through vegetation. The two large upper incisors have two tiny secondary incisors situated immediately behind them. The two lower incisors occlude just behind the upper primary incisors and wear against them to form a sharp cutting edge. There is a thick layer of enamel on the anterior aspect of the upper primary incisors but no enamel on the posterior aspect (Hirschfeld et al., 1973). The enamel on the lower incisors is evenly distributed on all aspects. The distribution of enamel in combination with the occlusal positioning of the upper and lower incisors allows the teeth to be constantly sharpened. Wild rabbits are capable of chewing through aluminium (Adams, 1987). The rate of growth of the upper incisors is approximately 2 mm per week (Shadle, 1936). Canine teeth are absent and there is a wide diastema between the incisors and the premolars and molars, which are grossly indistinguishable from each other. The premolars and molars form a row of five or six cheek teeth that are used for grinding the food before it is swallowed. The food is ground between the cheek teeth with jaw movements of up to 120 per minute (Brewer and Cruise, 1994).

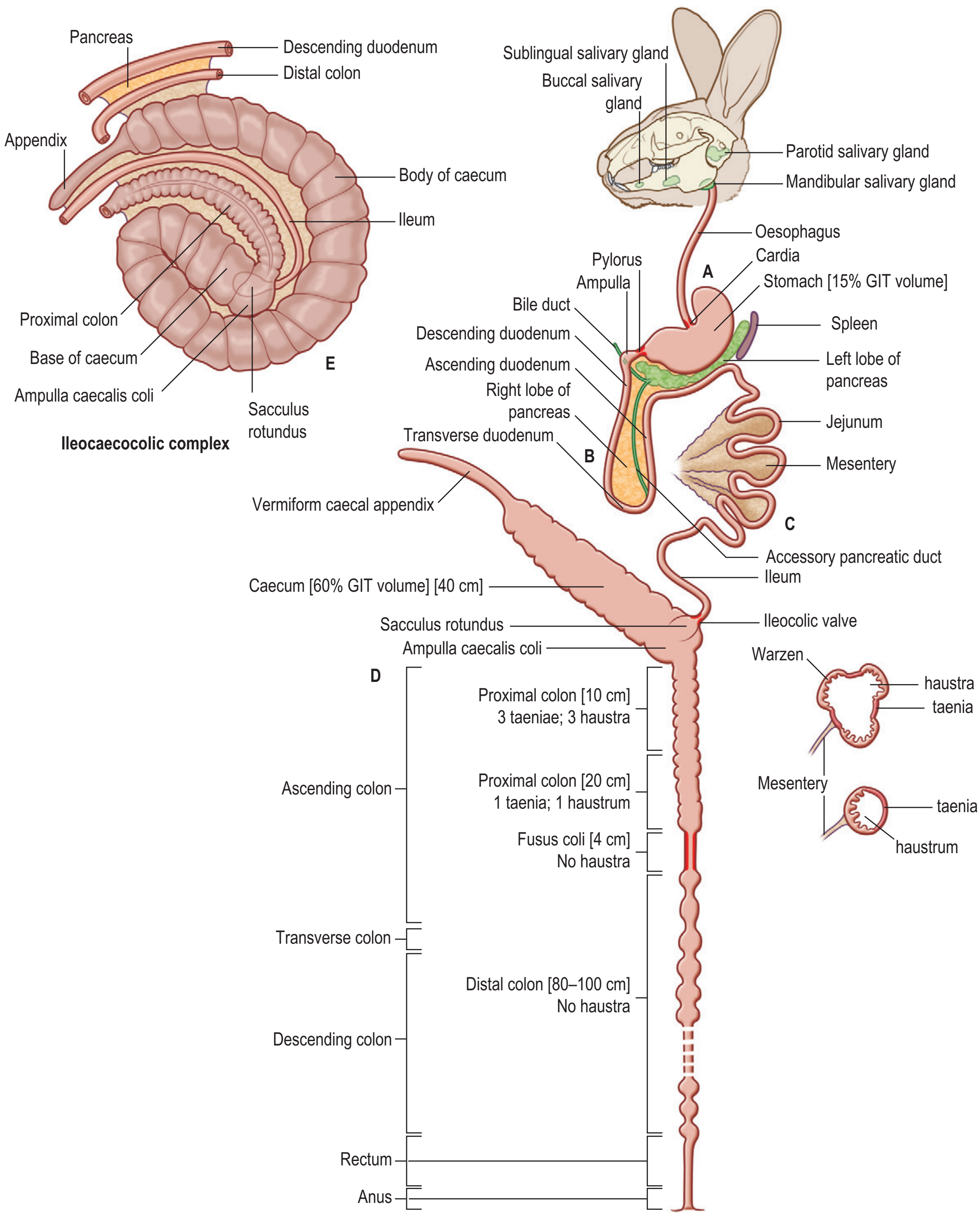

Figure 1.3 See legend on opposite page.

Saliva is continuously secreted and contains amylase. Hunger is stimulated by a dry mouth and contractions of an empty stomach or by a decrease in blood levels of metabolites such as glucose, amino acid, lactic acid or volatile fatty acids (Fekete, 1989).

1.3.3 Anatomy and digestion in the stomach and small intestine

The stomach comprises about 15% of the volume of the gastrointestinal tract (Cruise and Brewer, 1994). It has a well-developed cardiac sphincter that prevents vomiting, and a muscular pyloric area, although in general the muscular layer of the stomach is weaker than in other species. There is always food material in the stomach. Together, the caecum and the stomach contain over 80% of the digesta (Lang, 1981a) and the amount of material in them is dependent on age, breed, diet and time of day. Water and large quantities of acid are secreted into the stomach. The postprandial pH can fall to 1–2, which effectively sterilizes ingesta before it passes into the small intestine. The stomach pH of suckling rabbits is higher at approximately 5–6.5, which permits the passage of bacteria through the stomach to the hindgut to colonize the caecum. During the digestion of caecotrophs the stomach pH rises to 3.0 (Blas and Gidenne, 1998). Transit time of food through the stomach is approximately 3–6 h (Carabaño and Piquer, 1998).

Figure 1.3 Schematic diagram of the anatomy of the alimentary tract of the rabbit. (A) The alimentary tract of the rabbit is adapted for the digestion of large quantities of fibrous food. The teeth continually grow and wear against each other to maintain their shape. The incisors are worn to a fine cutting edge that can be used to slice through vegetation or gnaw hard substances such as bark or wood. The occlusal surfaces of the cheek teeth are worn to an effective grinding surface that is used to reduce food particles to a small enough size to be swallowed. There are a number of well-developed salivary glands. The cardia and pyloric sphincter are muscular and well-developed. The relatively voluminous stomach is simple in type and always contains food. The stomach contents comprise approximately 15% of the contents of the gastrointestinal tract. **(B)** The duodenum forms a loop with descending, transverse and ascending parts. It has an extensive mesentery. The duodenum begins with a slight enlargement approximately 1 cm from the pylorus that receives the bile duct. The right lobe of the pancreas is widely dispersed in the mesoduodenum as many isolated lobules. The main body and left lobe of the pancreas run in the mesentery that attaches the transverse colon to the stomach and spleen (see Figure 8.2). A single accessory pancreatic duct opens into the junction between the descending and transverse duodenum. **(C)** The jejunum is long, convoluted and relatively free of attachments. It occupies the dorsal half of the left flank and the caudal half of the abdomen (see Figures 1.13–1.15). The ileum is closely associated with the mesentery that connects part of the ascending colon to the caecum to form the ileocaecocolic complex (see E). The end of the ileum is expanded into a thick-walled sacculus rotundus. **(D)** The caecum and appendix are shown as a straight tube, but are in fact a coiled spiral (see E). The thin-walled caecum is a large organ that ends in an appendix that is heavily endowed with lymphoid tissue. The ascending colon of the rabbit can be divided into four sections. The first section is approximately 10 cm long and has three longitudinal flat bands of muscular tissue or *taeniae* that separate rows of *haustra* or sacculations. Small protrusions, 'warzen' (warts), approximately 0.5 mm in diameter, can be seen on the mucosa in this section of colon. The second section of ascending colon is approximately 20 cm in length and has a single taenia and fewer, smaller haustra. The third portion of the ascending colon is termed the *fusus coli* and is a muscular area about 4 cm long. The fusus coli opens into the fourth section of ascending colon that is histologically indistinguishable from the transverse and descending colon. Because the fusus coli forms such a natural division between two morphologically and functionally distinct sections of the rabbit colon, the terms 'proximal' and 'distal' colon are sometimes used instead of ascending, transverse and descending colon (Snipes *et al.*, 1982). The proximal colon includes the three taeniae section, the single taenia section and the fusus coli. The distal colon is 80–100 cm long and runs from the fusus coli to the rectum. **(E)** A ventral view of the ileocaecocolic complex, which occupies more than half of abdomen, mainly on the right side (see Figures 1.13–1.15). The complex has been slightly unrolled in order to illustrate its component parts. There are mesenteric attachments between the caecum, appendix, proximal colon, ileum, distal colon and descending duodenum. These organs form a complex three-dimensional structure in rabbits. The term 'ileocaecocolic complex' is used to describe the structure in this text. The body of the caecum has a spiral form consisting of one and a half turns, ending in an appendix that extends to the right flank. The axis of the spiral is the base of the caecum that receives the end of the ileum in the form of the sacculus rotundus. The ileum lies between the concavity of the body of the caecum and the convexity of the upper ascending colon and is attached to these two structures by peritoneal folds. Because of their peritoneal attachments to the spiral caecum, the ileum and upper ascending colon are also arranged in a spiral, and are integral components of the ileocaecocolic complex. The upper ascending colon begins as a smooth oval dilation, the *ampulla coli*, that forms the junction with the sacculus rotundus and the caecum. Parts of the descending colon and descending duodenum are attached to the distal end of the caecum by peritoneal folds. The left lobe of the pancreas lies in the peritoneal fold between the descending duodenum and descending colon.

The duodenum begins with a slight enlargement that receives the bile duct. The right lobe of the pancreas is diffuse and is situated in the mesoduodenum of the duodenal loop. The body and the left lobe of the pancreas are much denser than the right lobe. The left lobe lies between the stomach and the transverse colon and extends as far as the spleen. A single pancreatic duct opens at the junction of the transverse and ascending loops of the duodenum (see Figure 1.3B). This is the accessory pancreatic duct. The terminal part of the main pancreatic duct disappears during embryonic development. The accessory pancreatic duct communicates with both pancreatic lobes. The jejunum is long and convoluted. The end of the ileum is expanded into a spherical thick-walled enlargement known as the *sacculus rotundus* that forms the junction between the ileum, caecum and proximal colon. The sacculus rotundus is unique to the rabbit and has abundant aggregations of lymphoid tissue and macrophages in the lamina propria and submucosa. An ileocolic valve controls movement of digesta from the ileum into the sacculus rotundus and also prevents reverse flow into the small intestine. Motilin, a polypeptide hormone secreted by enterochromaffin cells of the duodenum and jejunum, stimulates gastrointestinal smooth muscle. Fat stimulates and carbohydrate inhibits its release. In the small intestine, motilin activity is decreased aborally. It disappears in the caecum and reappears in the colon and rectum (Brewer and Cruise, 1994).

Digestion and absorption of nutrients in the stomach and small intestine are similar to other monogastric animals. Caecotrophs are digested in this section of the gastrointestinal tract. Caecotrophs contain micro-organisms and are the products of microbial fermentation such as amino acids, volatile fatty acids and vitamins. They are encapsulated in a gelatinous mucous coating that protects them from the acidity of the stomach. Some fermentation takes place within the caecotrophs as they lie in the gastric fundus for 6–8 hours before being digested. Lysozyme is secreted by the colon and incorporated into the caecotroph during its passage through the large intestine (Camara and Prieur, 1984). The bacteriolytic activity of lysozyme enables microbial protein to be degraded and absorbed from the small intestine in addition to the amino acids and vitamins present in the caecotrophs. Amylase is produced by bacteria within the caecotroph that converts glucose into carbon dioxide and lactic acid, which is absorbed from the stomach and small intestine (Fekete, 1989).

Hydrochloric acid and pepsin initiate digestion in the stomach that continues in the small intestine in a manner similar to that of other mammals. Pancreatic amylase production is relatively modest. There are alternative sources of amylase such as saliva and caecotrophs. In rabbits, ligation of the pancreatic duct does not result in pancreatic insufficiency (Brewer and Cruise, 1994). Proteolytic enzymes and chymotrypsin can be found in the intestinal lumen within a few weeks of the operation. It is thought that small pancreatic ducts that connect directly with the duodenum are the source of the enzymes. Bicarbonate is secreted into the duodenum and neutralizes the acidic digesta as it leaves the stomach. In the jejunum bicarbonate is absorbed rather than secreted. Transit time through the small intestine is fast. Estimated retention times in the jejunum and ileum are 10–20 and 30–60 minutes, respectively (Carabaño and Piquer, 1998).

1.3.4 Anatomy of the hindgut

The anatomy of the rabbit's digestive system is illustrated in detail by Barone *et al.* (1973) and Barone (1997). A schematic representation of the rabbit's digestive system is given in Figure 1.3. The ileocaecocolic segment is illustrated in Figure 1.3E and the topographical anatomy of the small intestine and colon is described in Figure 8.2.

The sacculus rotundus opens into the *ampulla caecalis coli*, which forms a T-junction between the ileum, caecum and proximal colon. The ampulla caecalis coli, caecum and proximal colon are specially adapted for mixing and separating large quantities of food. Large particles of indigestible fibre are separated from small fermentable particles and fluid. The large particles are sent distally along the colon while the small particles and fluid are sent proximally into the caecum where bacterial fermentation takes place (Figure 1.4). The thin-walled caecum ends in a

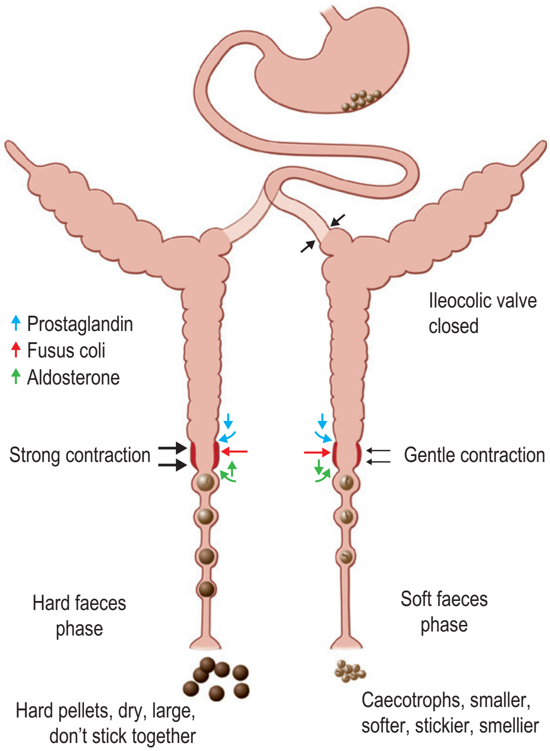

Figure 1.4 The activity of the digestive system during excretion of hard and soft faeces. (A) The motility and function of the hindgut can change depending on the type of faeces formed within the colon. The formation of hard faeces is known as the *hard faeces phase* and the expulsion of caecotrophs is known as the *soft faeces phase*. The phases of excretion follow a marked circadian rhythm. The hard faeces phase is shown in black. The soft faeces phase is shown in green. Exchange of water, electrolytes and nutrients across the intestinal epithelium alter with the phase of faeces excretion. The direction of water and electrolyte exchange is indicated by arrows. The proximal part of the ascending colon is able to separate digesta into two fractions that are simultaneously sent in opposite directions. During the hard faeces phase, water is secreted into the proximal colon and the intestinal contents are thoroughly mixed by contractions of the caecum and colon. Large indigestible particles (> 0.5 mm) tend to accumulate in the lumen of the proximal part of the ascending colon and are moved distally, whereas smaller particles accumulate at the circumference in the sac-like haustra. Haustrum is the Latin term for a pump. Haustral activity sends the small particles and fluid proximally into the caecum where bacterial fermentation takes place. The indigestible fraction, composed of large particles, is moved rapidly through the proximal colon to the fusus coli and distal colon where it is formed into hard, round, dry pellets that are excreted from the anus. Rhythmic caecal contractility is greatest during the hard faeces phase.

(B) Periodically, the motility of the caecum and proximal colon alters completely. Haustral activity ceases and the caecum contracts, sending caecal material swiftly along the large intestine. In the fusus coli the material is formed into soft pellets that become encapsulated in mucus (see Figure 1.5). This is the soft faeces phase of excretion when caecotrophs pass through the colon to be expelled from the anus. Expulsion of caecotrophs coincides with a decrease in rhythmic motility of the caecum and proximal colon, and increase in motility of the distal colon. Soft faeces or caecotrophs are expelled once or twice daily, at least 4 h after feeding, usually during periods of rest. The transit time for soft faeces through the colon is 1.5–2.5 times faster than that for hard faeces. Motility in the upper gastrointestinal tract remains the same during the hard and soft faeces phases. The differences in colonic motility during the hard and soft faeces phase of excretion are most pronounced in the second section of proximal colon that has a single row of haustra. The fusus coli is a specially adapted area of the colon that acts as a differential pacemaker for the initiation of peristaltic waves in the proximal and distal colon that alter with the phase of faeces excretion. The fusus coli is highly innervated and is influenced by hormones such as aldosterone and prostaglandins. During the hard faeces phase, the intestinal contents lose considerable quantities of water, potassium and sodium during their passage through the fusus coli. Water is mechanically squeezed out of the fibrous material before it passes to the distal colon where absorption of water, volatile fatty acids and electrolytes continues, leaving the residue of dry, indigestible matter that is expelled as hard faecal pellets.

narrow blind appendix that is heavily endowed with lymphoid tissue. The appendix is often described as 'vermiform' due to its worm-shaped appearance. The gut-associated lymphoid tissue (GALT) of the rabbit is predominantly in the hindgut and represents over 50% of the total lymphoid tissue, which may account for the relatively small spleen of rabbits (Percy and Barthold, 1993).

The ascending colon of the rabbit is divided into four sections. At the proximal end, the ampulla caecalis coli opens into the first section, which is approximately 10 cm long and has three longitudinal flat bands of muscular tissue or taeniae separating rows of haustra or sacculations. Small protrusions, approximately 0.5 mm in diameter, can be seen on the mucosa in this section of colon. These cauliflower-like protrusions have been termed *warzen* (warts) and are believed to be unique to lagomorphs. They represent an increase in the surface area of the colon that would favour increased absorption. The protrusions may also assist mechanical separation of intestinal contents. Histologically, the muscular layers of the taenia contain many autonomic fibres that are part of the myenteric plexus (Snipes *et al.*, 1982). The second section of ascending colon is approximately 20 cm in length and has a single taenia and fewer, smaller haustra. There is an abundance of myenteric plexus in this region. The third portion of the ascending colon is termed the *fusus coli* and is a muscular area about 4 cm long (see Figure 1.5). This area is highly innervated and vascular. The mucosal surface of the fusus coli is distinguished by prominent longitudinal folds and contains numerous goblet cells. The fusus coli opens into the fourth section of ascending colon, which is histologically indistinguishable from the transverse and descending colon. Because the fusus coli forms such a natural division between two morphologically and functionally distinct sections of the rabbit colon, many physiological texts have abandoned the traditional description of ascending, transverse and descending colon and

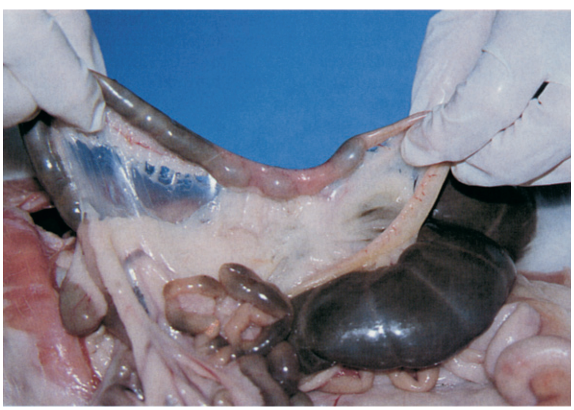

Figure 1.5 Fusus coli. The fusus coli is a highly innervated, vascular, muscular section of the ascending colon (see Section 1.3.5). The fusus coli acts as a pacemaker for colonic motility that alters with the type of faeces that are passing through the colon. It is influenced by the autonomic nervous system and hormones such as aldosterone and prostaglandins. The mucosa of the fusus coli is deeply folded and contains many goblet cells. This plate shows the fusus coli of a rabbit that died during the morning when the colon was in the soft faeces phase. Pasty caecal material is passing into the fusus coli from the proximal colon (left). In the fusus coli, the intestinal contents are squeezed into pellets that become encapsulated in mucus before being excreted as soft caecotrophs.

use the terms *proximal* and *distal* colon instead (Snipes *et al.*, 1982). The proximal colon includes the three taeniae section, the single taenia section and the fusus coli. The distal colon is 80–100 cm long and runs from the fusus coli to the rectum. The mucosa of the distal colon is smooth with no surface specialization. The tunica mucosa possesses short crypts with numerous goblet cells reaching into the base. This section of the colon is thin-walled and usually contains hard faecal pellets.

1.3.5 Motility of the hindgut

The motility and function of the hindgut can change, depending on the type of faeces formed within the colon. The formation of hard faeces is known as the hard faeces phase and coincides with feeding activity. The expulsion of caecotrophs is known as the soft faeces phase. The phases of excretion follow a marked circadian rhythm. In caged rabbits with ad lib access to food, feed intake increases from 15.00 to 18.00 h and remains high until midnight. Intake then reduces until 02.00, when a new phase starts, with a maximum at 06.00, ending at 08.00 when the soft faeces phase begins. This natural pattern of feeding behaviour and faecal excretion can be seen in pet rabbits, although it may be altered by type and availability of food, age, pregnancy and lactation (Carabaño and Piquer, 1998).

During the hard faeces phase, water is secreted into the proximal colon, which aids the process of mixture and separation. Intestinal contents are thoroughly mixed by contractions of the caecum and colon that separate the digesta into large indigestible particles, and small particles including bacteria and water-soluble components. The indigestible fraction is moved rapidly through the proximal colon to the fusus coli and distal colon before being excreted from the anus. The fermentable fraction is moved in a retrograde direction back into the caecum. The large indigestible particles ($>$ 0.5 mm) tend to accumulate in the lumen of the proximal part of the ascending colon and are moved distally, whereas smaller fermentable particles accumulate at the circumference in the sac-like haustra. Haustral activity sends the small particles proximally into the caecum. Caecal contractility is greatest during the hard faeces phase when the liquid intestinal contents are mixed and separated in the proximal colon. Periodically, the motility of the caecum and proximal colon alters completely. Haustral activity ceases and caecal material is moved swiftly along the large colon. In the fusus coli the material is then separated into pellets that become encapsulated in mucus. This is the soft faeces phase of excretion. Soft faeces or caecotrophs are expelled at least 4 h after feeding, usually during periods of rest.

The fusus coli is a specially adapted area of the colon that acts as a differential pacemaker for the initiation of peristaltic waves in the proximal and distal colon (Ruckesbusch and Fioramonti, 1976). The nature and direction of the peristaltic waves alter with the phase of faeces excretion. The fusus coli is highly innervated and is influenced by hormones such as aldosterone and prostaglandins. During hard faeces production aldosterone levels are high, but they fall during the soft faeces phase of excretion. Prostaglandins inhibit motility of the proximal colon and stimulate the distal colon, aiding the elimination of soft faeces or caecotrophs (Pairet *et al.*, 1986).

Three types of contractions occur in the proximal colon. Haustral activity results from high-frequency repetitive contractions of the haustral walls that last about 3 seconds and coincide with orally migrating shallow annular constrictions. Segmental activity is the result of low-frequency deep annular constrictions that move aborally and last about 14 seconds. The third type of contraction of the proximal colon is a monophasic progressive wave of peristaltic contractions. These peristaltic contractions last about 5 seconds during the hard faeces phase and 1.5 seconds during the soft faeces phase (Ehrlein *et al.*, 1982). Expulsion of caecotrophs coincides with a decrease in motility of the caecum and proximal colon and an increase in motility of the distal colon. The transit time for caecotrophs through the colon is 1.5–2.5 times faster than that for hard faeces (Fioramonti and Ruckesbusch, 1976). Motility in the upper gastrointestinal tract remains the same during the hard and soft faeces phases, with slow contractions of the small intestine occurring every 10–15 minutes (Ruckesbusch *et al.*, 1985). The differences in colonic motility during the hard and soft faeces phase of excretion are most pronounced in the second section of proximal colon that has a single layer of haustra.

During the hard faeces phase, the intestinal contents lose considerable quantities of water, potassium and sodium during their passage through the fusus coli (Snipes *et al.*, 1982). The compression of intestinal contents into faecal pellets during the hard faeces phase can be correlated with the strong muscular wall of the fusus coli and its dense innervation. Water is mechanically squeezed out of the fibrous material before it passes to the distal colon where absorption of water, volatile fatty acids and electrolytes continues, leaving a residue of dry, indigestible matter that is expelled as hard, dry faecal pellets.

1.3.6 Caecal fermentation

The end-products of digestion in the stomach and small intestine are separated in the colon into two components: small particles that can act as a substrate for caecal micro-organisms and large particles of indigestible lignified material. Small particles are propelled into the caecum, which acts as a huge bacterial fermentation chamber to which nutrients and water are continually added. Studies of the enzymatic activities of the caecal microflora indicate that ammonia use, ureolysis, proteolysis and cellulysis take place in that order. Xylanolysis and pectinolysis also occur (Carabaño and Piquer, 1998). The intestinal contents that reach the hindgut are composed of undigested food, excretion products and substances produced by the digestive tract itself. Small particles of complex carbohydrates such as oligosaccharides, cellulose, hemicellulose and pectins that are not digested in the small intestine reach the caecum for bacterial degradation. Plant proteins that are bound to cell wall constituents are also degraded in the caecum to form ammonia that is metabolized to amino acids by the caecal microflora. Products of intestinal cellular desquamation and digestive enzymes act as a nitrogen source for protein synthesis (Fraga, 1998). Soluble ions such as urea are osmotically transferred across the caecal wall to be metabolized. High protein diets increase blood urea levels and increase caecal ammonia levels (Fraga, 1998). During periods of protein deprivation, urea from catabolism passes into the caecum to provide a nitrogen source for bacterial amino acid synthesis (Fekete, 1989). Mucopolysaccharides secreted from goblet cells in the mucosa serve as a significant carbohydrate source for caecal fermentation. *Bacteroides* spp. ferment mucopolysaccharides (Cheeke, 1987).

In healthy rabbits, high numbers of large anaerobic metachromatic bacteria are present in the caecum (Lelkes and Chang, 1987). Non-pathogenic, Gram-negative *Bacteroides* spp. predominate in a flora composed of a wide variety of Gram-positive and -negative rods, cocci, filaments, coccobacilli and spirochaetes. Species such as *Bifidobacterium*, *Endophorus*, *Clostridium*, *Streptococcus* and *Acuformis* have been identified (Carabaño and Piquer, 1998; Cheeke, 1987). Over 74 strains of anaerobic bacteria have been isolated from the caecal mucosa and many of these species have not been identified (Straw, 1988). *Lactobacillus* and *E. coli* spp. are usually absent from the normal gut flora of adult rabbits but may be found in rabbits fed on a high-carbohydrate, low-fibre diet. The intestinal flora contains many non-pathogenic protozoa. *Entamoeba cuniculi* is a large sluggish amoeba found in large numbers in the lumen of the large intestine. The flagellate *Giardia duodenalis* can be found in the duodenum but does not cause clinical disease. *Eutrichomastix*, *Enteromonas* and *Retortamonas* spp. are non-pathogenic protozoa found in the caecum (Owen, 1992).

Volatile fatty acids are produced by the caecal microflora and absorbed across the caecal epithelium as an energy source for the rabbit. Caecal contents contain 60–70% acetic acid, 15–20% butyric acid and 10–15% propionic acid, although the ratios of volatile fatty acids can change in relation to the fibre content of the diet. The caecal epithelium has a high electrolyte transport capacity suited to the absorption of the large quantities of electrolytes present in the luminal fluid (Clauss *et al.*, 1989). The appendix secretes an alkaline fluid rich in bicarbonate ions that buffer volatile fatty acids produced by caecal fermentation. The appendix also contains lymphoid tissue.

The composition of the caecal microflora does not remain constant and is affected by time of day, age and diet. Caecal pH shows a diurnal rhythm similar to feeding behaviour and is most alkaline in the morning and most acid in mid-afternoon (Brewer and Cruise, 1994). Fluctuations in caecal pH have an effect on the population of caecal micro-organisms. Ammonia and volatile fatty acids produced by caecal degradation and fermentation affect caecal pH. Like any continuous culture system, there are a number of homeostatic mechanisms in place. Bicarbonate secreted from the appendix acts as a buffer. Other substances such as fibre also have a buffering capacity dependent on the carboxyl, amino and hydroxyl groups (Gidenne *et al.*, 1998). The rate of production and absorption of volatile fatty acids is dependent on type and availability of substrate. Gut motility affects the supply of nutrients and water for microbial fermentation and the absorption of nutrients. Energy appears to be the most limiting factor for optimum microbial activity (Fraga, 1998).

1.3.7 Expulsion and ingestion of caecotrophs

Bacterial fermentation within the caecum results in synthesis of amino acids, volatile fatty acids and water-soluble vitamins. Some nutrients produced by the caecal microflora are absorbed across the caecal wall. The remaining contents of the caecum form a soft, dark-coloured paste rich in bacteria, amino acids, vitamins and minerals. The paste is expelled as soft faeces or caecotrophs. Caecal contents pass into the colon rapidly without mechanical separation of solids and liquid and the faecal masses are divided in the fusus coli (see Figure 1.5). Lysozyme is secreted into the lumen of the distal colon during the soft faeces phase (Camara and Prieur, 1984) and incorporated into caecotrophs. The glandular portion of the fusus coli is instrumental in lubricating the intestinal surface of the colon, facilitating the rapid transport of intestinal contents. Goblet cells secrete mucus, which encapsulates the pellets and inhibits the diffusion of electrolytes. In this way, large masses of pelleted caecal contents are produced, which are expelled as intermittent bunches of caecotrophs.

In healthy rabbits, caecotrophs are consumed straight from the anus and are swallowed whole. Stimulation of rectal mechanoreceptors, the perception of the specific odour of the soft faeces and the blood concentrations of various metabolites and hormones trigger the ingestion of caecotrophs from the anus (Fekete, 1989). When food is scarce, all caecotrophs are consumed. When food is available ad libitum, the protein and fibre content of the ration influence the amount of caecotrophs consumed. Increased levels of fibre increase caecotrophy, whereas high protein levels reduce it.

Key Points 1.4 Gut physiology

- The gastrointestinal system of the rabbit is adapted for the digestion of large quantities of fibrous food.
- Rabbits are hindgut fermenters with a large caecum that periodically expels its contents into the colon. Microbial fermentation in the caecum results in the formation of a soft paste containing amino acids, volatile fatty acids, micro-organisms and vitamins.
- Mucus-encapsulated pellets of the soft caecal material or 'caecotrophs' are ingested as they emerge from the anus and subsequently digested to supply an additional source of nutrients. This process is known as caecotrophy
- Digestion in the stomach and small intestine is similar to other monogastric animals.
- The colon of the rabbit is adapted to mix and separate large indigestible fibre particles from small digestible fragments and fluid.
- The indigestible and digestible fibre components of the diet are simultaneously propelled in opposite directions in the proximal colon.
- Periodically, the pattern of motility in the large intestine and caecum changes completely to expel caecal contents as caecotrophs.
- A specially adapted area of the colon, the fusus coli, acts as a pacemaker to control colonic motility. The fusus coli is highly innervated and vascular and is influenced by blood metabolites and hormones such as prostaglandins and aldosterone.
- Small particles and fluid are directed in a retrograde direction from the proximal colon to the large caecum where bacterial fermentation takes place. Volatile fatty acids are the products of bacterial fermentation.
- The substrate for caecal fermentation is composed of undigested food that reaches the colon plus excretion products, and substances such as mucopolysaccharides and desquamated cells from the digestive tract.
- Urea can diffuse into the caecum from the bloodstream to act as a nitrogen source for the caecal bacteria.
- The population of micro-organisms within the caecum is finely balanced and changes with the time of day, caecal pH and dietary substrate.
- Long particles of undigested fibre are propelled through the distal colon and expelled as hard faeces. Absorption and secretion of water, electrolytes and volatile fatty acids in the large intestine alter according to the type of faeces passing through.
- Indigestible fibre stimulates intestinal motility.

1.3.8 Energy metabolism

Volatile fatty acids provide an energy source for herbivorous species, such as rabbits, that utilize bacterial fermentation as part of the digestive process. The proportion and type of volatile fatty acids produced depend on the substrate metabolized and the species of bacteria present. In ruminants, the predominant volatile fatty acid is propionate, which is produced by *Lactobacillus* spp. present in the rumen but absent from the rabbit caecal microflora (Cheeke, 1987). In rabbits, acetates predominate, followed by butyrate and propionate with small quantities of isobutyrate, isovalerate and valerate. Increased amounts of fibre in the diet increase the proportion of acetate that is produced. Lactate is produced by bacterial fermentation within the caecotroph in the stomach and is subsequently absorbed during digestion of the caecotroph in the small intestine.

Considerable energy is required by the hindgut for the metabolism and absorption of volatile fatty acids, electrolytes and other nutrients. This energy is mainly supplied by butyrate produced by *Bacteroides* spp. that predominate in the caecal microflora. Rabbit caecal-colonic epithelial tissue metabolizes butyrate without the production of ketone bodies. Volatile fatty acids absorbed from intestinal tract provide a regular energy source for the rabbit. Lactate enters the portal circulation from the stomach and small intestine while volatile fatty acids originate from the hindgut. Net absorption from the digestive tract is greatest during the hard faeces phase, which is matched by increased hepatic metabolism and the removal of propionate and butyrate from the circulation, leaving acetate and lactate available for extrahepatic tissue metabolism (Carabaño and Piquer, 1998). Due to alterations in hepatic metabolism, arterial concentrations of volatile fatty acids remain constant during both hard and soft phases of excretion, although their absorption and metabolism follow a circadian rhythm parallel to the activity of the adrenal gland (Vernay, 1987).

1.3.9 Water metabolism

Rabbits normally drink 50–100 mL/kg/24 h (Brewer and Cruise, 1994) although this quantity is affected by the water content and composition of the diet. The complex digestive processes of the rabbit require water to be continually absorbed and secreted along the gastrointestinal tract. Saliva is continuously secreted into the mouth and water is secreted into the stomach. In the caecum, water is absorbed from the contents, which contain 20–25% dry matter (Fekete, 1989). In the colon, absorption or secretion of water varies in each section of the colon and depends on whether hard or soft faeces are being formed. During the soft faeces phase, caecal contents pass through the colon with relatively little change in composition. During the hard faeces phase water is secreted into the proximal colon and mixed with intestinal contents. The water content of the digesta is highest immediately before the fusus coli and decreases sharply during the passage through the fusus and along the distal colon (Snipes *et al.*, 1982). The complex exchange of water across the intestinal wall permits changes in hydration status without obvious fluid loss.

The rabbit kidney differs from other mammalian species. In common with neonates and amphibians, there is a wide variation in the number of glomeruli active at any one time. Hydration, uncomplicated by vasoconstriction, leads to a marked increase in glomerular activity. As much as a 16-fold increase in water diuresis is possible without significant change in glomerular filtration rate. When blood pressure is increased, there is little or no change in renal plasma flow (Brewer and Cruise, 1994).

1.3.10 Electrolyte exchange

The absorption and secretion of electrolytes along the intestinal tract of the rabbit is complex. Saliva is continually formed by a two-stage process in which an isotonic fluid with a constant, plasma-like electrolyte composition is modified in the salivary glands (Fekete, 1989). Sodium and chloride are resorbed and potassium and bicarbonate are secreted.

Bicarbonate is secreted into the duodenum and absorbed from the jejunum in which there is an inter-relationship between bicarbonate secretion and sodium and chloride absorption. The caecal appendix secretes an alkaline fluid rich in bicarbonate that is also secreted in the proximal colon to moderate the rising pH due to volatile fatty acid production (Fekete, 1989).

The transport of electrolytes across the colonic wall is regulated by aldosterone and is related to the type of faeces being produced. During the soft faeces phase, aldosterone concentrations are at their lowest and water, sodium and chloride are secreted while potassium is conserved. During the hard faeces phase, water and bicarbonate are secreted into the proximal colon and water, volatile fatty acids, sodium, potassium and chloride are absorbed from the distal colon, thereby conserving water and electrolytes (Cheeke, 1987).

1.3.11 Acid–base balance

The renal regulation of acid–base balance is different in rabbits in comparison with other domestic species. Rabbits have a limited ability to transfer hydrogen or bicarbonate ions between blood and urine because some metabolic pathways that are present in other species are absent or restricted. The enzyme carbonic anhydrase is absent from the thick ascending limb of the renal tubule of rabbits (Brewer and Cruise, 1994; Dobyan *et al.*, 1982). In other species such as humans, monkeys and rats, carbonic anhydrase is present in the ascending tubule epithelial cells in large amounts. The enzyme is required for the rapid formation of carbonic acid, which is an important step in the excretion of hydrogen ions and conservation of bicarbonate. This infers a reduced ability to deal with acidosis.

In other mammals, ammonia is produced in the kidney by glutamine deamination in response to a fall in plasma pH or a decreased concentration of bicarbonate. Ammonia acts as part of the buffering system in the renal tubule by combining with hydrogen ions before being excreted in the urine as ammonium ions. In rabbits, glutamine deamination only takes place in response to reduced serum bicarbonate concentrations but not a drop in plasma pH, which compromises the rabbit's response to metabolic acidosis. In other species there are alternative biochemical pathways that result in ammonia synthesis but these pathways appear to be absent in the rabbit (Brewer and Cruise, 1994).

The rabbit also has problems correcting alkalosis. A large bicarbonate load can reach the kidney of rabbits as a result of bacterial fermentation in the gut and from tissue metabolism of acetate. In other species, bicarbonate is neutralized by the products of ureagenesis and alkalosis is avoided. In rabbits, insufficient ammonium may be available from tissue metabolism to neutralize bicarbonate, especially during periods of protein deficit (Brewer and Cruise, 1994). Alkaline secretion into the gut increases in response to metabolic alkalosis (Vattay *et al.*, 1989).

1.3.12 Calcium metabolism

Rabbits have an unusual calcium metabolism. It is characterized by total serum calcium concentrations that vary over a wide range and are 30–50% higher than other mammalian species (Buss and Bourdeau, 1984). Total serum calcium concentrations reflect dietary calcium intake (Chapin and Smith, 1967a, b). Hypocalcaemia is rare, although lactation tetany can occur in nursing does (Barlet, 1980). Experimentally, hypocalcaemic tetany can be induced by parathyroidectomy (Tan *et al.*, 1987) or by feeding diets deficient in calcium or vitamin D (Bourdeau *et al.*, 1986; Chapin and Smith, 1967a).

Key Points 1.5 Basic calcium and phosphorus physiology

- Parathyroid hormone (PTH) is secreted in response to low calcium. Increased phosphorus has *no* direct effect on PTH, but increased P can reduce Ca^{2+}, thereby stimulating PTH release.
- PTH increases serum calcium and decreases serum phosphorus and increases phosphorus excretion by the kidney.
- PTH causes:
  1. Calcium release from bone
  2. Phosphorus excretion by the kidney
  3. Accelerated formation of active vitamin D in the kidney
  4. Calcium absorption from the gut
  5. Calcium reabsorption by the renal tubules.
- The blood calcium level at which PTH release is stimulated in rabbits is *higher* than in other species.
- Calcitonin is produced by the thyroid parafollicular cells in response to hypercalcaemia.
- Calcitonin decreases serum calcium and phosphorus.
  1. Inhibits PTH-stimulated bone resorption
  2. Increases phosphorus excretion by the kidney.
- Active vitamin D: formation occurs in the kidney under regulation of PTH.
- 1,25-Dihydroxycholecalciferol is the metabolically active form of vitamin D.
  1. It promotes calcium *and* phosphorus absorption by the intestinal mucosa.

Continued

Key Points 1.5 Basic calcium and phosphorus physiology—cont'd

2. It may facilitate PTH action on bone.
3. Epithelial calcium transport channels are present in vitamin D-responsive tissues (Hoenderop *et al.*, 2000).

- Only ionized calcium is biologically active.
  1. Alkalosis decreases serum ionized calcium concentration.
  2. Acidosis increases serum ionized calcium concentration: in rabbits this manifests as reduced calcium excretion through the kidney and therefore clear urine.
- Phosphorus occurs in various ionic forms and functions with phosphoric acid as a buffer system in body fluids. *But* acid–base balance is primarily measured via the bicarbonate buffering system as the phosphorus buffering system is largely intercellular.
- Serum phosphorus is largely regulated by the kidneys. Losses occur when the tubular reabsorption capacity is exceeded.
  1. PTH may enhance phosphaturia by reducing tubular reabsorption.
  2. Dietary intake may directly affect serum phosphorus concentration.
  3. Abnormal serum phosphorus concentration is caused by altered dietary concentrations, decreased renal excretion and hormonal imbalances.

Table 1.1 Hormones affecting blood calcium

Hormones increasing blood calcium levels	Hormones reducing blood calcium levels
Parathyroid hormone	Calcitonin
Prolactin	Glucocorticoids
Vitamin D	Glucagon
Growth hormone	Gastrin
Oestrogen	Cholecystokinin
Progesterone	Secretin
Testosterone	

It is not clear why rabbits have higher blood calcium levels than other species, or why they seem to vary over a wide range. Their calcium metabolism has been studied extensively. Interestingly, blood phosphorus levels in the rabbit are tightly controlled and maintained at levels very similar to those of other species. This is a situation similar to that found in horses, who also have higher and more variable serum calcium levels than predicted while maintaining serum phosphorus levels analogous to those of other species and rigidly controlled. The relationship between calcium and phosphorus is well recognized, and it is difficult to look at calcium metabolism without considering that of phosphorus. Rabbits have evolved to live on pastures where calcium and phosphorus levels can vary widely over the year. In certain seasons rabbits must deal with high dietary calcium (typically during the summer) while over the winter, both calcium and phosphorus levels are very low. At times when dietary calcium is very low, rabbits rely on active calcium transport (vitamin D-dependent) in order to derive enough from the diet. When dietary phosphorus and hence blood levels are low, rabbits undergo significant calciuria as a mechanism for retaining phosphorus (Bourdeau *et al.*, 1990; DePalo *et al.*, 1988). In wild rabbits, dietary intake of calcium and phosphorus vary annually, and levels of both these nutrients are low in late winter/early spring, prior to the rapid pasture growth (Table 1.1).

Experimentally, hypocalcaemia or hypercalcaemia can be brought about by the infusion of EDTA or calcium gluconate. Reciprocal elevations in PTH or calcitonin in response to EDTA or calcium gluconate infusion indicates that these hormones regulate serum calcium concentrations in rabbits as in other species (Bourdeau *et al.*, 1986; Warren *et al.*, 1989). However, rabbits appear to differ from humans in the level at which serum ionized calcium is set to initiate a parathyroid hormone (PTH) response (Warren *et al.*, 1989). This tends to maintain serum calcium at higher levels. The effect of this on serum phosphorus is that renal phosphorus excretion is initiated at higher calcium levels. The advantage of this is unknown; however, it is suggested that it is a mechanism for the rabbit to successfully cope with wide variations in dietary calcium and phosphorus. An analogy has been made with the syndrome of benign familial hypercalcaemia in humans, which is a genetic condition characterized by hypercalcaemia without changes in renal function, blood pressure or any other potential sequels to chronic hypercalcaemia such as soft tissue mineralization.

Not only do rabbits have higher total serum calcium concentrations than other species but also they are different in the way calcium is absorbed from the gut and excreted by the kidney. Calcium can be absorbed from the intestinal tract either by passive diffusion or by active transport across the mucosa. In other mammals the amount of calcium taken up by the body is strictly controlled; however, in rabbits calcium uptake is directly proportional to the amount found in the diet, and any excess is excreted through the kidney. Active transportation involves a carrier protein that is synthesized in the intestinal mucosa in response to 1,25-dihydroxyvitamin D_3, the active metabolite of vitamin D. A drop in serum calcium concentration stimulates PTH release, which, in turn, stimulates the conversion of biologically inert 25-dihydroxyvitamin D_3 to 1,25-dihydroxyvitamin D_3 in the kidney, thereby indirectly increasing the absorption of calcium from the intestine (Chapin and Smith, 1967a).

Calcium is not only absorbed from the gastrointestinal tract but also secreted into the gut across the intestinal mucosa. This process is independent of serum calcium concentrations and can take place in a hypocalcaemic animal. It has been demonstrated that secretion of calcium into the gut continues during periods of calcium deprivation in rabbits (Barr *et al.*, 1991).

In rabbits, passive intestinal absorption of calcium is efficient. If dietary calcium concentrations are adequate, it appears that vitamin D is not required for calcium absorption (Bourdeau *et al.*, 1986; Kamphues, 1991). However, vitamin D increases intestinal absorption of calcium and is required if dietary calcium levels are low (Brommage *et al.*, 1988). Because it is absorbed passively, there is no feedback mechanism and calcium is absorbed in proportion to the dietary calcium concentration (Cheeke and Amberg, 1973). Blood calcium concentrations increase if dietary calcium levels are elevated.

The rabbit kidney is capable of excreting or conserving calcium according to metabolic need. Responses are mediated by PTH and 1,25-dihydroxyvitamin D_3 (Bourdeau *et al.*, 1988). Tubular reabsorption of calcium by the kidney increases during periods of calcium deprivation (Bourdeau and Lau, 1992). During periods of high calcium intake the rabbit kidney is capable of increasing the fractional excretion of calcium into the urine considerably (Whiting and Quamme, 1984). The excretion rates of calcium are proportional to dietary intake (Kennedy, 1965). Calcium precipitates as calcium carbonate in the alkaline urine of rabbits and high dietary calcium intake results in large amounts of urinary sediment. Normal rabbit urine is turbid due to the presence of calcium carbonate. Pregnant, lactating or growing rabbits or those that are anorexic or on a calcium deficient diet can excrete clear urine.

There appears to be a difference in calcium metabolism in immature and mature rabbits. Serum calcium concentrations are not as variable in growing rabbits as in mature rabbits (Gilsanz *et al.*, 1991; Kamphues *et al.*, 1986). Immature rabbits on forced high dietary calcium concentrations do not develop soft tissue calcification like their adult counterparts (Kamphues *et al.*, 1986).

Key Points 1.6 Calcium metabolism

- Some metabolic processes in rabbits differ from other mammalian species.
- The absorption and secretion of water and electrolytes along the intestinal tract is complex.
- Some of the metabolic pathways that correct acid–base disorders are absent from the rabbit kidney.
- In rabbits, calcium homeostasis is mainly regulated by the kidney, which is capable of both

Continued

Key Points 1.6 Calcium metabolism—cont'd

conserving calcium and excreting large amounts of calcium into the urine.

- Calcium is absorbed readily from the intestine in proportion to dietary concentrations.
- Blood calcium levels in rabbits are higher and not as closely homeostatically maintained as in other species.
- Excreted calcium forms calcium carbonate precipitates in the alkaline urine of rabbits. Normal rabbit urine is turbid. Growing, lactating, pregnant or acidotic rabbits may excrete clear urine.
- Serum calcium concentrations of growing rabbits are not as variable as in mature rabbits.

1.3.13 Nutrition

Rabbits are strict herbivores with a digestive system that is adapted to the ingestion of a high fibre diet (see Section 1.3.1, Digestive physiology). Briefly, indigestible fibre is separated from fermentable components in the proximal colon and is rapidly eliminated in hard faecal pellets. The fermentable components, which consist of small particles and fluid, are moved back into the caecum where bacterial fermentation takes place to release volatile fatty acids that are absorbed as an energy source. Caecal contents are expelled periodically as mucus-encapsulated caecotrophs that are re-ingested and digested as a source of amino acids and vitamins. This strategy permits the digestion of large volumes of fibrous foods without storage in the gastrointestinal tract. Digestion can take place when the rabbit is below ground and not vulnerable to predation.

Since their domestication, rabbits have been fed on a variety of diets. During the Second World War in the UK, when food was scarce, backyard rabbits were kept as a source of protein that could survive on weeds, household scraps and foods that the producer could grow himself. This still occurs in many developing countries where rabbits are fed on a range of forage materials. Large-scale rabbit production has led to the development of pelleted foods of known analysis suitable for commercial rabbits. The nutritional requirements for pregnancy, lactation, growth and fur production have been well researched but the requirements for long-term maintenance of unproductive rabbits has been overlooked. Nutritional disease is common in rabbits kept as pets. For owners, providing food that is eaten readily and enjoyed is one of the most rewarding aspects of keeping a rabbit. The visual appearance of food influences the owner when choosing a product, so pelleted diets became unpopular and a wide range of visually attractive, highly coloured cereal mixes evolved as 'rabbit food' in the UK. These diets are cheap to produce and many are put together by food compounders that normally make rations for farm animals. The choice of ingredients is based on general nutritional principles combined with cost and availability of ingredients. Scientific, long-term feeding trials are not carried out. The nutrient value, vitamin and mineral content of a diet is calculated by extrapolating figures taken from data tables of ingredients rather than analysing the food itself. In recent years, however, several companies have started to produce scientifically formulated mono-component pelleted and extruded feeds. These have been based on research and feeding trials and are nutritionally superior to many of the 'muesli'-type mixes. The advantage of these types of premium feeds are a reduction in the likelihood of nutrient deficiency; the disadvantage is the way that many of these pellets need to be chewed (a more vertical chewing motion, compared with the more lateral movement seen when a rabbit chews hay or vegetation) that can lead to dental problems. A good compromise is to feed ad lib hay and a small amount of good-quality pellets and to offer a selection of fresh vegetables daily. The Rabbit Welfare Association and the RSPCA support this recommendation. A hay and fresh food-only diet, which is as close to the natural diet as possible, should be viewed as the optimum; however, many owners can't or won't comply with this.

1.3.14 Appetite

Hunger is stimulated by a drop in blood glucose, lactic acid, amino acids and volatile fatty acids. Dryness of the mouth and contractions of the stomach stimulate eating (Fekete, 1989). The volume of food eaten is influenced by its composition and texture and by the individual likes and dislikes of the rabbit. Increasing the fibre content of the diet increases the total volume consumed (Bellier and Gidenne, 1996). Rabbits will eat a variety of foods but show a preference for fibre and may eat hay or straw in preference to their compound feed. It can be difficult to persuade rabbits to eat new foods once they have become accustomed to a particular diet. New batches of food may be refused despite it appearing to the owner to be exactly the same. Sweet foods are generally palatable. Molasses are used in many commercial rabbit foods to improve palatability (Cheeke, 1994). Bitter tastes such as the saponins in alfalfa are well tolerated (Cheeke, 1987). Foods that are palatable without the addition of simple sugars are preferable.

Most rabbits enjoy leafy plants. A whole variety of plants can be eaten, including many garden weeds and ornamental plants (see Box 1.7). Sunflower leaves were found to be most palatable in a study by Harris *et al.* (1983). Rabbits appear to enjoy foods of different textures. Pellets are preferable to ground meal. Biscuits or hard pieces of breakfast cereal are accepted readily. Bark is stripped from young trees or shrubs. All parts of the plant may be eaten including the stem and roots, although the growing tips are usually nibbled off first. Tree leaves are eaten, especially in the autumn when the leaves fall.

Like many activities in rabbits, appetite follows a diurnal pattern. Wild rabbits feed at dusk and dawn. Pet rabbits may not be hungry during the day and are most likely to eat in the early evening or overnight.

1.3.15 Dietary requirements of rabbits

1.3.15.1 Carbohydrate

Carbohydrates are compounds of carbon, hydrogen and oxygen with the empirical formula of $(CH_2O)_n$, where $n > 3$. Some molecules contain phosphorus, nitrogen or sulphur and not all follow the $(CH_2O)_n$ rule, e.g., deoxyribose $C_5H_{10}O_4$. Carbohydrates can be classified according to the complexity of their structure, i.e. monosaccharides, oligosaccharides, polysaccharides and complexed carbohydrates such as glycoproteins. Alternatively, they can be categorized into sugars, starches and fibre. Sugars and starches are principally found inside plant cells and may be digested by intestinal enzymes, whereas fibre tends to have a structural function (is found as part of the cell wall) and is digested, where possible, by enzymes produced by the intestinal microflora. Some fibre is expelled undigested (indigestible fibre) or fermented in the caecum to produce volatile fatty acids (digestible or fermentable fibre).

Carbohydrates are an important energy source. They can be digested and absorbed from the stomach and small intestine or degraded and fermented by the caecal microflora. Simple monosaccharide sugars such as glucose, fructose and galactose are absorbed from the small intestine in a manner similar to that of other species. Starches are polysaccharides that are abundant in seeds, fruits, tubers and roots and are broken down to simple sugars during digestion. The reaction is catalysed by amylase that is secreted by the salivary glands and pancreas and is also present in caecotrophs as a result of bacterial synthesis. The activity of amylase in the stomach is limited by the gastric pH, and at $pH < 3.2$ there is little or no amylase activity (Blas and Gidenne, 1998). During caecotrophy, where the gastric pH tends to rise, amylase activity increases.

The age of the rabbit, dietary levels and the type of starch influence digestion and absorption in the small intestine. For example, cereal starches are more fermentable than those found in roots or tubers. Starch is found in plants as granules that are insoluble in cold water, but when a suspension of starch in water is heated, the granules swell and eventually gelatinize. Gelatinized starches can form complexes with proteins that reduce the digestibility of both starch and protein (Cheeke, 1987). Feed manufacturing processes and exogenous enzyme supplements also affect starch digestibility (Blas and Gidenne, 1998). Pancreatic amylase is the most important enzyme, and as dietary levels of starch increase, more amylase is secreted. Most starch is broken down into glucose and directly absorbed. Starch that is not digested and absorbed in the small intestine passes into the caecum as a substrate for bacterial fermentation.

Residual starch that reaches the caecum is fermented by caecal microflora to lactate and volatile fatty acids and directly absorbed. Excess starch reaching the caecum or 'carbohydrate overload' is thought to be a predisposing factor in the development of enterotoxaemia in young rabbits. *Clostridium spiroforme* requires glucose as a substrate for iota toxin production and glucose is yielded during bacterial fermentation of carbohydrate (Cheeke, 1987). In commercial units, enterotoxaemia is seen in young rabbits in association with high carbohydrate, low fibre diets. However, the situation is different in the adult pet rabbit where the sensitivity to high starch diets is controversial (Lowe, 1998). Recent work has indicated that there is a difference in starch digestibility between young and adult rabbits. Adult rabbits appear to digest starch more efficiently than young ones. Very small amounts of starch reach the caecocolic segment of adults. Even in lactating rabbits that consume high quantities of carbohydrate, almost all the starch is hydrolysed before it reaches the caecum (Blas and Gidenne, 1998). Therefore the role of starch as a predisposing factor for imbalances of the caecal microflora and the development of enteric disorders remains unclear. Experimental work has given conflicting results (Blas and Gidenne, 1998; Cheeke, 1987). However, the general consensus of opinion is that overload of rapidly fermentable carbohydrates in the large intestine increases the likelihood of digestive disorders, at least in susceptible, recently weaned rabbits. Dietary starch has no influence on the chemical composition of caecal contents or on the production or composition of soft and hard faeces (Carabaño *et al.*, 1988).

1.3.15.2 Fibre

1.3.15.2.1 Digestible (fermentable) and indigestible fibre in rabbits

Dietary fibre is an important component of the diet for rabbits (see Box 1.2). Fibre is defined as 'that portion of ingested foodstuffs that cannot be broken down by intestinal enzymes and juices of monogastric animals and therefore passes through the small intestine and colon undigested' (Blood and Studdert, 1999). This definition is confusing in ruminants and hindgut fermenters because the gut flora breaks down and 'digests' some fibre molecules by microbial fermentation. Therefore, in herbivores, fibre can be either 'digestible' or 'indigestible' and digestibility varies with species and their digestive physiology. The term 'fermentable' fibre can also be used to describe digestible fibre that is broken down by microbial fermentation. In rabbits, fibre is separated in the proximal colon into large and small particles. Particles larger than 0.5 mm do not enter the caecum and are swiftly expelled undigested. This is the indigestible fibre component of the diet. Particles smaller than 0.3 mm are moved into the caecum where they are digested by bacterial fermentation. This component of the diet is known as digestible or fermentable fibre. Within the caecum the digestibility of fibre depends on the chemical composition and size of the particle. The ease with which bacteria can degrade fibre particles depends on the molecular structure and chemical properties of the fibre and the surface area to which the bacteria can adhere.

Box 1.2 The importance of dietary fibre to rabbits

Dietary fibre can be divided into *indigestible* fibre that passes straight through the alimentary tract without entering the caecum and *fermentable* (digestible) fibre that is directed into the caecum and provides a substrate for bacterial degradation and fermentation by the caecal microflora.

Indigestible fibre is important to:

- Stimulate gut motility that moves digesta and fluid into the caecum for fermentation.
- Provide forage material to prevent boredom and behavioural problems such as fur chewing.
- Provide dental exercise and optimal dental wear.
- Stimulate appetite and ingestion of caecotrophs.

Fermentable fibre is important to:

- Provide a substrate for caecal microflora.
- Provide optimal caecal pH and volatile fatty acid production.
- Prevent proliferation of pathogenic bacteria in the caecum.
- Increase fibre content of caecotrophs so they are of firm consistency.

Fibre is composed of plant cell walls. Plant cell walls consist of complex carbohydrates such as polysaccharides, oligosaccharides, cellulose, hemicellulose, gums and pectins, which are embedded in a lignin matrix. Most of these molecules can be broken down and digested by caecal fermentation. Some components such as oligosaccharides are water soluble, whereas most components such as pectins, cellulose and hemicellulose are insoluble. Hemicelluloses and pectins are the substances that glue plant cells together. Cellulose is a linear polymer of glucose that forms the skeleton of most plant structures and plant cells in which it can be closely associated with lignin. Lignin is not a carbohydrate but a complex cross-linked structure made up of many phenylpropanoid units (this is a structural polymer found in plants, synthesized from the amino acid phenylalanine) (McDonald *et al.*, 1996). Lignin and cellulose combine to provide structural rigidity to plants. Strong chemical bonds exist between lignin and plant polysaccharides and cell wall proteins that reduce the digestibility of these compounds. Lignin is almost completely indigestible and the lignin content of plants increases with age. Lignin is present in large quantities in wood, hulls and straw.

Therefore, in rabbits, fibre can be classified as either indigestible or fermentable. Indigestible fibre is composed of particles larger than 0.3–0.5 mm. Their chemical composition is not important, as these particles do not return to the caecum. These particles are mostly made up of lignin and cellulose. Fermentable fibre is composed of particles smaller than 0.3–0.5 mm and the digestibility is greatly affected by their chemical composition (see Figure 1.6).

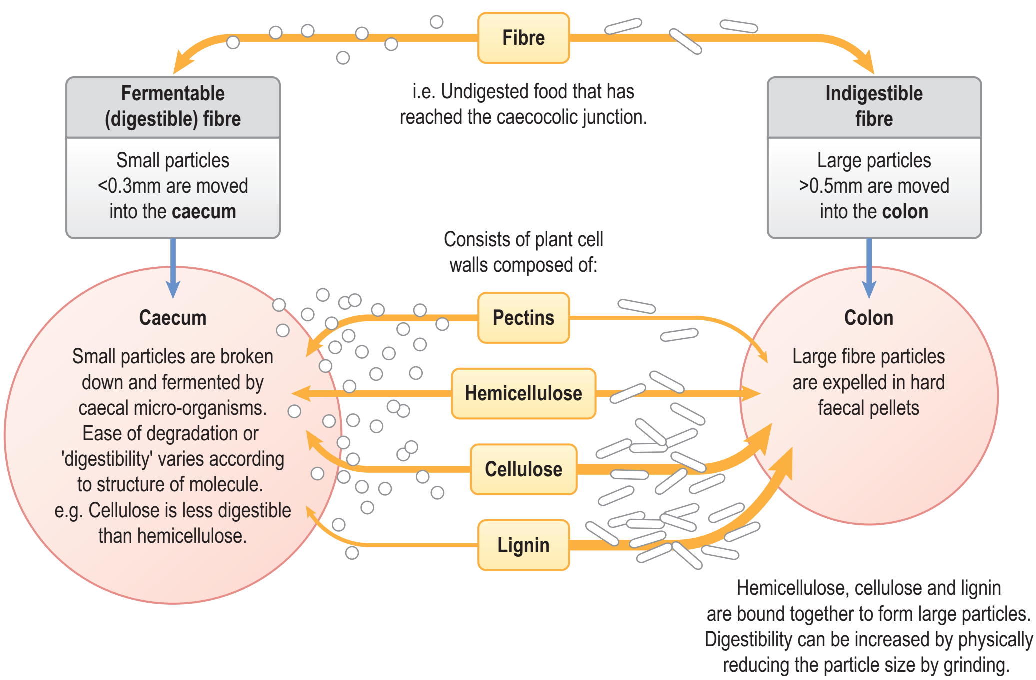

Figure 1.6 Digestion of fibre in rabbits. Some precaecal digestion of fibre takes place by enzymes in the stomach and small intestine. Fibre that reaches the hindgut is either degraded by caecal microflora or expelled undigested. The proximal colon is adapted to separate indigestible fibre from fibre that can be fermented in the caecum. Large undigestible fibre particles pass into the colon and are expelled rapidly. Small particles pass into the caecum to undergo bacterial fermentation. Indigestible fibre promotes gut motility but does not have any nutrient value. Digestible (fermentable) fibre provides nutrients but has no direct effect on gut motility.

1.3.15.2.2 Digestion of fermentable fibre within the caecum

In rabbits, there is evidence that partial digestion of fibre can take place in the stomach and small intestine by the action of enzymes such as pectinases and xylanases (Gidenne *et al.*, 1998). However, most digestion of fibre takes place by the microbial flora within the caecum. Digestibility within the caecum depends on the nature of the plant material and, to a lesser extent, processing procedures. Hemicelluloses and pectins are broken down more easily than cellulose, which requires degradation by cellulolytic bacteria and requires time for attachment of the bacteria to the cell wall before degradation starts. Degradation of cellulose takes longer than hemicellulose because of its linear polymer structure (Gidenne *et al.*, 1998), so it is less fermentable than hemicellulose. Cellulose can be closely associated, both chemically and physically, with other compounds such as hemicellulose and pectin and affect their digestibility. It can also be combined with lignin. The digestibility of fibre within the caecum affects the rabbit's appetite and growth rate. Grinding down lignin so that it passes into the caecum depresses voluntary food intake in comparison with cellulose that is more fermentable (Chiou *et al.*, 1998).

The chemical structure of fibre molecules gives them a buffering capacity that is dependent on the concentration of carboxyl, amino and hydroxyl groups (Gidenne *et al.*, 1998). The type of fibre has an effect on caecal pH, which, in turn, can affect the balance of caecal microflora. For example, wheat straw tends to increase caecal pH, whereas beet pulp decreases it. Balanced sources of fibre such as alfalfa do not modify caecal pH (Gidenne *et al.*, 1998).

Particle size within the caecum affects retention time for microbial fermentation (Gidenne *et al.*, 1998). Small particles have a larger surface area for bacteria to adhere to. The particle length of fibre depends on the plant source and processing procedures. Digestibility of lignified material can be increased by alkali treatment to dissolve lignin and release cellulose and other compounds for microbial degradation. Grinding down lignin to small particles causes it to be retained in the caecum where it cannot be digested. The degree of grinding is an important consideration as it alters the way in which fibre is separated in the proximal colon. Grinding fibre to particles small enough to be moved into the caecum rather than colon detracts from the beneficial effect of indigestible fibre on intestinal motility. There is general agreement that screen sizes for production of complete compound feeds should be 2 mm. Screen sizes of 1 mm induce digestive upsets (Lowe, 1998).

Some cell wall constituents, such as pectins and gums, are hydrophilic and tend to form gels in combination with water. This property is used to produce bulk laxatives for use in humans because the compound takes up water in the digestive tract and increases the volume of faeces and promotes peristalsis. In rabbits, these compounds are moved into the caecum where they absorb water and increase retention time. Caecal impactions have been associated with the use of bulk laxatives in rabbits.

1.3.15.2.3 The importance of indigestible fibre

Rabbits have a natural appetite for fibrous foods. They will strip and eat bark, will chew roots and dried fibrous vegetation and may eat hay in preference to fresh green foods. Indigestible fibre plays an important role in maintaining good health in rabbits. Chewing and grinding food wears the teeth and helps to maintain normal dental occlusion. A diet deficient in fibrous material has been implicated in cheek tooth overgrowth (Crossley, 1995). Diets low in indigestible fibre predispose to gastrointestinal hypomotility and the retention of food and hair in the stomach, which forms trichobezoars (hairballs). Slow gut motility and increased food retention time in the hindgut can result in alterations in gut flora and the development of enterotoxaemia. The provision of a diet high in indigestible fibre to house rabbits reduces the ingestion of non-food items such as carpet fibres or plastic litter trays. Fur chewing and barbering is also linked to low fibre diets (Quesenberry, 1994). Diets containing low dietary fibre depress voluntary food intake (Bellier and Gidenne, 1996).

Fibre has an effect on caecotrophy. The amount of fibre in the diet affects the time that digesta is retained in the caecum for microbial fermentation.

Carabaño *et al.* (1988) measured the weight of soft faeces produced by rabbits fed varying levels of fibre. The weight of soft faeces was then compared to the weight of caecal contents. They found that a relatively small amount of the caecal contents were removed each day in rabbits fed diets containing less than 14% fibre. In rabbits consuming a diet of greater than 14% fibre, the caecal material was almost entirely removed each day. Diets high in indigestible fibre increase the rabbit's appetite for caecotrophs (Fekete and Bokori, 1985). The fibre content of caecotrophs is proportional to the crude fibre level of the diet, although their dry matter content is unaffected by changes in dietary fibre content (Carabaño *et al.*, 1988). Indigestible fibre has no effect on the composition of caecotrophs because large fibre particles do not enter the caecum and are excreted in the hard faecal pellets.

1.3.15.2.4 Recommended dietary fibre for rabbits

The fibre content of a diet is often expressed as 'crude fibre'. This term refers to the percentage of the original food that remains after boiling in acid and alkali alternately. Crude fibre is mainly a measurement of the lignin and cellulose component of the diet and does not include other fermentable fibre components. Neither does crude fibre analysis give an indication of particle length or the effect on gut motility.

An alternative measurement of fibre is 'neutral detergent fibre' (NDF) and 'acid detergent fibre' (ADF). The NDF is made up of cell wall constituents – pectins, cellulose, hemicellulose, lignin, etc. ADF is the residue of NDF after acid extraction of the feed sample and is mainly indigestible lignocellulose complex. Digestible hemicellulose is the difference between NDF and ADF. ADF gives a better indication of indigestible fibre content than crude fibre.

Recommended dietary fibre levels for rabbits vary between texts. In many cases, crude fibre figures that are not particularly helpful are given. Dietary fibre requirements have been determined for commercial rabbits but not for pet ones. Rabbits used for meat production need to grow rapidly and convert food efficiently. The digestibility of the fibre content of the diet is an important consideration for peak performance. The importance of indigestible fibre is often overlooked. It is known that less than 10% crude fibre results in caecal acidosis and results in a high incidence of enteritis. Crude fibre levels of 10–15% are recommended for commercial rabbits for optimal growth rates (Cheeke, 1987).

In contrast to commercial rabbits, pet rabbits are not growing and do not need to convert food efficiently. The indigestible fibre component of the diet is of greater importance than fermentable fibre. In pet rabbits, it is important to promote intestinal motility and prevent obesity. Lowe (1998) recommends crude fibre levels of 13–20% for pet rabbits with a level of 12.5% indigestible fibre. Jenkins (1991) recommends a level of 18–24% fibre for pet rabbits, although the type of fibre is not specified. The fibre analysis of some ingredients of rabbit foods is summarized in Table 1.2. For pet rabbits, a permanent source of indigestible fibre such as ad lib grass or hay will ensure adequate fibre levels as long as the rabbit actually eats it. Soiled, unpalatable hay or underlying dental disease can substantially reduce indigestible fibre intake.

1.3.15.2.5 Sources of fibre for pet rabbits

Concentrated foods usually include a fibre source, such as grass or alfalfa. The fibre must be processed in some way to incorporate it into the food, which can affect its digestibility and its effect on gut motility. Grass and hay are good sources of fermentable and indigestible fibre for rabbits. Hay can be provided in addition to, or instead of, grass. It is not only a source of fibre but also enriches the environment and prevents abnormal behaviour (Berthelsen and Hansen, 1999). Alfalfa is a source of fibre used in commercial rabbit diets in many countries. Alfalfa hay not only provides fibre but also has a high calcium content. Alfalfa hay is now commonly available in the UK. Meadow hay suitable for feeding to pet rabbits is available from most pet shops. Meadow hay is preferable to alfalfa for pet rabbits. Fresh grass is the ideal food and rabbits have evolved to live on it. Garden weeds are also a source of fibre and give variety to the diet. Pet rabbits that are allowed free access to a garden will browse on a selection of plants. They have their own individual likes and dislikes and will eat tough fibrous vegetation as well as

Table 1.2 Fibre analysis of some rabbit foods

Analysis on dry matter basis

Crude fibre: The crude fibre content is determined by boiling an ether extracted food sample in dilute acid and alkali alternately before burning in a furnace. The difference in weight before and after burning is the crude fibre fraction. This is not an accurate measurement as many cell wall components are destroyed during process. Historically, this is the measurement that is included in food analysis tables (Cheeke, 1987).

Neutral detergent fibre (**NDF**) is the percentage of food remaining after boiling in neutral detergent that leaves most components of cell wall intact.

Acid detergent fibre (**ADF**) is the percentage of NDF that remains after boiling in acid, which removes the hemicellose component.

Indigestible fibre is represented by ADF.

Hemicellulose is represented by difference between NDF and ADF. Hemicellulose is fermented in the caecum.

Ingredient	Crude fibre (%)	NDF (%)	ADF (indigestible fibre guide) (%)	NDF – ADF (hemicellulose content) (%)	Comments
Alfalfa	30.2	49.3	37.5	11.8	
Beet, sugar	20.3	32.1	17.9	14.2	High in starch and sugars
Beans	8	16.8	12.3	4.5	
Bran	11.4	47.5	13.7	33.8	
Cabbage	17	24.4	13.6	10.8	
Carrots	9.4		13.4		
Grass, dried	21	54.1	28.2	25.9	
Grass growing	13	57.7	29.6	28.1	Fibre content varies with stage of growth
Hay (poor quality)	38	74.1	45.2	28.9	
Hay (good quality)	29.8	65	36.4	28.6	
Kale	17.9	24.3	19.7	4.6	
Maize	2.4	11.7	2.8	8.9	High in starch
Oats, rolled	10.5	31	14.9	16.1	High in starch
Oats, naked	4.5	11.4	4.2	7.2	High in starch
Peas	6.3	11.6	7.6	4	
Straw (wheat)	41.7	80.9	50.2		
Swedes	10.0	14	12.5	1.5	High in starch

Reference sources: Cheeke, P. (1987). Rabbit Feeding and Nutrition. *Academic Press. San Diego. McDonald, P.* et al. *(1995).* Animal Nutrition, *5th edn. Longman, London.*

soft new shoots. Tree leaves are eaten, especially in the autumn when the leaves have fallen and are within easy reach. Leaves from apple and hazel are especially enjoyed by rabbits (Richardson, 1999). Bark may be stripped from branches and from the base of trees. Exposed roots may be chewed through. Young docks, brambles, raspberry leaves, sow thistle, chickweed, groundsel, dandelions, clover, plantain, goose grass, ground elder and vetches are among a host of plants enjoyed by pet rabbits. Annual bedding plants, herbs and other decorative garden shrubs will also be enjoyed and destroyed by a rabbit that is given the run of the garden. These can provide a good source of nutrition as well as environmental enrichment; however, where damage to these plants would prove upsetting, garden access should be supervised.

Fresh fruit and vegetables can be fed as an additional source of fibre, especially when natural vegetation is scarce. Broccoli, Brussels sprouts, cabbage, spring cabbage, carrots, carrot tops, celery, cauliflower leaves, maize plants, pea pods, swedes, corncobs, spinach, kale and culinary herbs are all enjoyed by rabbits. Although there can be problems if a single item is fed all the time, a mixed diet including three different items each day is safe. Fruit and succulent salad items such as lettuce, tomatoes and cucumber are poor fibre sources and can lead to transient uneaten soft caecotrophs. These should be reserved for occasional treats.

1.3.15.3 Oligosaccharides

Oligosaccharides are molecules with a low degree of polymerization that are not digested by enzymes in the digestive tract but are rapidly degraded and fermented by caecal microflora (Blas and Gidenne, 1998). Oligosaccharides can be classified as 'soluble fibre' as they are water soluble. The type of oligosaccharide is important in its effect upon the microbial population. A diet containing gluco-oligosaccharides that release glucose after hydrolysis in the caecum causes diarrhoea in young rabbits, whereas fructo- or galacto-oligosaccharides do not have the same effect (Lebas *et al.*, 1998). Currently, there is considerable interest in fructo-oligosaccharides because they are reputed to be beneficial in the human gastrointestinal tract by providing the correct substrate for the proliferation of desirable bacterial species such as bifidobacteria (Campbell *et al.*, 1997). Certain plants such as chicory, asparagus, bananas and artichokes contain fructo-oligosaccharides that stimulate the growth of *Bifidobacterium* spp. in the human colon: hence the term 'bifidogenesis', which may be used to describe this effect. Fructo-oligosaccharides have been called 'prebiotics', as the principle of their beneficial effects is similar to probiotics, i.e. to encourage the growth of beneficial bacteria and inhibit pathogenic species. Fructo-oligosaccharides are utilized by *Bacteroides* spp. that prevail in healthy caecal microflora of rabbits. Fructo-oligosaccharides increase calcium, magnesium and iron absorption from the colon and rectum of rats (Ohta *et al.*, 1995a,b) and reduce serum triglyceridaemia in humans (Roberfroid, 1997). In rabbits, a reduction in morbidity after the introduction of pathogenic *E. coli* has been reported in rabbits fed on a fructo-oligosaccharide-supplemented diet (Maertens and Villamide, 1998). Fructo-oligosaccharides are now included in many proprietary rabbit foods.

1.3.15.4 Protein

Proteins are made up of essential and non-essential amino acids. Essential amino acids are those not synthesized by the animal and must be ingested in the diet. The requirement for essential amino acids is affected by growth, lactation, pregnancy and wool production. Certain amino acids can be partly replaced by other amino acids. For example, methionine can be replaced by cystine, and tyrosine can partly replace phenylalanine. Although rabbits have an essential amino acid requirement (see Box 1.3), the situation is complicated by caecotrophy. Micro-organisms within the caecum synthesize amino acids that are absorbed from the caecotroph during digestion. The amino acid composition of soft faeces is affected by the microbial population and the digestibility of dietary protein.

Herbivores such as wild rabbits obtain their protein entirely from plants, although animal protein such as fish, meat or bone meal has been used historically in commercial feeds for rabbits (Cheeke, 1987). Proprietary pet foods for rabbits no longer contain

Box 1.3 Essential amino acid requirement of rabbits

Arginine
Glycine
Histidine
Isoleucine
Leucine
Lysine
Sulphur amino acids:
  Methionine + cystine
  Phenylalanine + tyrosine
Threonine
Tryptophan
Valine

From Lang (1981a).

animal-derived protein. Plant proteins can be divided into two major classes – seed and leaf proteins. Seed proteins are contained in the endosperm and in the outer bran layer. The proteins of forage plants are concentrated in the leaves, tightly bound to cellulose in the cell wall. The digestibility of protein varies according to its source and is also influenced by the age of the animal. Dietary protein levels are important to produce good growth rates and performance in commercial rabbits and are a major consideration for commercial rabbit feeds. High protein levels are not required for maintenance of unproductive pets.

Grass is a source of protein and amino acids for rabbits. The protein content of grass decreases with maturity, although the relative proportions of amino acids do not alter greatly and are similar between plant species (McDonald *et al.*, 1996). Grass is rich in arginine, glutamine and lysine but methionine and isoleucine are limiting. Cereal proteins are deficient in certain amino acids, particularly lysine and methionine. Legume seeds such as peas and beans are good sources of protein and their high lysine content is often used to balance the lysine deficiency of cereals in mixed rations. Supplementation with sulphur-containing amino acids such as methionine and cysteine is required for wool production by Angora rabbits (Lebas *et al.*, 1998).

The optimum dietary protein level for maximum growth is 16% and 18–19% for lactation (Cheeke, 1994). This level of protein is excessive for the maintenance of non-productive pet rabbits that are prone to obesity. High dietary protein reduces the rabbit's appetite for caecotrophs. Excess dietary protein alters the caecal microflora and increases the pH, thereby predisposing the proliferation of pathogenic bacteria (Cheeke, 1994). High dietary protein also increases ammonia production and excretion and reduces air quality in poorly ventilated housing. This irritates mucous membranes, thereby contributing to the development of upper respiratory tract and conjunctival infections.

Insufficient dietary protein or essential amino acid deficiency results in impaired protein synthesis and poor tissue regeneration. Excessively low protein diets should be avoided and some consideration of the protein quality is important for the pet rabbit (Lowe, 1998). Rabbits that do not eat their caecotrophs or selectively eat a restricted diet can suffer from essential amino acid deficiency. Lysine and methionine are most likely to be the limiting essential amino acids. Protein levels of 12–16% are adequate for pet rabbit rations (Lowe, 1998).

1.3.15.5 Fats

The digestion and absorption of fats in rabbits is similar to monogastric animals. Fat globules are emulsified by the action of bile salts before being broken down by pancreatic lipase and absorbed from the small intestine. Fats and oils have been used in rabbit rations to provide an energy source that avoids carbohydrate overload of the hindgut. Dietary fat reduces intestinal absorption of calcium due to the formation of calcium soaps in the gut. Fat stimulates gastrointestinal motility and improves palatability of the diet. Vegetable oils are more digestible than animal fats (Cheeke, 1987). The fat content affects the keeping quality of pellets and the cost of production.

For pet rabbits, high dietary levels of fats and oils are disadvantageous due to the propensity of rabbits to become obese. High fat diets increase the risk of hepatic lipidosis by altering lipid metabolism and promoting ketogenesis and hypoglycaemia during periods of starvation (Jean-Blain and Durix, 1985).

Obese animals with a fatty liver are at great risk of developing fatal fatty degeneration of the liver and kidneys if they become anorexic.

Most commercial diets contain 2.5–4.0% fat, but treat foods such as chocolate drops or sweet biscuits contain higher amounts.

1.3.15.6 Vitamins

1.3.15.6.1 Vitamin A

Vitamin A, or retinol, is a fat-soluble, organic alcohol formed in animal tissues from carotenoid pigments in plants of which β-carotene is the most important. β-Carotene is converted to vitamin A primarily in the intestinal mucosa and is stored in the liver, from where it is transported, protein bound, to cells according to metabolic need. Preformed vitamin A is only found in animal tissues; plants only contain vitamin A precursors.

Vitamin A is necessary for vision, bone development, maintenance of epithelial integrity, reproduction and immunological response. Retinol makes up part of a retinal pigment, rhodopsin, which is necessary for vision, especially in dim light. Vitamin A is required by epithelial tissue and deficiency results in squamous metaplasia and keratinization. Vitamin A also plays an important role in combatting infection and has been termed the 'anti-infective vitamin'. In several species, vitamin A deficiency is accompanied by low levels of immunoglobulins, although the exact function of the vitamin in the formation of these proteins is unknown (McDonald *et al.*, 1996). Growth and reproduction are affected by vitamin A deficiency, leading to depressed fertility in both males and females. Excessive quantities of vitamin A lead to toxicity with symptoms similar to those of deficiency.

The vitamin A precursor (β-carotene) content of plants varies considerably. The long hydrocarbon chain is easily oxidized, especially when exposed to heat, light, moisture and heavy metals (McDonald *et al.*, 1996). Exposure to sunlight during the curing process destroys much of the β-carotene in hay or alfalfa. Storage and rancidity of feeds also reduces β-carotene content, although the addition of antioxidants can reduce the loss. Cereals, with the exception of yellow maize, are poor sources of β-carotene.

Grazing animals generally obtain more than adequate amounts of β-carotene to convert to vitamin A from pasture and build up liver reserves. Deficiency is rare in farm animals that are fed on silage and well-preserved hay over the winter months, although vitamin A deficiency has been reported in cattle housed indoors on high cereal rations (McDonald *et al.*, 1996).

Rabbits housed indoors or in hutches and fed on cereal mixtures and poor-quality hay are candidates for vitamin A deficiency if they do not eat the parts of the diet that contain the vitamin and mineral supplement. Because of the role of vitamin A in the maintenance of epithelial tissues and mucous membranes, deficient animals are susceptible to disease and infection. A high incidence of enteritis occurs in vitamin A-deficient rabbits (Cheeke, 1994).

Experimental vitamin A deficiency has been studied in rabbits. Retarded growth and weight loss occur in growing animals with the development of neurological symptoms in severe cases. Hydrocephalus and cerebellar herniation can occur in immature rabbits (Phillips and Bohstedt, 1937). In the adult, eye lesions can be the first sign of deficiency, with the development of keratitis that progresses to iridocyclitis, hypopyon and permanent blindness (Hunt and Harrington, 1974). Lacrimal gland tissue and the bone surrounding the optical foramen has been found to be unaffected by vitamin A deficiency, although these tissues are affected in other species (Fox *et al.*, 1982; Ubels and Harkema, 1994). Reproductive problems such as fetal malformations, low fertility and abortions have been associated with both vitamin A deficiency and excess (Cheeke, 1987). Intercurrent disease such as hepatic coccidiosis due to *Eimeria stiedae* infection can interfere with vitamin A metabolism and therefore increase dietary requirement.

Vitamin A activity is expressed in international units (IU) and the dietary requirement for rabbits has been quoted from 6000 (for growing rabbits) to 10,000 IU/kg for breeding does (Mateos and de Blas, 1998) to 10,000–18,000 IU/kg (Lowe, 1998). The National Research Council (1987) recommends the addition of *no more* than 16,000 IU as the safe upper level. Fresh green foods and grass are good sources of vitamin A.

1.3.15.6.2 Vitamin D

Vitamin D is a fat-soluble vitamin that is also a hormone which plays an important role in calcium and phosphorus metabolism. A vitamin is defined as 'an organic substance found in foods that is essential in small quantities for growth, health and survival' (Blood and Studdert, 1999). A hormone is defined as 'a chemical transmitter substance produced by cells of the body and transported by the bloodstream and other means to the cells and organs which carry receptors for the hormone and on which it has a specific regulatory effect' (Blood and Studdert, 1999). Therefore, vitamin D is both vitamin and hormone and has a range of physiological effects in addition to its role in calcium metabolism. Vitamin D receptors are found in many tissues including the stomach, brain, pituitary gland, gonads, parathyroid glands, epidermis, dermis, monocytes and activated T and B lymphocytes, although the exact physiological action in these tissues is unclear (Holick, 1990).

There are several metabolites of vitamin D that are either ingested in the diet or synthesized in the body. The number of terms and abbreviations that refer to vitamin D and its metabolites can be confusing. These terms are defined in Box 1.4.

Ultraviolet light is required to convert an endogenous vitamin D precursor, 7-dehydrocholesterol, to pre-vitamin D_3 in the skin. Further conversion to vitamin D_3 (cholecalciferol) takes place before it is transported to the liver, bound to plasma protein. Plants contain a different vitamin D precursor, ergosterol, which is also converted by ultraviolet light to produce ergocalciferol or vitamin D_2. This process takes place in the plant when vegetation, such as hay, dries in the sunshine. Ergocalciferol is transported, protein bound, from the gut to the liver where, like vitamin D_3 (cholecalciferol), it is hydroxylated to form 25-hydroxycholecalciferol (25-OH-D), which is, in turn, converted to the active vitamin D metabolite 1,25-dihydroxycholecalciferol ($1,25(OH)_2D$) in the kidney. Conversion of 25-OH-D to $1,25(OH)_2D$ is stimulated by parathyroid hormone (PTH) released from the parathyroid gland in response to low serum calcium concentrations.

The main function of vitamin D is to maintain serum calcium levels within the normal range. This is achieved by its effects on the intestinal absorption of calcium, mobilization of calcium to and from bone and renal regulation of calcium excretion. $1,25(OH)_2D$ stimulates intestinal absorption of calcium and osteoclastic activity in bone. High quantities of vitamin D causes bone resorption and raise blood calcium levels. Low quantities of vitamin D reduce intestinal absorption and renal conservation of calcium and result in a drop in blood calcium, which stimulates PTH release. PTH stimulates bone resorption to release calcium and restore blood

Box 1.4 Definition of terms relating to vitamin D

Vitamin D: A group of closely related steroids with anti-rachitic properties.
Vitamin D_2 (ergocalciferol, calciferol): An exogenous provitamin formed from ergosterol in plants when they are exposed to ultraviolet light. Vitamin D_2 is converted to 25-OH-D in the liver.
Vitamin D_3 (cholecalciferol): An endogenous provitamin that is converted to 25-OH-D in the liver.
Vitamins D_4 and D_5: These vitamins occur naturally in the oils of some fish.*
Ergosterol: A sterol that occurs in plants. It is converted to vitamin D_2 under exposure to ultraviolet light.
7-Dehydrocholesterol: A derivative of chlolesterol that is metabolized to vitamin D_3 in skin exposed to ultraviolet light.
25-OH-D (25-hydroxycholecalciferol, calcifediol, 25-dihydroxyvitamin D): A metabolite of vitamin D formed and stored in the liver. There is a negative feedback controlling the conversion of provitamins (vitamins D_2 and D_3) to 25-OH-D.
$1,25(OH_2)D$ (1,25-dihydroxycholecalciferol, calcitriol, 1,25-dihydroxyvitamin D): The active metabolite of vitamin D formed in the kidney from 25-OH-D under the influence of parathyroid hormone (PTH) that is released in response to low serum calcium concentrations.

*From Blood et al. (1979).

levels. Therefore, osteomalacia can result from both deficiency and excess of vitamin D. Elevated PTH concentrations stimulate the kidney to conserve calcium.

Vitamin D toxicity can be the result of excessive dietary intake. Intestinal absorption of calcium and osteoclastic activity are increased and result in blood levels that exceed the renal capacity for excretion. This leads to deposition of calcium in soft tissue such as the aorta and kidney.

Vitamin D deficiency can arise from inadequate dietary intake of exogenous precursors, or inadequate exposure to ultraviolet light that is required for conversion of endogenous precursors. Deficiency of vitamin D results in rickets in growing animals and osteomalacia in adults. In humans, vitamin D deficiency is now recognized as a major cause of metabolic bone disease in elderly people (Holick, 1996).

The role of vitamin D in calcium regulation in rabbits differs from that in other species. Vitamin D does not appear to play the same regulatory role in intestinal absorption as in other mammals. Studies into chronic vitamin D deficiency in adult rabbits indicate that intestinal absorption of calcium is passive and efficient and does not require vitamin D (Bourdeau *et al.*, 1986). However, vitamin D increases intestinal absorption of calcium and is required if dietary levels are low (Brommage *et al.*, 1988; Tvedegaard, 1987).

In rabbits, vitamin D plays an important role in phosphorus metabolism. Vitamin D deficiency results in a reduction in intestinal absorption of phosphorus. Experimental studies have shown that chronic vitamin D deficiency can result in hypophosphataemia and osteomalacia (Brommage *et al.*, 1988).

Photosynthesis of vitamin D takes place in the skin of fur- and fleece-bearing animals such as horses and sheep, although it is absent from some carnivorous species such as cats, which obtain vitamin D from prey (How *et al.*, 1994). Sunlight is required for endogenous vitamin D synthesis by rabbits. Rickets can be induced in growing rabbits by keeping them in the dark or under artificial light (Curry *et al.*, 1974; Kato, 1966). It takes approximately 5 months for serum concentrations of 25-OH-D and 1,25(OH)$_2$D to become undetectable in rabbits on a vitamin D-deficient diet (Brommage *et al.*, 1988; Nyomba *et al.*, 1984).

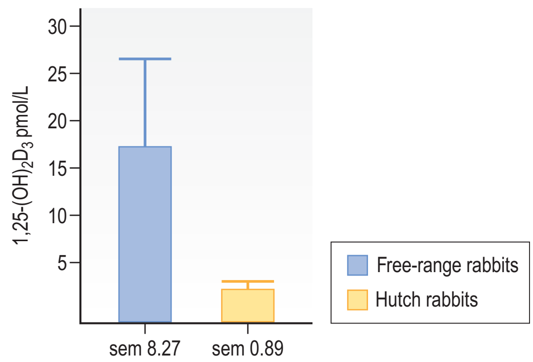

Figure 1.7 Mean (sem) plasma vitamin D (1,25-(OH)$_2$D$_3$ concentration in pet rabbits. During the spring, blood samples were taken from seven rabbits that lived in hutches and four rabbits that had been kept under free-range conditions with unlimited access to natural daylight through the winter months. The samples were spun and the plasma frozen immediately before shipping in a frozen state to a laboratory for 1,25-(OH)$_2$D$_3$ assay. Four rabbits, one from the free-range group and three from the hutch group, had undetectable plasma 1,25-(OH)$_2$D$_3$ concentrations (< 2.5 pmol/L), indicating that vitamin D deficiency can be present in pet rabbits, especially after the winter. The rabbits were kept in North Yorkshire where winter sunshine is minimal. In laboratory rabbits kept without exposure to ultraviolet light and fed on a vitamin D-deficient diet, it takes approximately 5 months for serum concentrations of 25-OH-D and 1,25-(OH)$_2$D$_3$ to become undetectable. (From Fairham and Harcourt-Brown (1999), reprinted with permission from *Veterinary Record*.)

Undetectable serum concentrations of 1,25(OH)$_2$D have been found in pet rabbits during the spring after they were confined to hutches for the winter (see Figures 1.7 and 1.8). Pet rabbits kept under free-range conditions with unrestricted access to natural daylight through the winter had significantly higher 1,25-(OH)$_2$D$_3$ concentrations (Fairham and Harcourt-Brown, 1999). Vitamin D deficiency may be a contributory factor in the development of dental disease (see Section 5.5.1.1).

Vitamin D is rare in foods. Liver and animal fats are a source of vitamin D for carnivorous species but not for an obligate herbivore such as a rabbit. Instead, vitamin D must be metabolized endogenously or obtained from a dietary source such as sundried vegetation or a vitamin supplement. Irradiated plant sterols with anti-rachitic potency occur in the dead leaves of plants or sun-cured hays rather than in the green

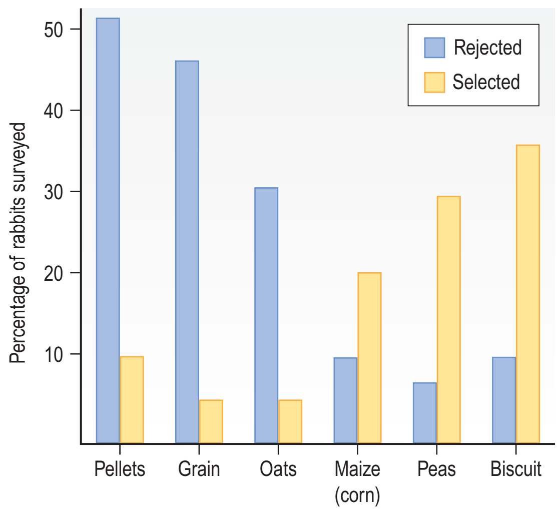

Figure 1.8 Selective feeding in rabbits. Results of owner questionnaire: food preference of pet rabbits. Ninety rabbit owners completed a questionnaire about the feeding habits of their pet. All the rabbits were fed on mixed rations purchased as 'rabbit food'. Hay was offered to all the rabbits in the survey although they did not always eat it. Some rabbits were given additional vegetables or allowed to graze in a run periodically through the summer months. In nearly every case, a bowl of 'rabbit food' was left with the rabbit permanently. Discarded food was thrown away and the bowl topped once or twice daily. This feeding practice allowed rabbits to select their favourite food items and eat nothing else. Some rabbits existed on one or two ingredients. The low calcium cereals and peas were the rabbits' favourite part of the ration. The pellets that contain a vitamin and mineral supplement were the least palatable part of the mixture. However, some rabbits would eat the entire mixture and a minority would select the pellets. (From Harcourt-Brown (1996), reprinted with permission from *Veterinary Record*.)

leaves of growing plants. Therefore vitamin D content of the natural diet increases when potential for endogenous synthesis is reduced. Variation in the vitamin D content of hay can occur with different methods of curing. Exposure to irradiation by sunlight for long periods causes a marked increase in anti-rachitic potency of cut fodder, whereas modern haymaking techniques with its emphasis on rapid curing tends to keep vitamin D levels at a minimum (Blood *et al.*, 1979). Rabbits enjoy eating dried vegetation such as fallen tree leaves in the autumn and will often eat them in preference to the grass available at that time. This is where they get oral vitamin D intake in the wild. There is also an interaction between vitamin A and vitamin D. Vitamin A appears to intensify the severity of rickets and inhibit the ability of vitamin D to cure the disease. Vitamin A administration to rats produced a decrease in total bone ash, increased the epiphyseal bone width and eliminated the ability of vitamin D to elevate serum calcium levels in a study by Rohde *et al.* (1999).

Commercial rabbit pellets are supplemented with vitamin D. In a study by Warren *et al.* (1989) rabbits from a breeding farm were found to have blood levels of 25-OH-D ten times higher than their laboratory counterparts despite comparable 1,25(OH_2)D values. The diet of the farmed rabbits contained 2200 IU/kg of vitamin D; yet PTH and serum total and ionized calcium values were not statistically different from the laboratory rabbits. Vitamin D toxicity has caused soft tissue mineralization in rabbits that were erroneously fed excessive quantities of supplement (Zimmerman *et al.*, 1990). Dietary levels above 2300 IU/kg appear to be toxic (Cheeke, 1987). A level of 800–1200 IU/kg is recommended for pet rabbits (Lowe, 1998). In view of the risk of inducing vitamin D toxicity by dietary administration, it seems sensible to expose rabbits to sunlight so they can synthesize their own vitamin D rather than rely on dietary supplementation. Sunlight has many beneficial physiological and psychological effects.

1.3.15.6.3 Vitamin E

Vitamin E or α-tocopherol is a fat-soluble vitamin that acts synergistically with selenium in most animals and prevents oxidative damage to tissues caused by peroxides. Peroxides are formed during normal metabolic processes and are detoxified during a process catalysed by glutathione peroxidase, which contains selenium. Vitamin E is a natural antioxidant that inactivates the peroxides that cause widespread tissue damage. Vitamin E is also involved in blood clotting, stability of membrane structure and maintenance of immunity. Vitamin E and/or selenium deficiency classically results in nutritional muscular dystrophy, which has been described in rabbits (see Section 10.6.1.4). Other effects of deficiency include myocardial damage, exudative diathesis, hepatosis, increased incidence of lactation problems and reproductive failure.

Green forages and cereals are good sources of vitamin E. Young grass contains more vitamin E than mature herbage. Leaves contain 20–30 times as much vitamin E as stems and up to 90% can be lost during haymaking, although losses are lower during artificial drying. Similarly, the vitamin E activity of cereal can decline rapidly if the grain is kept under moist conditions (McDonald *et al.*, 1996).

In rabbits, intercurrent liver disease caused by *Eimeria stiedae* infection affects the metabolism of fat-soluble vitamins and predisposes to the development of muscular dystrophy. The requirement for vitamin E increases with dietary levels of polyunsaturated fatty acids and vegetable oils. A dietary level of 40–70 mg/kg has been suggested for pet rabbits (Lowe, 1998).

1.3.15.6.4 Vitamin K

Vitamin K is a clotting factor. Deficiency causes impaired blood clotting, resulting in haemorrhagic disorders including lameness in growing rabbits, and abortion in pregnant does. Recent evidence suggests that vitamin K also has a role in the formation of bone (McDowell, 1989). Vitamin K is produced by caecal micro-organisms and is a constituent of caecotrophs. Grass also contains vitamin K. Deficiencies are unlikely to occur in pet rabbits. However, in cases of subclinical coccidiosis or where certain oral medications (e.g., sulphonamides) are being used, vitamin K supplementation may be warranted, particularly in pregnant does.

1.3.15.6.5 B-complex vitamins

The B-complex vitamins are a group of compounds that have wide-ranging roles within the body. Choline, folate, biotin, thiamine, riboflavin, niacin, pyridoxine pantothenic acid and vitamin B_{12} make up this group. Caecotrophs are a rich source of the B vitamins niacin, riboflavin, pantothenic acid and vitamin B_{12}. Primary deficiencies of these vitamins are unlikely to occur in rabbits, as most diets contain sufficient quantities, in addition to the amounts synthesized by the caecal flora. Niacin and choline deficiencies have been induced under experimental conditions. Unlike other B vitamins, choline must be synthesized in the liver, and a deficiency can contribute to hepatic lipidosis and necrosis (Mateos and de Blas, 1998). In cases of reduced liver function it may be sensible to consider supplementation. Vitamin B_{12} requires cobalt, which could be a limiting factor in the diet.

1.3.15.6.6 Vitamin C

Vitamin C or ascorbic acid is synthesized from glucose in the liver by most mammals. In these species it is not strictly a vitamin. It is required for the maintenance and repair of connective tissue, and plays a protective role in many oxidative biochemical processes. Ascorbic acid is stored in tissues with high metabolic activity such as adrenal glands, hypophysis and leucocytes (Verde and Piquer, 1986). Rabbits can synthesize vitamin C. However, there is evidence that the vitamin C requirements of rabbits increase during periods of stress (for example, overheating, transport, subclinical disease) when plasma ascorbic acid has been shown to decrease significantly as synthesis does not match demand (Verde and Piquer, 1986). Under these conditions supplementation may be useful (Mateos and de Blas, 1998). Administration of vitamin C in conjunction with vitamin E prevented an increase in liver enzymes in rabbits experimentally infected with *Trypanosoma brucei brucei* (Umar *et al.*, 1999) and an improved reproductive performance in rabbits under heat stress (Ismail *et al.*, 1992).

Key Points 1.7 Vitamin requirements

- Intercurrent disease such as coccidiosis increases the requirement for vitamins such as A or E.
- Vitamin A deficiency can occur in housed rabbits on cereal diets and poor-quality hay; 500–100 IU/kg can be given as a *single* dose for hypovitaminosis A.
- In most species, vitamin D is required for active transport of calcium from the gut to the bloodstream but in rabbits with sufficient dietary concentrations, calcium is absorbed efficiently and passively from the gut in the absence of vitamin D.

Continued

Key Points 1.7 Vitamin requirements—cont'd

- Passive calcium absorption is dependent on a diffusion gradient across the gut wall. Low dietary calcium results in a lower gradient and less absorption.
- In rabbits, the regulatory role of vitamin D is due to its interaction with PTH and its effects on renal excretion and conservation of calcium.
- If dietary calcium is low, active vitamin D-dependent calcium absorption may be required because the passive diffusion gradient is low.
- Vitamin D-deficient young rabbits can develop rickets and adults develop osteomalacia.
- Sunlight is required for endogenous vitamin D synthesis; however, vitamin D can also be absorbed orally.
- Undetectable vitamin D levels have been found in pet rabbits.
- Chronically vitamin D-deficient rabbits were studied (fed on a diet containing 1% calcium). Findings included that mild hypocalcaemia and moderate hypophosphataemia occurred, with increased PTH levels. There was no difference in gut absorption of calcium in deficient and vitamin D supplemented groups. But significant retention of both calcium and phosphorus occurred in the kidney, meaning that the net balance for each mineral was more positive in vitamin D-deficient animals (Bourdeau *et al.*, 1986).
- Cereal mixes contain supplements that contain calcium and vitamin D. Rabbits that selectively feed may leave the portion of the diet containing the vitamin and mineral supplement uneaten. Pelleted and extruded monocomponent diets are also supplemented and selective feeding can be avoided.
- Vitamin D can be obtained in the diet from sun-dried vegetation such as hay. Modern techniques can dry hay without the need for sunshine and, therefore, hay may be vitamin D deficient
- Vitamin D toxicity has been recorded in rabbits and causes mineralization of soft tissues, especially the kidneys and aorta.
- Rabbits can synthesize vitamin C but requirements vary.
- Caecotrophy provides a source of vitamins B and K.

1.3.15.7 Minerals

1.3.15.7.1 Calcium

Calcium is the most abundant mineral in the body. In combination with phosphorus it forms the dense, hard material of bone and teeth. It is an important cation in intracellular and extracellular fluid and is essential for blood clotting, muscle contractions, nerve cell activity, hormone regulation and the maintenance and stability of cell membranes. Rabbits require a constant supply of calcium for their teeth that continually erupt at a rate of approximately 2 mm per week. Calcium metabolism and its unusual aspects in rabbits are discussed in Section 1.3.12 and Key Points 1.6. Briefly, rabbits absorb calcium readily from the diet and do not homeostatically maintain blood levels as closely as other species. Total serum calcium levels vary across a wide range and are higher than in other mammals. Increased dietary calcium levels bring about an increase in serum calcium (Chapin and Smith, 1967a), which is excreted in the urine in the form of calcium carbonate, which gives the urine a thick creamy appearance (Cheeke and Amberg, 1973). Urinary calcium levels are also related to dietary calcium intake (Kennedy, 1965).

Absorption of calcium across the intestinal mucosa is achieved by two parallel processes: active vitamin D-dependent transcellular transport (unidirectional) and passive paracellular diffusion across a concentration gradient, a bidirectional process (Breslau, 1996). In the rabbit, the main mechanism of calcium absorption appears to be passive diffusion, although active transport is important if dietary levels are low. Passive diffusion is bidirectional and depends on the concentration gradient between the intestinal lumen and the blood. Calcium is absorbed primarily in its ionic form and compounds that bind with calcium to form insoluble complexes reduce its availability, e.g., oxalates (Breslau, 1996). The solubility of minerals such as calcium, magnesium and phosphorus in intestinal contents is affected by pH. For example, calcium absorption is increased in horses fed a high fibre diet due to lower stomach pH and increased saliva and pancreatic secretions that increase the solubility of calcium in the gut (Meyer *et al.*, 1992). It is not known whether an analogous situation exists in the rabbit. Phytates, oxalates and acetates form complexes with calcium and other minerals and can prevent absorption (Fowler, 1986). Phytic acid (inositol hexaphosphoric) is present in high quantities in grains and beans. Oxalates are present in a number of plants including swede, spinach and alfalfa in which 20–30% of the calcium is in the form of calcium oxalate that reduces its availability. In a study by Cheeke *et al.* (1985), 49% of the calcium in calcium oxalate was available to rabbits. Low oxalate, high calcium vegetables include kale, broccoli, turnip, collard and mustard greens (Breslau, 1996). Calcium can also bind with long-chain unsaturated fatty acids in the intestine to form insoluble soaps.

Calcium absorption can be enhanced by certain dietary factors. Soluble complexes can be formed with certain amino acids such as lysine and arginine and antibiotics such as chloramphenicol and penicillin. The soluble complexes prevent the formation of insoluble complexes and therefore facilitate calcium absorption. Lactose also increases the absorption of calcium from the gut (Breslau, 1996).

Many ingredients of rabbit food have a low calcium content that decreases the concentration gradient for passive diffusion from the gut into the blood. Vitamin D may not be available for active calcium transport across the gut wall. Undetectable vitamin D levels have been recorded in pet rabbits (Fairham and Harcourt-Brown, 1999). Calcium deficiency can be a contributory factor to poor tooth and bone quality and dental disease in pet rabbits. The selection of cereals and legumes from mixed rations results in a diet containing less in calcium than the amount required for bone calcification (Table 1.3) (Harcourt-Brown, 1995, 1996). Excessive dietary calcium may contribute to the development of urolithiasis (Kamphues *et al.*, 1986). Therefore,

Table 1.3 Mean calcium (Ca) and phosphorus (P) content (%) of three randomly selected brands of mixed rations sold as rabbit food

Sample	Food A	Food A (no pellets or grain)	Food B	Food B (no pellets or grain)	Food C	Food C (no pellets or grain)
1. Ca (%)	0.70	**0.26***	0.56	0.46	0.79	**0.16****
P (%)	0.35	**0.28**	0.39	0.30	0.32	**0.26**
2. Ca (%)	0.63	**0.28***	0.51	0.38*	0.87	**0.11****
P (%)	0.41	**0.34**	0.39	0.32	0.36	**0.27**
3. Ca (%)	0.65	0.39*	0.49	0.48	0.98	**0.14****
P (%)	0.41	0.29	0.39	0.32	0.36	**0.29**

Samples of rabbit food were taken from batches of mixed rations bought from the same three pet shops on three different occasions. One pound (0.45 kg) of food was sent for analysis. The remainder of the batch was picked over to remove the whole grain and the pellets, which are the ingredients most likely to be rejected by pet rabbits (see Figure 1.8). One pound (0.45 kg) of the remaining ration (without pellets and grain) was sent for analysis. Figures in **bold** *denote an inverse calcium:phosphorus ratio.*

***NB**. A level of at least 0.44% calcium has been determined for maximum bone ash and bone density (Chapin and Smith, 1967a).*

**Calcium levels below the 0.4% minimum level recommended for rabbits by National Research Council (1977)* Nutrient Requirements of Rabbits.

***Calcium level below the 0.22% minimum dietary requirement for rabbits determined by Chapin and Smith (1967a).*

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the dietary level of calcium is important. The calcium requirement for rabbits has been determined (Chapin and Smith, 1967a). A minimum of 0.22% is required to support normal growth but a level of 0.44% is required for bone calcification. A level of 0.6–1.0% is recommended for pet rabbits (Lowe, 1998). The calcium and phosphorus content of some ingredients of rabbit food are summarized in Table 1.4.

1.3.15.7.2 Phosphorus

Phosphorus has many physiological functions. It is closely associated with calcium and forms a major constituent of bone. Phosphorus occurs in phosphoproteins, nucleic acids and phospholipids and plays a vital role in energy metabolism. Absorption and excretion is regulated by vitamin D. Dietary phosphorus levels affect calcium absorption as calcium binds with phosphorus to form insoluble calcium phosphate in the gut. Phytates that are found in many plants, especially grains, contain phosphorus that is released into the digestive tract of some species due to the action of ruminal or caecal fermentation. Investigations have shown that phytate phosphorus is available to rabbits (Cheeke, 1987). Phytates or oxalates can bind with calcium in the gut and affect the calcium:phosphorus ratio. The availability to rabbits of phosphorus in alfalfa is low (Cheeke *et al.*, 1985).

Phosphorus deficiency results in rickets in growing animals and osteomalacia in adults. In some areas the soil is deficient in phosphorus and grazing animals show symptoms of 'pica' (depraved appetite) where they chew wood, bones and other foreign material. Growing parts of plants are richer in phosphorus (McDonald *et al.*, 1996). In rabbits, dietary restriction of phosphorus causes hypophosphataemia and an increase in urinary excretion of calcium.

The calcium:phosphorus ratio in the diet affects bone density. In rabbits, a low calcium:phosphorus ratio of 1:2 or 1:3 does not affect bone calcification

Table 1.4 Calcium and phosphorus content of some common foods for rabbits

Type of food	Water (%)	Dry matter (%)	Calcium (% of dry matter)	Phosphorus (% of dry matter)	Calcium: phosphorus ratio (approx.)	High, medium or low source of calcium
Alfalfa	10	90	1.5	0.30	5:1	High
Apple	79	21	0.06	0.06	1:1	Low
Barley (grain)	11	89	0.07	0.39	1:6	Low
Banana	76	24	0.03	0.11	1:36	Low
Beans, e.g., kidney	10	90	0.14	0.46	1:3	Low
Bran	11	89	0.16	0.14	1:1	Low
Bread	36	64	0.09	0.16	1:17	Low
Cabbage	78	12	0.64	0.35	2:1	Moderate
Carrot tops	83	17	1.94	0.19	10:1	High
Carrots	88	12	0.37	0.325	1:1	Moderate
Celery	94	6	0.66	0.47	1:1	Moderate
Chickweed			0.8	0.6	1:1	Moderate

Table 1.4 Calcium and phosphorus content of some common foods for rabbits—cont'd

Type of food	Water (%)	Dry matter (%)	Calcium (% of dry matter)	Phosphorus (% of dry matter)	Calcium: phosphorus ratio (approx.)	High, medium or low source of calcium
Clover	80	20	1.4	1.30	1:1	High
Dandelion	85	15	1.3	0.46	3:1	High
Grass	80	205	0.50	0.37	1:1	Moderate
Goosegrass			1.5	0.4	4:1	High
Kale	85	15	1.60	0.50	3:1	High
Lettuce	95	5	0.86	0.46	2:1	Moderate
Maize	88	12	0.04	0.28	1:7	Low
Oats	10	90	0.03	0.33	1:11	Low
Peas	11	89	0.12	0.41	1:3	Low
Pineapple	75	15	0.14	0.07	2:1	Low
Shepherd's purse			2.0	0.6	3:1	High
Sunflower seeds	8	92	0.22	0.68	1:3	Low
Sowthistle			1.5	0.5	3:1	High
Spear thistle			1.8	0.4	4:1	High
Swede	88	12	0.36	0.32	1:1	Moderate
Turnip	91	9	0.56	0.28	2:1	Moderate
Wheat	11	89	0.16	1.14	1:7	Low

Reference sources: The Nutrient Requirements of Farm Livestock *(1976), no. 4; Composition of British Feedingstuffs: Technical Review and Tables (Agricultural Research Council, London); P. Cheeke (1987),* Rabbit Feeding and Nutrition *(Academic Press. San Diego); P. McDonald et al. (1995),* Animal Nutrition, *5th edn (Longman, London).*

or growth rate unless dietary phosphorus levels are high. If dietary phosphorus concentrations increase to more than 1%, then bone density decreases Many cereals have phosphorus levels greater than 1% and a calcium:phosphorus ratio that is less than 1:1 and can therefore affect bone density. Rabbits are tolerant of a high calcium:phosphorus ratio. Growth rate and bone density are not affected by increasing calcium concentrations to a ratio of 12:1 (Chapin and Smith, 1967b).

The minimum requirement of phosphorus for optimum bone strength in growing rabbits is 0.22% (Mathieu and Smith, 1961). A nutritional requirement of phosphorus for maintenance of adult rabbits has not been determined. A dietary level of 0.4–0.8% has been suggested for pet rabbits (Lowe, 1998). The phosphorus content of grass and hay is less than 0.4% (McDonald *et al.*, 1996) and this varies seasonally. Phosphorus levels may be the limiting factor in many metabolic processes due to the variation in supply from the natural diet.

1.3.15.7.3 Other minerals

The nutritional requirement of magnesium, manganese, iron, zinc, copper and cobalt have been determined for rabbits. The precise role of magnesium in rabbit nutrition is largely unknown but deficiency has been linked with alopecia and alterations in fur texture. Experimentally induced magnesium deficiency results in poor growth, hyperexcitability and convulsions (Cheeke, 1987). Theoretically, excessive quantities of goitrogenic vegetables such as cabbage and Brussels sprouts could result in iodine deficiency. These vegetables contain glucosinolates that convert to thiocyanate, which can cause iodine deficiency and goitre. Suggested dietary levels of trace elements are given in Box 1.5.

Box 1.5 Suggested food analysis for adult pet rabbits

- Crude fibre: > 18%
- Indigestible fibre: > 12.5%
- Crude protein: 12–16%
- Fat: 1–4%
- Calcium: 0.6–1.0%
- Phosphorus: 0.4–0.8%
- Vitamin A: 6000–10,000 IU/kg
- Vitamin D: 800–1200 IU/kg
- Vitamin E: 40–70 mg/kg
- Trace elements: magnesium, 0.3%; zinc, 0.5%; potassium, 0.6–0.7%

NB. It is especially important to ensure that growing rabbits receive sufficient calcium. Mixed rations are not suitable for young rabbits that are kept in groups where it is impossible to ensure that each individual is eating a balanced diet.

Key Points 1.8 Calcium and phosphorus

- The correct amount of dietary calcium is important for rabbits.
- Rabbits teeth grow at approximately 2 mm per week and require a constant supply of calcium.
- Calcium deficiency results in poor mineralization of the bones and teeth. Excessive amounts of dietary calcium result in large amounts of calcium carbonate sediment in the urine, and predisposes to sludgy urine and cystitis.
- A minimum level of 0.44% calcium is required for bone calcification.
- Rabbits that select cereals and legumes from cereal mixes will be on a low calcium diet.
- Poor-quality hay can be deficient in either calcium or vitamin D, or both.
- Some fruit and root vegetables such as apples and carrots are deficient in calcium.
- Alfalfa contains a high level of calcium.
- Grass, weeds and hay contain the correct dietary level of calcium for rabbits, *but* this varies seasonally.
- Factors such as pH, phytates, phosphates, oxalates and fats in the intestinal lumen can influence calcium uptake from the gut.
- Phytate phosphorus is available to rabbits.

1.3.16 Salt licks and mineral blocks

Salt licks are sold for rabbits and are available from most pet shops. They attach to the cage bars or wire mesh. There is little evidence that additional salt is required but some rabbits like the taste. Mineral blocks are also unnecessary as there is no need to supply extra minerals to a rabbit on a balanced diet. Some blocks contain high levels of calcium that could be harmful if the rabbit gnaws and eats them in large amounts. A rabbit confined to a hutch may destroy and eat the mineral block as a displacement activity, not because it has a need for additional minerals.

1.3.17 Grass and hay for pet rabbits

The natural food of rabbits is pasture grass. Grass is a balanced source of vitamins, minerals and fermentable and indigestible fibre. Rabbits have evolved to live on grass, which they find palatable and enjoyable. Ideally, pet rabbits should be given the opportunity to graze for several hours a day. If a predator-free enclosure cannot be provided, then fresh grass can be picked daily throughout the summer months to feed to pet rabbits. Clippings from the lawn mower are not suitable as they ferment rapidly. There is a small risk of transmitting parasites from wild rabbits, dogs and foxes through grass collected from contaminated pasture. Viral haemorrhagic disease vaccination is advisable. If fresh grass is unavailable, then hay can be provided as a substitute. Hay and grass can be offered together. Preserved grasses such as 'Readigrass' are a suitable addition to the diet. The calcium and fibre content is similar to hay, and it helps to wear the teeth down in a similar manner.

Natural grasslands are made up of a number of grass species and include legumes and other wild plants. The chemical composition of the pasture alters throughout the year. Grass grows rapidly during warm, wet weather and dries out as the herbage matures, leaving a feed resource that is sometimes referred to as 'standing hay' (McDonald *et al.*, 1996). The crude protein content of pasture grass can vary from 0.3% in mature herbage to 3% in young heavily fertilized grass. The fibre content tends to increase as the protein levels decrease. The water-soluble carbohydrates of grass include glucose, fructose and sucrose and vary with the species. The cellulose content is generally 20–30% and hemicelluloses vary from 10 to 30% (McDonald *et al.*, 1996). Lignin content increases with age and affects the availability of other nutrients except the water-soluble carbohydrates. The lipid composition is low and rarely exceeds 0.6%. The mineral content varies with species, stage of growth, soil type, cultivation conditions and fertilizer application. Green herbage is a rich source of vitamin A, vitamin E and many B vitamins, especially riboflavin. The vitamin D content increases as grass matures and is present in greater quantities in sun-dried hay than in young grass.

The species of grass depends on the type of pasture. In the UK, perennial ryegrass (*Lolium perenne*) is the most important species of sown pastures, but Italian ryegrass (*Lolium multiflorum*), timothy (*Phleum pratense*) and the fescues (*Festuca* spp.) are all common. In older pastures, these are accompanied by 'weed' grass species, particularly meadowgrass (*Poa pratensis*), Yorkshire fog (*Holcas lanatus*) and the bents (*Agrostis* spp.). In moorland pastures other species such as mat grass (*Nardus stricta*) and purple moor grass (*Molinia caerulea*) are found.

The digestibility of perennial ryegrass, Italian ryegrass and timothy are similar, although hay made from timothy is slightly higher in crude fibre (34.1%) than ryegrass (30.5%). The protein content of timothy is lower than that in other grasses (McDonald *et al.*, 1996).

Traditional haymaking is dependent on a period of fine weather, which cannot be relied upon in the UK. The ideal haymaking weather is dry and sunny with a mild breeze. Rapid drying techniques using field machinery and barn drying equipment have recently been introduced to overcome some of the problems associated with unpredictable weather. The aim of haymaking is to reduce the moisture content of the green crop to a level low enough to inhibit the action of plant and microbial enzymes. Valuable nutrients are lost during the drying process due to the action of enzymes, oxidation, leaching and mechanical damage. The vitamin content of hay depends on the manner in which it was dried and the length of exposure to sunlight. Prolonged exposure to sunlight increases the vitamin D content, whereas rapid drying preserves the vitamin A content. Increased drying time allows bacterial fermentation to take place and rain on a partly dried crop leaches out minerals and encourages the growth of moulds (McDonald *et al.*, 1996). Ideally, good-quality, sweet-smelling, dust-free fresh hay suitable for feeding to horses should be selected for rabbits.

Lucerne or alfalfa (*Medicago sativa*) is a leguminous plant found in warm temperate areas and is grown as a forage crop. In the USA, alfalfa is used for grazing and for artificial drying to make hay. In the UK, some alfalfa is grown and harvested for silage or for artificial drying to make hay. The drying process can affect the vitamin D content. Dried alfalfa is approximately 25% crude fibre and is also rich in protein, calcium and vitamin A. It is high in oxalate that binds with calcium in the gut and affects absorption. Alfalfa can easily be grown under dry conditions and has proven to be a useful feed for rabbits in many parts of the world. In the UK, alfalfa is recognized as a useful foodstuff for rabbits,and is increasingly used as a source of both fibre and calcium in many proprietary foods. In tandem with the increased interest in lower calcium manufactured foods, there has been a backlash against alfalfa within the rabbit community, making it less popular as an ingredient, due to its high calcium levels and many rabbit owners are now very aware that alfalfa hay is not an appropriate feedstuff. Some breeders use a high fibre horse food made from alfalfa to feed to rabbits. Alfalfa is retained in the digestive tract for longer than plain cellulose, suggesting that it is digested to some degree in the caecum (Chiou *et al.*, 1998).

Problems associated with feeding hay include the risk of transmitting infections and parasites to rabbits from vermin which have inhabited the crop prior to purchase. In the USA skunks and raccoons harbour ascarids, *Baylisascaris procyonis*, for which rabbits act as paratenic hosts. Visceral larva migrans can result in tissue damage to a variety of organs including brain, heart and liver. Hay that has been contaminated with raccoon or skunk faeces is a potential source of infection. *Baylisascaris* eggs require 30 days outside the host to become infective.

Seeds and stems of hay can cause foreign body reactions and are a common cause of disease in pet rabbits. A number of conditions including tracheitis, rhinitis, abscesses, malocclusion, conjunctivitis and skin irritation are caused by stalks or seeds penetrating the oral and pharyngeal mucosa. They can also lodge in the nasal passages, nasopharynx or larynx. Grass seeds may become entangled in the fur and work their way into the dermis causing irritation and infection. Dusty hay can cause conjunctival and respiratory tract irritation and predispose secondary *Pasteurella* infections. Overhead feeders and hayracks increase the likelihood of dust and fragments of hay entering the nose or eyes.

1.3.18 Types of commercial rabbit food

A suggested food analysis for adult pet rabbits is summarized in Box 1.5.

There are a variety of rabbit foods available in the UK. The owner's choice is often based on advice from the pet shop or breeder or on marketing and advertising literature. There are legal requirements for the labelling of rabbit food that are summarized in Box 1.6. Commercial feeds are divided into complementary and complete diets. Complementary diets are meant to be fed as part of a diet that includes other foods, usually hay. Complete diets do not require any supplementary food items.

The visual appearance of the food is important to the owner but probably not to the rabbit. The rabbit has a wide visual field that enables it to observe surrounding predators while it is eating. The visual field does not include the area below the mouth, so food selection is based on odour and tactile information from the vibrissae. Feeding recommendations for pet rabbits are summarized in Box 1.7.

1.3.18.1 Pelleted diets

Pelleted food consists of small cylinders of ingredients that have been ground and compressed together with a binding agent. Vitamins and minerals can be incorporated into the pellet along with sweetening agents such as molasses to improve palatability. Particle size of the ingredients is important, as it affects the digestibility of the ration and its rate of passage through the digestive tract (Lang, 1981a). Small particles tend to accumulate in the caecum and lead to an increased incidence of enteritis (Sanchez *et al.*, 1984). Pelleted diets can be complete or complementary. They vary in quality. Coccidiostats are usually incorporated into the pellet to reduce the incidence of coccidiosis in intensive rabbit units. The actual pelleting process does not kill any oocysts that may be contaminating the feed (Owen, 1978).

The advantages of pelleted diets are that they are convenient, are easy to store and do not allow the rabbit to select out certain ingredients. Different formulations can be pelleted to provide diets for rabbit that are pregnant, lactating or growing. Fibre can be incorporated into the pellet but processing reduces some of its beneficial properties and tends to make the pellets friable. Pellet binders can be used to overcome this problem. Substances such as magnesium lignosulphate, which is a by-product of the wood pulp industry, or a clay mineral binder such as sodium betonite can be used (Lang, 1981a). Disadvantages of pelleted diets are their low palatability in comparison with mixed cereal rations (often leading to the addition of simple sugars in order to improve this) and the

Box 1.6 Labelling requirements for rabbit food

In the UK there are legal requirements covering the information given to purchasers of rabbit food. Guidelines may be found at http://www.pfma.org.uk and http://www.food.gov.uk

- Commercially prepared feeds are considered to be complete, complementary or a food supplement and this information should be displayed on the packaging. Complete feeds should provide all the nutrients required by the animal in the correct quantities. Complementary feeds require additional foods to be included in the diet. Feed supplements are concentrated sources of nutrients such as vitamins and minerals used to supplement other diets.
- Labelling should include the name and address of the person guaranteeing that the information is accurate and the name and description of the feed plus a list of ingredients.
- There must be directions for use, storage and a 'best before' date.
- For food sold loose, the pet shop should display a statutory notice indicating the nutritional properties of the feed and the species of animal for which the product is intended. The statutory statement should be displayed in close proximity to the feed. The minimum requirements, which must be displayed, are protein, oil, fibre and ash.
- For pre-packed food the statutory notice should be displayed on the packaging or on a label attached to the packaging of the feed itself.
- Despite the requirement to display information, there is no requirement to produce feeds to certain compositional standards.
- The stated composition of the feed should not, although small variation (±20%) may be acceptable.

Producers that make false claims are liable for prosecution under the Trades Description Act 1968 but only statements pertaining to some measurable parameter can be proved to be false. Therefore phrases such as 'for a happy, healthy pet' or 'for the rabbit that has everything' are unlikely to be challenged although such statements can be misleading.

Current pet food labelling legislation includes:

- The Animal Feed (England) Regulations 2010 (there are separate but parallel Regulations for Scotland, Wales and Northern Ireland). These Regulations provide for the enforcement of EU Regulation 767/2009 on the marketing and use of animal feed, which applied directly in Member States from 1 September 2010. The Regulations also transpose EU provisions on undesirable substances and particular nutritional purposes, and set down the offences and penalties for breaches of feed legislation.
- EC Regulation 1831/2003 on Feed Additives. This Regulation contains provisions for the control of feed additives in pet food.
- EC Regulation 183/2005 on Feed Hygiene. This Regulation sets out the operating standards with which pet food establishments must comply.

owners' perception that they look boring. As a complete diet, pellets provide little in the way of dental exercise and are not a good source of indigestible fibre. Supplementary hay is required.

1.3.18.2 Extruded or expanded diets

Expanded diets are produced by blending and heating the raw ingredients to a high temperature, before being extruded and dried. The basic ingredients are ground and mixed prior to steam heating. A paste is formed that is forced through a shaped die and cooled. The result is a lightweight biscuit that can be any size or shape. It stores well and is virtually sterile. Long fibre particles can be incorporated without the pellets becoming friable and disintegrating. Vitamins are partly denatured by the processing and need to be added to the initial mixture in higher quantities to allow for this. Heat treatment increases starch digestibility (Cheeke, 1987) and reduces carbohydrate overload of the hindgut. Extruded diets are more palatable and digestible than pelleted rations (Tobin, 1996). They do not allow the animal to eat an unbalanced diet by selecting out favourite

Box 1.7 Feeding recommendations for pet rabbits

- Introduce new foods gradually.
- Good-quality hay or grass should be available at all times, unless a complete diet is provided that specifically states that no other food is needed. Even with a complete diet, additional hay, grass or vegetables will not be harmful.
- Feed a wide range of green foods and vegetables every day. Fruit and succulent vegetables such as tomatoes should be given in moderation.
- Follow manufacturer's instructions when feeding proprietary rabbit food. If the rabbit does not eat all the mixture, change the diet.
- If possible, allow rabbits outside to exercise in natural daylight. Care is needed to prevent them escaping or being predated. Rabbits can be very destructive in the garden.
- Feed small amounts of concentrated food, such as pellets, cereal mixes or extruded diets, only once a day and remove the bowl after a couple of hours. If there is food left in the bowl, feed less food the next day. Hay or grass is available if the rabbit feels hungry.
- No more than 2–3% of the rabbit's bodyweight of cereal mixes, pelleted or extruded rations should be fed daily.

Safe plants for rabbits

- Grass of any type is safe, palatable and ideal for rabbits. Vaccination against viral haemorrhagic disease (VHD) is advisable due to the risk of transmission from wild rabbits/hares.
- Wild plants that are safe include agrimony, brambles, chickweed, clover, coltsfoot, cow parsnip (hogweed), dandelion, young docks, goosegrass, ground elder, groundsel, knapweed, mallow, mayweed, plantain, raspberry, sea beet, shepherd's purse, sow-thistle, trefoil, vetch, wild strawberry and yarrow. (**NB**: Many of these plants are illustrated in Virginia Richardson's book *Rabbit Nutrition*.)
- Safe cultivated plants include artichoke leaves, apple, beetroot, broccoli, brussel sprouts, cabbage, carrots and carrot tops, celery, cauliflower leaves, chicory, coriander, corncobs, green beans, kale, kohl rabi, lettuce (in moderation), parsley, peapods, pear, parsnip, radish, spinach, spring greens (spring cabbage), sprout peelings, sunflower plants, swedes, sweetcorn plants, turnips and watercress. Turnips and spinach should be fed occasionally (not more than once a week) due to their oxalate content.
- Tree leaves can be eaten by rabbits, especially from fruit trees and hazel.

ingredients. Although extruded pellets can be made in a variety of sizes, shapes and colours, they still look less attractive than mixed rations to the owner and do not provide high quantities of indigestible fibre.

1.3.18.3 Mixed rations

The composition of mixed rations varies between sources. They can be complete or complementary. Most mixed rations are complementary and are designed to be fed with hay to provide indigestible fibre. Feed companies decide on the formulation according to cost, availability of ingredients and the experience of the nutritionist. Nutritional data are obtained from analysis tables and extrapolated to formulate a feed based on the requirements of commercial rabbits. Mixed rations are often sold loose from pet shops with no labelling information. Owners are encouraged to leave a bowl full of food with the rabbit permanently. The rations usually consist of flaked, micronized or rolled cereals and legumes mixed with highly coloured extruded 'biscuits' and pellets. Stems of alfalfa can be incorporated as a source of calcium and fibre. The colour of the extruded portions in combination with green flaked peas and yellow flaked maize make these mixtures visually appealing to the owner. Molasses or liquid sweetening agents can be added along with other ingredients such as locust beans or compressed linseed. Some rations contain by-products from the human food industry, such as stale breakfast cereals. Whole grains are incorporated to prevent the rabbit picking out the kernel and leaving the fibrous husk. However, most rabbits are able to separate and eat the kernel and leave the husk uneaten. Wheat has a tendency to be pasty (Lowe, 1998) and is usually extruded into a coloured biscuit that is included in mixed rations. Pellets are added to the mixture as a vehicle for a powdered vitamin and mineral supplement. Some brands now incorporate the supplement into the extruded wheat portion or spray the whole mixture with a supplemented coating.

The advantages of mixed rations are that they are universally available, palatable, cheap, convenient and visually attractive to the owner. They are available from pet shops, supermarkets, agricultural suppliers, garages, garden centres and wholesalers under the universal name of 'rabbit food'. Apart from the general problems associated with feeding ad lib concentrated foods (obesity, insufficient dietary fibre, dental exercise and foraging), mixed cereal rations have the additional disadvantage of allowing rabbits to select out their favourite ingredients and leave the rest uneaten (see Figure 1.8). Discarded food is generally taken away by the owner and replaced with a fresh bowlful for the rabbit to select from. Owners worry about their pets being bored or hungry and sometimes refill the bowl several times a day so the rabbit may exist on only one or two favourite ingredients. In order to be nutritionally balanced, this type of food must be fed full to empty bowl. The pellets, which contain the vitamin and mineral supplement, are often left uneaten. The most palatable portions of these diets are the flaked peas and flaked maize which are deficient in calcium and have a low calcium-to-phosphorus ratio. Selection of these ingredients results in a diet with calcium concentrations below the rabbit's known dietary requirement (Harcourt-Brown, 1996). Demineralization of the bones and teeth results in dental problems (see Section 5.5.1.1). A balanced diet is especially important to juvenile rabbits that are growing rapidly and therefore susceptible to metabolic bone disease. Selection of low calcium cereals and legumes from mixed rations at this stage can have life-long detrimental effects on bones and teeth.

Key Points 1.9 Common feeds and ingredients

- Grass is a balanced source of vitamins, minerals and fermentable (digestible) and indigestible fibre for rabbits.
- The digestibility of the species of grasses found in UK pastures are similar, although timothy (*Phleum pratense*) has a slightly higher crude fibre and lower protein content.
- Alfalfa (lucerne, *Medicago sativa*) is used for grazing and haymaking in warm countries, although it is now available in the UK.
- Alfalfa has a high fibre and calcium content.
- Infections may be transmitted to pet rabbits from hay that has been contaminated by vermin (VHD and *Baylisascariasis*).
- Seeds and stems of hay can become lodged in the eye, mouth, nose, nasopharynx or larynx and are an underdiagnosed cause of clinical disease.
- Commercial foods for rabbits are composed of pelleted, extruded or mixed rations.
- Pelleted diets consist of ingredients that have been ground and compressed.
- Extruded foods are ground, blended and cooked to form a lightweight biscuit that is sterile and palatable, and stores well.
- Mixed rations vary between sources and contain a range of ingredients including flaked, micronized, rolled or whole grains such as corn, wheat, oats and barley plus legumes such as peas and beans. Dried vegetables such as carrots and leeks may be added. Most mixed rations also contain pellets and/or extrusions.
- Mixed rations that are available in countries outside the UK contain other ingredients such as sunflower seeds, peanuts, corn kernels and dried peas.

1.3.19 Problems associated with feeding

1.3.19.1 Toxic plants

Owners are often worried about the possibility of plant toxicity if they pick natural vegetation or give their rabbit the freedom of the garden. Rabbits will eat almost anything, including plants known to be toxic to other species and so it is not easy to reassure owners that their pet will not suffer any adverse effects. Toxicity varies and depends on a number of factors, such as the amount ingested, the part of the plant that is eaten and the frequency of ingestion. Drying can cause an increase or decrease in toxicity or have no effect at all.

Many plants that contain toxic compounds are acrid and unpalatable. Irritant compounds cause oral discomfort and are unlikely to be ingested in large quantities. Many plant poisons are not fatal and so the fact that a pet rabbit has eaten a known poisonous plant does not necessarily mean it will die. Conversely, plants that are considered safe can be toxic if ingested in large quantities or daily over a period of time. Examples in other species include apples or clover, both of which can cause digestive upsets in ruminants. In general, if no ill effects are observed within 6 h of the ingestion of a potentially poisonous plant, then it is unlikely that signs will develop (Veterinary Poisons Unit, personal communication).

There are few definite reports of plant toxicity in rabbits. Instead, rabbits are reported to be resistant to the effects of pyrrolizidine alkaloids, which are found in plants such as ragwort and comfrey (Cheeke *et al.*, 1982). *Amaranthus* species (*A. retroflexus*, redwort pigweed; *A. viridis*, green amaranthus) causes ascites with lemon yellow serous fluid (Lorgue *et al.*, 1996). Although *Amaranthus* spp. are not native to the UK, garden escapes may be found on waste ground (Fitter *et al.*, 1974). *Amaranthus retroflexus* has been used in rabbit feeds with poor results (Cheeke, 1987). *Amaranthus albus* is the common garden plant 'love lies bleeding'.

Key Points 1.10 Toxins

- Although owners worry about plant toxicity in rabbits, there are few confirmed reports.
- Rabbits appear to be resistant to many plant toxins such as ragwort, deadly nightshade, comfrey and laburnum.
- Some agrochemicals used as weedkillers are toxic to rabbits.
- Rabbits are sensitive to mycotoxins, such as aflatoxin.

A condition known as 'head down disease' is caused by ingestion of woollypod milkweed (*Asclepias eriocarpa*) in the USA. Affected animals develop paralysis of the neck muscles and loss of coordination. Drooling, rough hair coat, subnormal temperature and tar-like faeces occur. Recovery is possible (see Section 10.6.1.2). The toxic principal is a resinoid. Woolly milkweed does not grow in Great Britain.

The houseplant *Dieffenbachia* is reputed to be poisonous to rabbits, Avocado leaves are also toxic to rabbits, although the toxicity of the plant varies with the variety. Mexican avocados are less toxic than Guatemalan varieties. Post-mortem examination shows lung congestion (Craigmill *et al.*, 1984).

Daffodil bulbs and horse chestnuts are poisonous to dogs if they are eaten in quantities (Campbell, 1998) and many other garden plants can cause toxic symptoms, such as gastrointestinal effects, although they are not necessarily fatal. Examples include cotoneaster, honeysuckle and pyracantha. Plants used for Christmas decorations, i.e. holly, ivy and mistletoe, are all known to be toxic in other species. The houseplants leopard lily and Christmas cherry cause vomiting and diarrhoea in dogs (Campbell, 1998).

Long-term, continuous ingestion of certain vegetables can cause toxicity. Although the effects of goitrogenic vegetables such as cabbage, spring greens and brussel sprouts have not been documented in rabbits, there is a theoretical risk associated with feeding large amounts of these vegetables. Similarly, oxalates in spinach, alfalfa and turnips can affect the absorption of some minerals such as calcium or magnesium. Problems with toxic principals in vegetables can be avoided by offering two or three types daily and changing the range each day. Grass is safe and can be given ad lib. Plants that may be toxic to rabbits are listed in Table 1.5.

1.3.19.2 Chemicals

Cultivated crops do not cause the same amount of owner anxiety as natural vegetation, and yet there are health implications for rabbits fed on treated vegetation. Although rabbits appear relatively resistant to plant toxins, they are susceptible to some agrochemicals. For example, nitrophenols, which

Table 1.5 Potentially toxic plants for rabbits

Rabbit owners are often concerned about the safety of feeding naturally growing plants and weeds to their rabbits. During an extensive search of the literature, few definite reports of plant toxicity in rabbits could be found, although many plants were cited as potentially poisonous. There are anecdotal reports of bizarre behaviour in rabbits after presumed ingestion of some species of wild mushrooms. The following table is a list of potentially toxic plants for rabbits although in many cases, extrapolations have been made from other species.

The following plants can be bought as vegetables or grown in gardens and hedgerows in the UK. Poisonous plants from other countries are not included.

Plant	Toxic principal	Comments
Amaranthus: *A. retroflexus* (redwort) *A. viridis* (green amaranthus)	Oxalic acid	Redwort is known to be toxic to rabbits. *Amaranthus albus* is the garden plant love-lies-bleeding.
Antirrhinums		Known to be poisonous in other species.
Arum	Calcium oxalate and other irritants	Can cause swelling and discomfort of the oral cavity in other species.
Buttercups (fresh)	Protoaneminin	Causes irritation to mucous membranes including GI tract in other species.
Bracken	Thiaminase	Toxic in cattle, sheep and horses + bone marrow suppressant.
Bryony	Irritant substance and histamine	Berries and rhizomes are poisonous.
Cabbage	Glucosinolate	Goitrogenic if fed in large quantities.
Celandines	A variety of alkaloids	Unpalatable. Irritant effects. Purgative.
Charlock		Poisonous in other species.
Comfrey	Pyrrolizidine alkaloids	Hepatotoxic (rabbits appear to be resistant to toxic effects).
Convolvulus		Poisonous in other species.
Crotalaria	Pyrrolizidine alkaloids	Hepatotoxic (rabbits appear to be resistant to toxic effects).
Dahlia		Known to be poisonous in other species.
Evergreens (except conifers)		Known to be poisonous in other species.
Figwort		Reputed to be poisonous.
Foxglove	Cardiac glycoside (digitalis)	Known to be poisonous in other species.
Hellebore (Christmas rose)	Variety of alkaloids	Known to be poisonous in a range of species. Whole plant is toxic especially during flowering.

Continued

Table 1.5 Potentially toxic plants for rabbits—cont'd

Plant	Toxic principal	Comments
Hemlock	Variety of alkaloids	Whole plant is toxic. Unpalatable.
Henbane	Anticholinergic	Seeds are most toxic part of the plant. Unpalatable.
Horsetails	Thiaminase alkaloids Silica	Toxic to other species (horses) if ingested over long periods. Remains toxic after drying, i.e., hay.
Irises		Reputed to be poisonous.
Ivy	Unidentified	Whole plant, including berries poisonous. Large quantities need to be ingested.
Kale	Thiocyanates S-methyl-cysteine-sulphoxide Nitrates Antithyroid	Toxicity reported in ruminants. Needs to be ingested in large quantities. Can cause haemolytic anaemia in other species.
Laburnum	Alkaloids	Seeds especially are known to be poisonous in other species. Rabbits may be resistant to toxic compounds.
Lily of the valley	Variety of alkaloids	Variety of symptoms.
Linseed	Cyanogenetic heteroside	Ingestion of > 400 g/100 kg of oil-seed cake can be toxic in other species.
Lupins	Quinolizidine alkaloids	Most cultivated lupins are of low toxicity.
Milkweed	Cardiac glycoside	
Monkshood (aconite)	Alkaloid	Unpalatable, irritant.
Nightshade	Atropine	Many rabbits are resistant to poisoning due to presence of atropinesterase.
Oleander	Cardiac glycoside	
Poppies	Opium alkaloids	Entire plant is toxic even after drying.
Potato plants	Solanines	Can cause haemolysis in other species (cattle and pigs) if large quantities of leaves or stems are fed or small quantities over a long period.
Potatoes	Nitrophenol	Potatoes may be sprayed with nitrophenols to prevent sprouting. The spray can be toxic to rabbits.
Privet	Tannins Heteroside	Can be fatal in other species.
Ragwort	Pyrrolizidine alkaloids	Hepatotoxic. Rabbits appear to be resistant to toxic effects.
Scarlet pimpernel		Reputed to be poisonous.
Speedwell		Reputed to be poisonous.

Table 1.5 Potentially toxic plants for rabbits—cont'd

Plant	Toxic principal	Comments
Spurges	Alkaloids	Cause intense local irritation to mucous membranes in other species.
Toadflax		Reputed to be poisonous.
Tomato plants	Solanines	Can cause haemolysis in other species (cattle and pigs) if large leaves or stems are fed or small quantities over a long period.
Travellers joy (*Clematis vitalba*)		Reputed to be poisonous.
Wild celery		Reputed to be poisonous.
Yew	Taxine	Cut branches more toxic than when fresh. Very toxic in other species. Can cause sudden death. Probably toxic to rabbits.

There are other toxic plants not included in this list that are wise to avoid, e.g., acorns, box hedging, laurel, cypress, verbena, potentilla, rhododendron, water dropwort. In general, plants that grow from bulbs can be considered to be potentially poisonous.
Reference sources: Cheeke (1987); Gfeller and Messonier (1998); Lang (1981a); Lorgue et al. *(1996); Richardson (1999); Sandford (1996).*

are used as herbicides, fungicides or antisprouting agents on potatoes, can make the plants extremely toxic to rabbits (Lorgue *et al.*, 1996). Ingestion of the toxin occurs by eating recently treated vegetation. The compounds stimulate tissue respiration while simultaneously impairing adenosine triphosphate (ATP) synthesis. Hyperthermia, methaemoglobinaemia, jaundice and pulmonary oedema are among the clinical signs. Ingestion of hay grown from a monoculture sprayed with a selective herbicide such as a triazine can cause poisoning. Treated, triazine-resistant weeds are dried and eaten in contaminated hay. Symptoms of poisoning in other species are non-specific and include anorexia, weight loss, depression, salivation, muscle atonia, weakness and paraplegia or hyperexcitability. Treatment is symptomatic and the prognosis generally good. Garden fungicides that are used to treat lawns also belong to the triazine group. Herbicides such as glycosate and substituted ureas are unlikely to be poisonous to rabbits.

1.3.19.3 Mycotoxins

Mycotoxins are toxic metabolites of fungi such as *Aspergillus* spp. that causes a range of diseases in many species. Aflatoxin is produced by *Aspergillus flavus* and may be found in mouldy feeds, especially peanuts. Subclinical aflatoxicosis affects natural defence mechanisms and immunogenesis. Rabbits are susceptible to aflatoxin toxicity, which causes gastroenteritis and liver damage. It is not known how widespread this problem is in pet rabbits that consume cereals and grains of uncertain age and quality. In a study by Fekete and Huszenicza (1993), rabbits did not refuse grain that contained sufficient aflatoxin to cause immunosuppression and fatal secondary bacterial infection.

1.3.19.4 Locust beans and dried pulses

Locust beans are pods of either the Mediterranean carob tree (*Ceratonia siliqua*) or the African locust bean (*Parkia filicoidea*). The pod consists of a woody husk that is sweet and palatable to rabbits and contains hard shiny beans. The beans are used for the manufacture of gums and oils in the cosmetic industry. Crushed locust bean husks are sometimes included in rabbit foods and occasionally a hard bean can make its way into the mixture along with the husk. Unfortunately, these beans are too hard for rabbits to chew and can be swallowed whole.

They pass through the stomach undigested and can lodge in the small intestine, causing an acute obstruction and death. Dried peas and sweetcorn carry the same risk. Because of the risk of intestinal obstruction, many leading rabbit food manufacturers no longer use locust beans in their rations.

1.3.20 Obesity

Rabbits are animals that convert food efficiently and are often overfed by indulgent owners. They are used as laboratory models to study the effects of obesity in humans. Obese rabbits have high resting heart rates and can develop hypertension and cardiac hypertrophy (Carroll *et al.*, 1996). Hyperinsulinaemia, hyperglycaemia and elevated serum triglycerides occur in obese rabbits and hepatic lipidosis develops readily after short periods without food, especially if the rabbit is stressed. Obese rabbits are poor surgical candidates.

Fat rabbits are unable to groom inaccessible parts such as the nape of the neck and the base of the tail (Figure 1.9). They are often unable to reach the perineum to consume caecotrophs. Fly strike and cheyletiellosis can be the result of inadequate grooming and soiled fur. Arthritic conditions are exacerbated by obesity. Sludgy urine and cystitis are also associated with inactive overweight rabbits (see Section 12.4).

Figure 1.9 Patchy hair loss. Some breeds of rabbit with fluffy coats, notably dwarf lops and minilops, develop hairless patches of skin during moulting. The alopecic areas often cause concern to owners. The bald skin is not inflamed. A typical lesion is illustrated. Regrowth of hair is rapid. Dense fur starts to grow at the centre of the lesion within 7–10 days and takes place simultaneously with hair loss at the periphery of the lesion. This is a self-limiting physiological process.

Weight reduction can be difficult to achieve in rabbits. It is sometimes difficult to persuade owners that their rabbit has a problem. Many obese rabbits have very little exercise and eating is their main pastime. Owners often feel guilty about not allowing their pet out to exercise and worry about it being bored so they give it lots of food instead. A high fibre, low calorie diet that would result in weight loss in humans and other animals may not have any effect in rabbits. The caecal micro-organisms can digest fibre to release volatile fatty acids that can be converted into fat. Only lignocellulose in the form of fibrous, lignified vegetation such as hay, straw or really tough weeds will pass through the digestive tract undigested.

Changing a rabbit's diet can be fraught with difficulty. Many rabbits are finicky, even obese ones, and will steadfastly refuse to eat anything at all if they are not offered their favourite foods. Starvation quickly leads to hepatic lipidosis in obese rabbits. Care should be taken at the outset to ensure that the rabbit is actually eating its new diet and is passing hard faeces. Quantities of cereal mixtures or pellets should be reduced or phased out over a couple of weeks. Eventually a diet of ad lib hay or grass with no concentrates can be given until the rabbit has lost weight. Small amounts of vegetables can be given as treat foods. As much exercise as possible is important. The weight loss must be maintained in the long term, and a return to old feeding habits avoided. Most companies that manufacture rabbit food now produce 'light' or low calorie pellets as an alternative to their adult diets.

Key Points 1.11 Weight management in rabbits

- Obese rabbits have high resting heart rates and can develop hypertension and cardiac hypertrophy. They are prone to developing fatal hepatic lipidosis if they become anorexic.
- High fibre diets that would result in weight loss in other species may not be effective in rabbits. Fibre is fermented by the caecal microflora to volatile fatty acids.

Key Points 1.11 Weight management in rabbits—cont'd

- Weight reduction can only be achieved in rabbits by providing a diet low in digestible fibre and high in indigestible fibre.
- Many rabbit food producers now have a low energy or diet formulation of their adult feeds.
- Increased amounts of exercise are an important part of a weight reduction programme.
- Rabbit weight loss clinics can be run in the surgery in much the same way as those for cats and dogs.

Key Points 1.12 Practical rabbit nutrition

- Pet rabbits should have access to ad lib hay. As a general rule an adult rabbit will eat a bundle of hay approximately the same size as its body every day.
- Pet rabbits should be offered fresh vegetables every day, a portion size approximately the same size as the rabbit's head is enough.
- A small amount of good-quality pellets can be offered twice daily (approximately a tablespoon per kg of rabbit per day).
- Incorrect feeding causes many diseases of pet rabbits.
- Owners are often confused by conflicting advice given by breeders, pet shops or food manufacturers. The advice may be based on anecdotal evidence, marketing material or data obtained from commercial production that is not relevant to the pet animal.
- Digestion of starch in the small intestine is affected by the age of the rabbit. Adults digest starch more efficiently than young animals. Undigested starch that reaches the caecum can act as a substrate for bacterial fermentation and predispose to the development of enterotoxaemia. It can also lead to uneaten caecotrophs.
- Fibre is important to maintain optimum digestion and a healthy caecal microflora. Digestible fibre provides a substrate for bacterial fermentation in the caecum. Indigestible fibre stimulates gut motility.
- The amount of indigestible fibre in the diet is very important. Too little results in reduced gastrointestinal motility and digestive disorders. Too much results in malnutrition.
- Grass and good-quality meadow hay are ideal sources of digestible and indigestible fibre. Wild plants and garden weeds are also good sources of fibre.
- It is possible to transmit infectious or parasitic disease from wild animals by feeding contaminated grass or hay.
- High levels of dietary protein are not necessary for pet rabbits although they do have an essential amino acid requirement.

1.4 Taking a clinical history

1.4.1 Clinical history

It is not always easy to elicit an accurate case history. Owners have preconceived ideas of the correct or incorrect way of keeping rabbits and will often wish to give the 'right' answer rather than a truthful one. As with any anamnesis it is important to ask non-biased questions in order to avoid leading owners to the answer they think you want.

In addition to discussing the owner's perception of the presenting problem, important points to cover include:

- Diet offered: Has this been changed (new food/new bag) (Figure 1.10)?
- Diet eaten: Have preferences changed? Is the animal definitely eating?
- How water is offered: Has this been changed?
- Kept indoors or outdoors: access to fresh grass and vegetables? Is there possible contact with wild rabbits or hares?
- Presence of bonded companions and their health status: Is there a new rabbit that may be bullying the existing ones or introducing infection?
- Vaccination status.
- Neutering status.

Effects of anorexia

- Reduced intake of indigestible fibre and reduced intestinal motility
- Slow gastric emptying resulting in impaction of stomach contents and trichobezoar formation
- Reduced supply of nutrients to caecal microflora resulting in changes in caecal pH and balance of micro-organisms
- Gas production in bowel, especially the caecum, causing visceral distension and pain
- Reduced glucose absorption from the gut leading to increased mobilization of free fatty acids from adipose tissue that can lead to fatal hepatic lipidosis. Obese rabbits are at greater risk as fatty infiltration of the liver is already present
- Disturbances in electrolyte and water balance
- Gastric ulceration

Step 1: History and clinical examination:

- General condition and demeanour
- Duration of anorexia
- Passage of hard faeces. Absent or small hard faeces is a significant finding
- Dental examination (see Section 7.6)
- Abdominal palpation: look for gastric distension, masses, impacted stomach or caecum
- Look for other signs, e.g. diarrhoea, dyspnoea, drooling, myxomatous lesions

Step 2: Hospitalization

- Permits observation of appetite and faecal output (see sections 3.85, 3.8.6)
- Nursing is often required (see Section 3.10)
- Intensive medication, injectable analgesics, intravenous fluid therapy and syringe feeding are often needed (see Section 4.11)

Step 3: Diagnostic workup

- Low dose Hypnorm [0.2mL/mg] is useful for radiography and venepuncture)
- Take blood samples: especially for PCV (should be <40%) glucose, urea, electrolytes. Lipaemia or extreme hyperglycaemia carry poor prognosis (see Chapter 6)
- Radiographs show impactions, gas or fluid distensions, uroliths, tumours, etc. Painful skeletal conditions may be seen

Step 4: Surgery

- Anaesthesia is necessary to trim elongated spurs
- Abdominal surgery is indicated for obstructions, neoplasia etc. but not indicated for gastric stasis or 'trichobezoars' that can be treated medically
- Surgery needs to be performed promptly

Management factors

- Poor-quality food
- Change of diet
- Loss of companion
- Elizabethan collars

Dental disease

- Common.
- Usually anorexia is due to spurs on cheek teeth impinging on tongue (see Section 7.5.9)
- Often associated with weight loss, salivation and lack of grooming
- Can be sudden onset
- Requires general anaesthesia and treatment (see Section 7.9.2)

Gastrointestinal hypomotility

- Usually sequel to pain, stress or fright
- May pick at food. Progresses to total anorexia
- No hard faeces are passed
- Impacted stomach may be palpable
- End point is death from hepatic lipidosis
- Can be treated successfully in early stages (see Section 10.3.4)

Gastric dilatation

- Sudden onset, severe depression
- Often associated with intestinal obstruction and treatment is surgical (see Section 10.5)
- Site of obstruction may be identified from gas shadows on abdominal radiographs.

Caecal impaction (see Section 10.7)

Slow onset

May be part of to mucoid enteropathy syndrome (see Section 10.9)

Metabolic disease

- Renal failure, may be associated with urolithiasis (see Section 14.5)
- Liver disease

Neoplasia

- Uterine adenocarcinoma and lymphoma are common

Systemic disease

- Myxomatosis, enterotoxaemia, VHD, pasteurellosis, coccidiosis are accompanied by other clinical signs
- Toxicity, e.g. lead, plant poisons

Figure 1.10 Approach to the anorexic rabbit. The anorexic rabbit requires prompt diagnosis and appropriate treatment. Chance medication with antibiotic, vitamin or corticosteroid injections is unlikely to be effective and wastes valuable time.

- Faecal production: Is this increased/decreased? Are the faeces normal? Are the caecotrophs being eaten?
- Is the rabbit walking or hopping? Is it able to groom itself (Figure 1.9)? Can it exhibit normal behaviours such as 'Binkying'?
- Owners may describe symptoms such as tooth grinding or a change in demeanour. Some rabbits exhibit low-grade neurological disorders such as head nodding or scanning when they are relaxed or appear unaware of loud noises. These behavioural clues are unlikely to take place in the consulting room when the rabbit is apprehensive and have to be elicited from the owner.

1.4.2 Breed incidence

Diseases associated with particular breeds may be related to the breed specifications (fur matting leading to myiasis in lionhead and Angoras, entropion in French lops) or simply related to the genetic make-up of individuals of that breed independent of the breed characteristics (splay-leg in New Zealand red and white rabbits). Dwarf breeds appear to be predisposed to developing incisor malocclusion. Giant breeds are more susceptible to cardiomyopathy and arthritic conditions. The giant English and French lops are prone to superficial pyoderma in the large skin folds that can develop under the chin and around the perineum. Entropion also occurs in these breeds. The thin fur on the hocks of rex rabbits makes them susceptible to developing sore hocks and the short maxilla and foreshortened face of the Netherland dwarf can alter the anatomy of the nasolacrimal duct so it is prone to blockage. Dwarf breeds appear to have a susceptibility to developing torticollis due to *Encephalitozoon cuniculi* infection (Kunstyr and Naumann, 1983).

1.4.3 Age

Young rabbits that are newly purchased are more likely to be affected by infectious diseases than adult rabbits kept alone. Newly weaned rabbits are susceptible to various enteric conditions. Colibacillosis is more prevalent in suckling rabbits, and hepatic coccidiosis and mucoid enteropathy are most likely to occur in the post-weaning period. Stress predisposes young rabbits to pasteurellosis. Rhinitis is often seen in young rabbits that have been taken from breeding colonies and presented for sale in pet shops. Congenital malocclusion is seen in the young rabbit, whereas the incidence of acquired dental disease, neoplasia and musculoskeletal problems increases with age. Neoplasia is relatively rare in rabbits; thymomas and a variety of skin tumours are among the types of neoplasms that have been reported. Although tumours are usually encountered in elderly patients, it is possible to discover neoplasms in young animals. Lymphosarcoma has been reported in an 8- to 10-week-old rabbit (Cloyd and Johnson, 1978).

1.4.4 Husbandry

It is important to find out whether the rabbit lives on its own or with a mate. Fur chewing or fights can result in alopecia, wounds or abscesses. Does that are kept with other does or neutered males are more likely to suffer from false pregnancies than those housed on their own. Contact with wild rabbits is also a relevant part of the history. It is not unknown for does to dig out of their enclosure, escape and return or be found a few days later. Myxomatosis or pregnancy can be the result. Rabbits kept in enclosures or hutches can be visited by wild rabbits, especially during the night. There is often a pile of droppings as evidence of the visit.

House rabbits are prone to chewing household fixtures. Heavy metal toxicity or electrocution is more likely to occur in a house rabbit than one kept in a hutch outside. They are also at a greater risk of traumatic injuries and fractures. The material used in the litter tray is also an important part of the history. For example, pine shavings can cause hepatotoxicity or clay materials can cause caecal impactions.

Hutch rabbits are more likely to suffer from diseases of neglect. It is not uncommon for hutch rabbits with long-standing conditions such as large abscesses, advanced dental disease and terminal neoplasia to be presented with no clinical history at all. Hutches kept in poorly ventilated areas predispose to pasteurellosis and upper respiratory tract infections. Hutches exposed to severe weather conditions predispose to heat stroke or stress-related diseases such as gastric stasis following predator attack, a thunderstorm or severe frost.

1.4.5 Eating and drinking

Rabbits normally drink 50–100 mL/kg/24 h (Brewer and Cruise, 1994). The composition and water content of the diet affects this quantity. Rabbits that eat fresh greens may not drink at all (Cheeke, 1987). High protein diets require a high water intake. Fibrous, dry foods absorb water in the intestinal tract and therefore increase thirst. During periods of water deprivation, food intake is reduced, sometimes to the point of anorexia. Conversely, food deprivation results in an increase in thirst, with rabbits drinking up to 650% more water (Brewer and Cruise, 1994). Some rabbits never learn to use automatic drinkers and will only drink out of a bowl. Water deprivation eventually leads to dehydration and prerenal azotaemia. Increased drinking or alteration in food preference can be early signs of dental disease.

1.4.6 Urination and defecation

Many owners do not know whether their rabbit is urinating or defecating normally, especially if it is kept in a hutch or lives with another rabbit. Faecal consistency, size and output are an important part of the clinical history. Sometimes there are some faecal pellets in the carrier that can be examined during the consultation. A healthy rabbit, that is eating well, passes large quantities of hard faeces and eats the soft caecotrophs (see Table 1.6). The number of hard faeces varies with the fibre content of the diet. A healthy 2.5- to 3-kg rabbit produces about 150 hard faecal pellets a day (Lowe, 1998). Hard pellets can be expelled at any time but are always produced overnight. Absence of hard faeces is indicative of anorexia or reduced intestinal motility. Small faecal pellets are produced following periods of reduced food intake.

Observant owners may see their rabbit ingesting caecotrophs from the anus. Uneaten caecotrophs are sometimes seen as shiny clusters of dark pasty pellets in the bedding of normal animals. Uneaten caecotrophs are often interpreted as diarrhoea. This is not surprising as caecotrophs have a strong smell and a soft consistency in comparison with the hard faecal pellets. Obesity, spinal problems and dental disease are among the many reasons for caecotrophs to be left uneaten (see Figure 8.6). Uneaten caecotrophs can become entangled in the fur under the tail and form an unpleasant, malodorous faecal mass

Table 1.6 Significance of faecal output

Clinical condition	Hard faeces	Soft faeces (caecotrophs)
Normal	Large numbers (~150) of hard pellets produced each day Microscopically consist of strands of undigested fibre	Usually not seen, although occasional cluster of caecotrophs in the bedding is not abnormal Microscopically contain an abundance of bacteria, protozoa and occasional yeast
Anorexia or starvation	Reduced in number and size	Not seen
Gut stasis	Absent	Not seen (absent)
Enteritis	Soft or liquid	Soft or liquid. Cannot be differentiated from hard faeces
Uneaten caecotrophs	Normal, i.e. produced in large quantities	May be seen as clusters in bedding or entangled in fur under tail
Soft uneaten caecotrophs	Normal	Periodic expulsion of soft, faecal paste which easily becomes entangled in fur under the tail

that in turn can lead to myiasis. Changes in the consistency of caecotrophs can follow ingestion of a new food or a succulent item such as lettuce or fruit. Soft, sticky or liquid caecotrophs may be passed. It is thought that this is due to alterations in the caecal microflora. Rabbits on a high fibre diet have a healthy caecal microflora that can withstand dietary changes. Uneaten caecotrophs are not life threatening although they are unpleasant for the owner and rabbit, and predispose to other conditions such as superficial pyoderma, fly strike and problems with urination due to inflamed painful perineal skin (see Sections 7.7.2, 8.6 and 12.4.3). Discrimination between uneaten caecotrophs and true diarrhoea is often possible by checking whether normal droppings are being passed concurrently. If they are, then the 'diarrhoea' noted is likely to be uneaten caecotrophs.

Enteritis is signified by excretion of faecal material that cannot be identified as either hard or soft faeces. Microscopic examination of the faecal material can be helpful (see Section 2.6). Caecotrophs consist of a paste rich in bacteria that are easily seen on a faecal smear stained with Gram's stain. Hard faeces consist of particles of indigestible fibre and little else. Sometimes it is necessary to hospitalize the rabbit to observe faecal output.

Urination should take place with no pain or discomfort. Normal rabbit urine varies considerably in its visual appearance. The colour can vary from the pale yellow colour that is familiar in other species through a range of oranges and brown to a deep red that can be mistaken for blood. The colour depends on the diet and is the result of the excretion of plant pigments. Vegetables such as cabbage, broccoli and dandelions often result in the excretion of red urine. There are clinical conditions such as urolithiasis and uterine disorders that will cause haematuria. Examination of the urine with a dipstick differentiates between blood and plant pigments. Alternatively, a Wood's lamp can be used as urinary pigments fluoresce when exposed to ultraviolet light (Benson and Paul-Murphy, 1999).

Normal rabbit urine can be cloudy due to the presence of calcium carbonate precipitates. The rabbit kidney is adapted for the excretion of large amounts of calcium (see Section 1.3.12). Intestinal absorption is related to the calcium content of the diet and excess amounts are excreted by the kidney. Therefore the amount of calcium carbonate precipitate varies with the calcium content of the diet. The hydration status of the animal and pH of the urine also affect the amount of precipitate. The urine can be clear during periods of high calcium demand such as growth, pregnancy or lactation. A small amount of precipitate is a good sign as it reflects adequate calcium content in the diet. Excessive precipitate can form a thick sludge, especially in the bladder of rabbits that do not urinate frequently (see Section 12.4). High dietary calcium levels exacerbate the problem. Cystitis, urethritis and urinary incontinence can be the result. It can be difficult to differentiate between normal calcium carbonate deposits and abnormal amounts of sludge. Normal rabbit urine is often radiopaque. Calcium carbonate deposits in the urine of an otherwise healthy animal with no sign of urinary tract disease do not require treatment; however, it should be recognized that if the situation changes the calcium deposits may become clinically significant. Similarly, triple phosphate crystals can be a normal finding in rabbit urine.

1.5 Handling

1.5.1 Handling rabbits during the consultation

There are many techniques described for handling rabbits (Burgmann, 1991; Mader, 1997; Malley, 2000; Quesenberry, 1994; Richardson, 2000b). Most pet rabbits are used to human contact and do not object to being picked up and examined. Rough handling and overzealous restraint can be counterproductive and alarm the rabbit and upset the owner. A quiet, gentle but firm approach is preferable, with the option to restrain the animal more firmly should the need arise. Rabbits seldom bite vets in the consulting room even if they bite their owners at home. Instead they inflict nasty scratches with their powerful hind feet.

It is usually possible to lift pet rabbits out of carriers by placing a hand round either side of the chest and lifting them in the same manner as a cat or small dog. Placing a forefinger around each front leg can be helpful. Fractious or nervous animals can be lifted by the scruff with a supporting hand under the rear end. Very excitable or aggressive rabbits can be caught and removed from the carrier in a towel. Picking rabbits up by their ears is not acceptable and is no longer advocated, although it is recommended in some older texts. After being removed from the carrier, it is often useful to allow the rabbit to hop around the floor of the consulting room as long as this is safe. In this way the rabbit can become acquainted with a new environment, and important information about its general condition and mobility can be gained. Alternatively the rabbit can be held on the consulting table and observed while a clinical history is being obtained from the owner. To examine the perineum, the rabbit can be restrained in dorsal recumbency either by holding the scruff and lying the rabbit on its back or by cradling it like a baby in the arms of an assistant or the owner. Dorsal recumbency may evoke an immobility response but can be a source of stress, leading to kicking and struggling. An alternative approach is to hold the rabbit upright and rest its rear end on the consulting table. There are many approaches and each clinician will find a method that suits them.

Wrapping a rabbit in a towel is a satisfactory method of restraint for examination of the face and mouth or for venepuncture. A large towel is placed on the table and the rabbit placed on top of it before being wrapped up so the whole body is enclosed with only the head exposed. An assistant, who may be the owner, is needed to hold the rabbit firmly against them or pressed gently on to the table. The front legs can be held. Jackson (1991) found that restraining laboratory rabbits by wrapping them securely in a towel not only reduced the stress of handling but also reduced the incidence of gastrointestinal stasis. It is important to remember that rabbits can still cause themselves harm whilst wrapped in a towel, and isometric contraction of the powerful lumbar muscles can result in spinal fracture. Attention to the behaviour of the rabbit being examined and modification of approach if struggling occurs is less likely to result in injury to either handler or patient.

Key Points 1.13 Rabbit handling

- While most rabbits tolerate handling well, some respond by struggling and jumping. This can result in broken bones and teeth as well as injury to the handler.
- Rabbits have spinal muscles strong enough to break their own spines should they contract forcibly, for example when trying to kick out with their back legs. Isometric contraction of the spinal muscles can still result in significant spinal damage, for example when a struggling rabbit is wrapped in a towel.
- In the surgery setting, rabbits should be picked up from the carrier. In the home setting it is much less stressful for the rabbit to be approached from its own level.
- Rabbits should be picked up by placing a hand under their chest and using the other hand to support the back end of the body. For some aggressive rabbits it is necessary to pick them up using the scruff; however, it is still vitally important to support the body weight at the back end of the body.
- Rabbits should **never** be picked up by their ears
- Rabbits can often be examined using minimal restraint, and an owner or nurse simply gently holding the rabbit in place is enough. For rabbits that try to escape, covering their eyes with a hand is often helpful and calms them down enough for examination.
- For procedures that are intimidating (looking inside the mouth) or painful, using a towel to wrap the rabbit may be necessary. It is still possible for a rabbit to injure itself in this situation.
- Tonic immobility can be used as a means for restraining rabbits for portions of the clinical examination. Some rabbits are resistant to this technique and it is thought to be stressful.
- Ultimately some rabbits will benefit from sedation in order to allow complete examination. This is likely to be less stressful than the alternatives.

A good method of carrying a rabbit is to hold it with its face tucked in under the handler's elbow, with the rest of the body resting on the forearm. The close physical contact and covering the face appears to placate fractious animals. This can also be a good method of restraint for venepuncture of the lateral saphenous vein, as the restrainer can easily raise the vein on the external rear leg.

1.5.2 Immobility response (tonic immobility, freeze response or 'hypnosis')

The immobility response is often described as 'hypnosis', 'tonic immobility', 'the freeze response' or 'trancing'. Hypnosis can be a useful method of restraining rabbits for minor procedures (Bivin, 1994). Although hypnosis has been described for more invasive techniques such as castration (Okerman, 1988), it is not a humane alternative to anaesthesia or analgesia. There is controversy about placing conscious rabbits in dorsal recumbency at all. On one hand, some practitioners lie rabbits on their backs to perform a variety of procedures such as nail clipping, oral administration of medicines and even inserting mouth gags to examine or clip molars. On the other hand, there is a view that the immobility response occurs in stressful situations and that rabbits lying on their backs are terrified and waiting to be eaten. However, it is a useful technique in some situations. For, example, it is possible to immobilize conscious rabbits for long enough to take abdominal radiographs.

The immobility response is exhibited in prey species under conditions that are stressful or threatening. The more highly a species is preyed upon, the easier it is to induce the response. The immobility response is a transitory and reversible state of profound motor inhibition. The phenomenon is characterized by lack of spontaneous movement and failure to respond to external stimuli for several minutes. In rabbits, there is hypotonia of flexor and extensor musculature, abolition of the righting reflex, depression of spinal reflexes, miosis and a drop in blood pressure, heart rate and respiratory rate. An awareness of external stimuli is maintained, although there is a decreased response to noise and painful stimuli (Danneman *et al.*, 1988). This trance-like state is induced in the laboratory by placing the rabbit in dorsal recumbency, covering its eyes with its ears and flexing its chin against the neck. The hind legs are stretched out for a few minutes before releasing the legs and gently stroking the chest and abdomen. As long as the head is flexed, the rabbit remains immobile and restraining devices have been designed to maintain this position (Bivin, 1994).

There are similarities between the immobility response and an opiate-induced state. The exact role of endogenous opioid systems is controversial and there are conflicting reports about the effects of naloxone which, theoretically, should prevent or reverse the hypnotic state (Danneman *et al.*, 1988). Sudden noise or painful stimuli can interrupt the trance and there is considerable variation in individual susceptibility to the technique. In a study by Danneman *et al.* (1988), the immobility response could not be evoked in 25% of rabbits. In the consulting room, some pet rabbits can be calmed and restrained by placing them in dorsal or lateral recumbency and gently stroking their stomach while quietly speaking to them. Blowing gently on their face or stroking the bridge of the nose can also be effective.

The physiological response noted in rabbits following induction of the immobility response is similar to that found following a stressful event. Rabbits having this response induced repeatedly initially become sensitized and then habituated to it; however, corticosteroid levels remain elevated afterwards (Farabollini *et al.*, 1981, 1990). Fear behaviours were also noted in six rabbits who were tranced repeatedly (McBride *et al.*, 2006). This supports the assertion that this phenomenon is indicative of a fear-motivated stress response (Day, 2004). It is therefore inappropriate to advocate the use of the immobility response in order to promote bonding between a rabbit and an owner; however, its use in veterinary practices in order to avoid unnecessary anaesthesia is justifiable.

1.6 External characteristics and physical examination

1.6.1 External characteristics

As prey animals, the external characteristics of the rabbit reflect the need to be aware of their surroundings. The defining external feature of rabbits is their prominent external ears. These can range from 5–6 cm long and upright to 30 cm or more and draped/lopped to the ground. In the wild rabbit these are constantly used to identify and localize potential threats. The eyes are prominent and found on either side of the head, giving nearly 360° vision. The nose is almost constantly moving and twitching and as well as having an acute sense of smell the nostrils are sensitive to touch with large numbers of tactile vibrissae.

Rabbits have a thin skin and dense fur that consists of a soft undercoat and stiff guard hairs. They do not have footpads; instead, the feet are covered with thick fur. The skin on the neck is loose and pendulous and forms a pronounced dewlap in females of some breeds. Scent glands are situated in the deep inguinal spaces found on either side of the anus immediately dorsal to the urogenital opening. In the male rabbit, the testicles are found in hairless scrotal sacs on either side of the penis. The inguinal canal remains open and the testicles can be retracted into the abdomen. Retraction occurs during periods of sexual inactivity or during periods of insufficient food. Male rabbits have rudimentary nipples.

1.6.2 Clinical examination

A list of differential diagnoses for some commonly encountered conditions of pet rabbits is given in Table 1.7.

1.6.2.1 General condition

The general health of a rabbit can be assessed by the state of its coat and its body weight. Obese animals are prone to grooming difficulties, sludgy urine, cystitis, parasitic skin disease, perineal soiling from uneaten caecotrophs, fly strike, cardiovascular disease, arthritis, hepatic lipidosis and death. At the other end of the scale, weight loss is a significant clinical finding as rabbits are seldom given insufficient food unless there is serious neglect taking place. Dental disease, gastrointestinal hypomotility, renal or liver disease or neoplasia can cause weight loss despite the rabbit looking lively and well to its owner.

Reusch (2010) proposed a method for body condition scoring in rabbits. Condition scoring relies on the palpation of certain anatomic landmarks to assess body fat, rather than relying on just weighing the animal. With this method, areas of the body associated with body fat deposition (hips, ribs, spine) are scored to assess whether a rabbit is obese. In trials conducted at the University of Edinburgh, the rib area proved to be the most useful for assessing body fat, with the hips and spine only showing appreciable changes at extremes of body weight. The ribs are felt just behind the elbow and the amount of pressure required to feel the ribs is assessed. The greater the pressure required, the more fat is present (Table 1.8).

1.6.2.2 General demeanour

A healthy rabbit is responsive and alert, with its nose constantly twitching. It is aware of its surroundings and once comfortable should be eager to explore. The response to pain is to become quiet, immobile and oblivious of the surroundings. Visceral problems such as gut stasis or urolithiasis appear to be more distressing to rabbits than the abscesses or fractures. Occasionally, overt signs of pain such as tooth grinding can be evident. This is usually associated with visceral pain, especially impactive intestinal problems such as mucoid enteropathy (see Section 8.9). Intestinal obstruction is associated with severe depression and immobility, which gives a characteristic clinical presentation (see Box 1.8). The presence of spurs on the molars that traumatize the sensitive mucosa of the tongue is also very painful for rabbits.

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits

Symptoms	Differential diagnosis	Comments
Abdominal distension	Gastric dilatation Obesity Pregnancy	
	Hepatic coccidiosis	Can cause ascites
	Liver tumour	Can cause ascites
	Uterine adenocarcinoma	
	Cardiac disease	Can cause ascites
Abdominal mass	Pregnancy	
	Neoplasia	Especially uterine adenocarcinoma
	Caecal impaction	
	Extra-uterine pregnancy	
	Abscess	
	Fat necrosis	
	Full bladder,? urolithiasis	
	Tapeworm cysts	
	Renal enlargement	Neoplasia, hydronephrosis, renal calculi
Abortion	*Listeria monocytogenes* *Treponema paraluiscuniculi*	
Anorexia (see Figure 1.13)	Unpalatable diet Stress	Pain, unfamiliar surroundings, predator proximity, loss of companion
	Dental disease	• Spurs on cheek teeth lacerating the tongue • Elongated incisors physically impeding intake of food • Fractured teeth causing pain
	Gastrointestinal hypomotility 'Gut stasis', 'trichobezoars' Intestinal obstruction	Secondary to any stressful situation Predisposed by inadequate dietary fibre Acute onset Associated with severe depression May be caused by ingested felts of hair, foreign bodies such as dried peas and pulses May be due to extramural lesion such as abscesses, tumours or tapeworm cysts
	Mucoid enteropathy	Slow onset Tooth grinding Absence of faeces or mucus ± diarrhoea Associated with stress Juvenile rabbits most commonly affected May have palpably impacted caecum

Continued

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
	Caecal impaction	Idiopathic Excess dietary fibre and inadequate water intake Ingested clay litter material
	Infectious disease	Pasteurellosis, myxomatosis, VHD, enterotoxaemia
	Systemic disease	Renal disease, hepatopathy
	Neoplasia	
	Trauma	Jaw fracture
Ataxia	Spinal cord compression *Encephalitozoon cuniculi* Ketoacidosis Starvation Trauma Septicaemia Heat stroke Lead poisoning	
Blepharospasm	Keratitis Keratitis in association with dacrocystitis Corneal ulcer	
	Conjunctivitis	May be secondary to poor air quality or dust from hay
	Conjunctival foreign body Uveitis	? Hay seeds
	Entropion	May be congenital or acquired from fight wounds involving eyelids
	Swollen eyelids	Myxomatosis
		Treponema paraluiscuniculi
		Neoplasia
		Abscesses
Deafness	Middle ear infection	Pus in tympanic bulla as a result of ascending infection from the eustachian tube
	Encephalitozoon cuniculi encephalitis Pus, wax and exudate in external ear canal	
Diarrhoea (see Table 8.2)	Uneaten caecotrophs	Uneaten caecotrophs are often interpreted by owners as 'diarrhoea'

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
	Uneaten soft caecotrophs	Soft uneaten caecotrophs can be induced by dietary change, especially after introduction of succulent foods such as lettuce
	Antibiotic-associated diarrhoea	Some antibiotics, e.g., oral penicillin, ampicillins, clindamycin and lincomycin can induce diarrhoea by their effects on the gut flora
	Enteritis Enterotoxaemia Coccidiosis	
Exophthalmos: bilateral	Fear Males in breeding season Natural appearance Paraneoplastic disease	 e.g., short-nosed dwarf breeds Thymoma
	Bilateral glaucoma Bilateral retrobulbar abscesses	
Exophthalmos: unilateral	Glaucoma	Congenital Secondary to other diseases such as trauma, tumours or *E. cuniculi* lens rupture
	Retrobulbar disease	Abscess
		Tumour
		Haemorrhage
		Tapeworm cyst
		Iatrogenic rupture of nasolacrimal duct and infiltration of periorbital space with fluid
Haematuria	Cystitis ('sludgy urine') Urolithiasis Uterine adenocarcinomas Uterine polyps Endometrial venous aneurysms	**NB**: Blood from the uterus may be voided in urine as the vaginal vestibule fills with urine during micturition. Blood clots may be present
	Chronic polypoid cystitis, renal infarcts and disseminated intravascular coagulopathy have also been described as causes of haematuria in laboratory rabbits	

Continued

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
Head tilt	*Encephalitozoon cuniculi*	Granulomatous inflammation of central nervous tissue
	Infection of the vestibular apparatus	Usually ascending *Pasteurella multocida* from nasal cavity via eustachian tube
		May be abscesses along vestibular tract
	Other CNS disease	Trauma, neoplasia, etc.
	(In USA) *Baylisascaris* larva	Raccoons are natural host
Increased respiratory rate	Stress	Due to unfamiliar surroundings or proximity of predators
	Metabolic acidosis	Ketoacidosis
	Heat stroke	Hot stuffy shed
		Transport by car
	Paradoxical breathing	Hutch situated in sun Heatpads Fear/distress
	Trauma	? Predator attack
		Penetrating injuries of chest wall
		Haemothorax, pneumothorax, etc.
	Rhinitis	Pasteurellosis
		Nasal foreign body, e.g., hay or seed
		Tooth root abscess
	Obstruction of nasopharynx, larynx or trachea	Inflammation caused by pasteurellosis
		Abscess
		Foreign body, hay or seed
		Exudate from lung disease
	Lung disease	Primary bacterial pneumonia, e.g., pasteurellosis
		Secondary pneumonia, e.g., myxomatosis, mucoid enteropathy
		Viral haemorrhagic disease
		Aspiration pneumonia
		Primary or secondary neoplasia
		Pulmonary abscess
	Pulmonary oedema	Congestive heart failure
		Heat stroke
		Electrocution

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
	Pleural effusion	Neoplasia
		Cardiomyopathy
		Coronavirus
	Congestive heart failure	
Liver disease	Hepatic lipidosis	
	Hepatic coccidiosis	
	Viral haemorrhagic disease	
	Hepatopathy	Has been associated with pine wood shavings as litter material
		Aflatoxin
	Neoplasia	*Cysticercus pisiformis*
	Bile duct obstruction	? Neoplasia
	Toxoplasma gondii	Adhesions
Polydypsia	Anorexia	
	Food deprivation	
	Renal disease	*? E. cuniculi*
	? Diabetes mellitus	There is debate about incidence of diabetes mellitus in pet rabbits
Paresis/paralysis	Spinal fracture	Trauma? predator attack
		Spontaneous due to pre-existing bone disease
	Degenerative disc disease	Disc protrusion may follow trauma
	Spinal deformities	Kyphosis, scoliosis, spondylosis
	Neoplasia	Primary or secondary bone tumours can cause spinal cord compression
	Spinal abscess	Spinal abscess can cause cord compression
	'Floppy rabbit syndrome'	
Pruritus	Flea infestation	Usually dog or cat fleas
	Louse infestation	
	Allergic skin disease	
	Compulsive self-mutilation	
	Ringworm	
Renal disease. *NB*	Nephrolithiasis	

Continued

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
Asymptomatic renal disease can be present due to benign embryonal nephroma, congenital renal cysts or encephalitozoonisis	*E. cuniculi* Hydronephrosis Renal calcification	
Reversible azotaemia can occur due to stress, dehydration or water deprivation	Renal abscesses Staphylococcal nephritis Pyelonephritis Lymphoma Neoplasia	
	Amyloidosis	
	Renal agenesis	
	Toxic compounds	
Seizures	Encephalitozoonisis	
	Viral haemorrhagic disease	
	Toxicity, e.g., lead	
	Terminal hepatic lipidosis	
	Arteriosclerosis	
	Toxoplasma	
	Idiopathic epilepsy	
	CNS disease	
Skin lesions: alopecia	Physiological, moulting Fur pulling for nestmaking	Some fluffy haired breeds lose fur in patches
	Treponema paraluiscuniculi Barbering	Associated with pregnancy or pseudopregnancy
	Fighting	Caused by dominant cage mate
	Cheyletiellosis	
	Ringworm	
	Nutritional	e.g., essential sulphur amino acid deficiency
Skin lesions: crusty	Ringworm	
	Superficial pyoderma secondary to trauma	
	Ectopic *Psoroptes cuniculi*	

Table 1.7 List of differential diagnoses for some common conditions in pet rabbits—cont'd

Symptoms	Differential diagnosis	Comments
	Allergic dermatitis	
	Atypical myxomatosis	
	Treponema paraluiscuniculi	Rabbit syphilis
	Rectoanal papilloma	
Skin lesions: nodules	Primary tumours Circumscribed abscesses	e.g., fibromas
	Atypical myxomatosis	
Skin lesions: swellings	Abscesses Tumours	
	Hernias	
	Subcutaneous *Cysticercus serialis* cysts	Dogs/foxes are intermediate hosts
Sudden death	Enterotoxaemia	
	Viral haemorrhagic disease	
	Intestinal obstruction	
	Choking Predator attack	Especially rabbits with advanced dental disease that can choke on pieces of hay
	Trauma	
	Acute pasteurellosis	
	Electrocution	
	Cardiomyopathy	
	Neoplasia	
	Poisoning, e.g., yew	
	Listeriosis	Females in late pregnancy
Weight loss (see also anorexia)	Dental disease Gastrointestinal hypomotility	
	Renal disease	
	Caecal impaction	
	Chronic liver disease	Hepatic coccidiosis in young rabbits
	Neoplasia	
	Change of diet	
	Bullying by cage mate	
	Pseudotuberculosis	

Table 1.8 Body condition scoring in rabbits

Score 1 Emaciated	Score 2 Lean	Score 3 Ideal	Score 4 Fat	Score 5 Obese
• Pelvis and ribs are very easily palpated and very sharp • **Ribs feel like a pocket full of rulers** • Concave rump area	• Pelvis and ribs easily palpated and feel sharp • Rump area is flat	• Pelvis and ribs easily palpated but rounded edges • **Ribs feel like a pocket full of pens** • Rump area is flat	• Firm palpation required to palpate ribs • Rump round	• Hard to palpate ribs • **Ribs can't be felt** • Rump very convex

Box 1.8 Intestinal obstruction in pet rabbits

Intestinal obstruction in pet rabbits gives a characteristic clinical presentation. The most common cause of obstruction is a felt of hair that is groomed out of the coat, especially the hind feet, during moulting. Dried pulses, foreign objects, tumours and tapeworm cysts are among other causes of obstruction (see Chapter 8). If the condition is recognized early and surgery is performed promptly, there is a reasonable chance of success. If the condition is not recognized and treated, the rabbit will die unless the foreign body happens to pass into the colon.

Presentation

- Sudden onset. The rabbit was well until a few hours before presentation.
- Severe mental depression. The rabbit is unresponsive and totally anorexic.
- Abdominal distension. The owners may have noticed a bloated appearance although it may be masked by a thick coat.
- Palpably distended stomach. A 'strange feeling' or distended abdomen or abdominal pain is a clear indication for abdominal radiography.
- Shock, dehydration and collapse. Depending on the site of the obstruction, the rabbit's condition will deteriorate rapidly.

Diagnosis

- Abdominal radiographs are diagnostic. A stomach distended with gas and fluid is clearly visible (see Figure 8.5). A section of gas-filled intestine can usually be seen radiographically, proximal to the site of obstruction. If the obstruction moves into the colon, gas can be seen in the caecum and proximal colon.
- Other causes of gastric dilatation include mucoid enteropathy or dysautonomia, both of which carry a poor prognosis.
- Abdominal palpation. An impacted organ, intussusception or foreign body may be palpable, especially if the rabbit is anaesthetized or moribund.
- Prompt exploratory laparotomy is indicated.

Treatment

- Motility stimulants are contraindicated prior to surgery. Postoperatively, metoclopramide (with caution) and ranitidine are required to prevent ileus. Cisapride may be used if available.
- Effective analgesia is important. Low dose fentanyl/fluanisone (Hypnorm, Janssen 0.2 mL/kg) provides analgesia, sedation and vasodilation that facilitates intravenous fluid therapy.
- Decompress the stomach by passing a stomach tube (a stomach tube should remain in place throughout surgery). This can usually be done after the rabbit has been sedated.
- Fluid therapy. Intravenous (or intraosseous) fluid therapy is essential. Subcutaneous fluids will be ineffective in restoring and maintaining blood pressure and correcting dehydration and electrolyte imbalances.
- Anaesthesia, gradual mask induction with isoflurane is recommended. Anaesthesia and perioperative care are described in Chapter 4.
- Enterotomy. Midline incision. The obstruction is often easy to find. The gas-filled small intestine can usually be identified and followed to the site of the obstruction. (Basic surgical principles in rabbits are described in Chapter 13.) Fine suture material (5/0 or 6/0 PDS or Monocryl) is required to repair the intestinal incision. A set of fine instruments is essential (a detailed description of surgical procedure is given in Chapter 8).

1.6.2.3 Gait

It is often helpful to allow the rabbit to hop around the consulting room floor, providing the owner and practitioner are confident that the animal can be caught again. Slippery vinyl is a difficult surface for rabbits to move about on. Placing a large towel on a slippery floor aids assessment of the patient's gait. Abnormal gait associated with spinal problems or fractures may be discovered. Neurological deficits can become evident and the rabbit's general demeanour is easier to assess. It is useful to note whether the rabbit is hopping or walking. Healthy rabbits will tend to hop in most situations even if moving slowly while rabbits with neurological or skeletal disorders will often walk.

1.6.2.4 Sex, age and sexual maturity

Rabbits can be difficult to sex, especially when they are immature, wriggling and presented individually, so no comparison can be made. It is often simpler to sex neonates than animals of 4–6 weeks of age. Adults are usually straightforward because entire males have prominent descended testicles. Bucks tend to be larger and have a broader head than does. Mature, entire males develop a thick skin, especially around the scruff and on the dorsum. Females often have a dewlap as a secondary sexual characteristic although some males can develop quite a pronounced dewlap, especially if they are castrated or overweight. Pressure on the genital orifice everts either the penis or the vulva. The vulva can look like a small penis to the novice but is shorter, less round and has a slit-like opening rather than the circular orifice of the male (see Figure 1.11). Testicles descend at 10–12 weeks, although they can be retracted into the abdomen during periods of ill health or starvation.

There are conflicting reports on the life expectancy of rabbits. Five to 7 years is the life span given by Gillett (1994), with a comment that rabbits can live

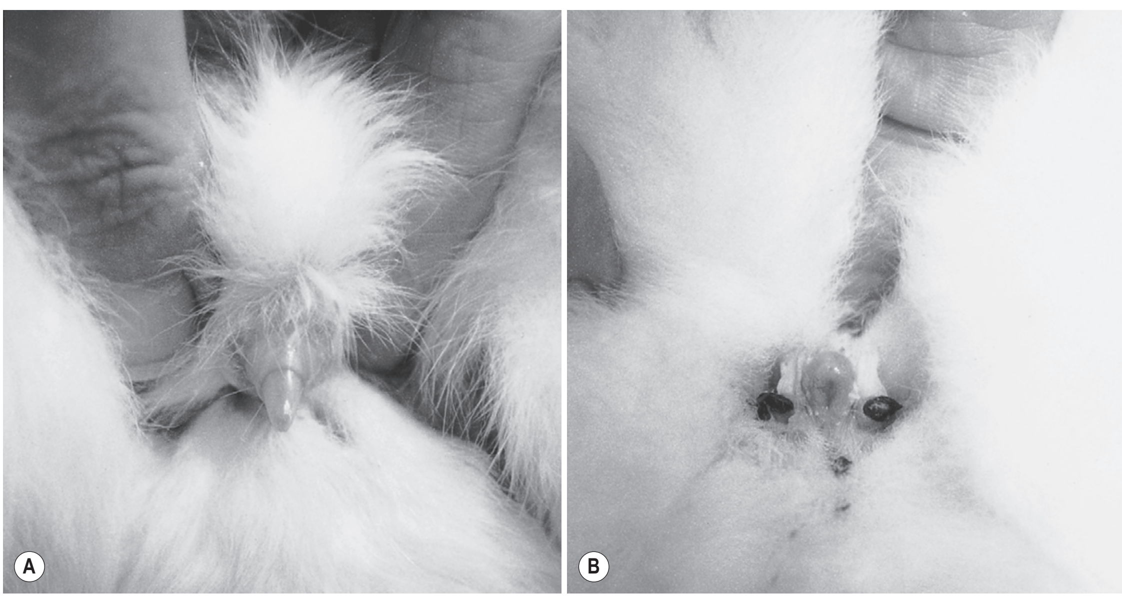

Figure 1.11 Inguinal skin folds and male and female genitalia. In both sexes, deep skin folds lie on either side of the genital orifice. These folds contain scent glands. It is normal for the folds to contain a waxy, odorous exudate. In (B), a brown exudate can be seen. Rabbits can be sexed by applying gentle pressure on the genital orifice to extrude the genital organ. (**A**) *Male genitalia*. In the male, the penis is extruded. Testicles can usually be seen in the scrotal sacs of sexually mature rabbits (> 10–12 weeks) although they can be retracted during periods of stress, illness or shortage of food. (**B**) *Female genitalia*. In the female, the vulva is extruded. The vulva can look similar to a small penis but is shorter and less round, and has a slit-like opening rather than the circular orifice of the male.

to be 15. Many pet rabbits live longer than 7 years and can easily attain 11–12 years, although geriatric diseases are common in this age group. With the increased availability of good veterinary care many more rabbits are achieving a long life expectancy.

It is difficult to age living rabbits with any degree of accuracy. The epiphyseal line in the tibia closes at approximately 9 months of age. The epiphyses of the lumbar vertebrae close much later. Counting the adhesion lines in the periosteal zone of the mandible by histopathological examination can be used to age mature rabbits accurately (Henderson and Bowen, 1979) but this is not possible during life. The deciduous teeth are shed at birth and so the only criteria to make an assessment of age during clinical examination are the size and appearance of the rabbit, both of which vary according to breed and state of health and experience. The claws of the rabbit do not project beyond the fur until the rabbit reaches maturity (Sandford, 1996), but this age varies according to breed and size. Fanciers may be able to give an indication of age by feeling the ears, which are soft in young rabbits and become tougher with age (Sandford, 1996). Pedigree rabbits may have rings over their hocks on which the year of birth will be recorded. Smaller breeds mature at 4–5 months of age and the larger breeds mature at 5–8 months (Donnelly, 1997). Bucks reach puberty later than does, so immature females housed with their brothers are unlikely to conceive even though the buck may mount and appear to mate her. Obviously, the two sexes should be separated or neutered at this stage if pregnancy is to be prevented.

1.6.2.5 Examination of the skin, fur and mucous membranes

A healthy rabbit will spend a lot of time grooming. Rabbits that are kept together groom each other, especially around the head. There are many clinical conditions that can prevent a rabbit from licking and grooming properly (see Figure 1.9), which are manifested by a dull coat full of dead hair and skin debris. Combing through the fur with a flea comb gives an idea of the amount of dead hair and debris and also reveals the presence of fleas, flea dirt or mites. Mites can just be seen with the naked eye, especially under good illumination. A magnifying glass can be used to examine the fur thoroughly. Microscopic examination of skin brushings or sellotape strips confirms their presence and gives an idea of numbers. Most rabbits have some degree of infestation, which is not always significant; however, extensive infestation can be a sign that something is causing stress to the animal or preventing grooming (see Section 7.14.2). The areas of skin between the shoulder blades and above the base of the tail are difficult for the rabbit to reach and groom, especially if it obese or has limited flexibility due to spondylosis (see Figure 1.19). Cheyletiellosis often starts to become evident on the back of the neck and along the dorsum. During the summer, soiled fur at the base of the tail or the perineum must be examined closely for the presence of maggots. The area under the dewlap is prone to superficial pyoderma, predisposed by factors such as poor hygiene, dental disease or obesity. Some rabbits are unable to drink without immersing their dewlap in the water bowl, leading to wet macerated skin and dermatitis or myiasis. Excess salivation as a result of dental disease can result in a wet dewlap that is prone to bacterial infection. Fat rabbits with excessive skin folds and large dewlaps experience problems grooming and may lick the cranial surface of the dewlap obsessively as a type of displacement activity because they cannot groom other areas such as the underside of the dewlap or the perineum which is infected, inflamed and sore. Steatitis within the fat of the dewlap can also lead to chronic skin mutilation. This can be the result of previous trauma.

The forelegs are used to clean the face. Examination of the inner aspect of the carpus and metacarpus may show saliva staining indicative of dental disease. Dried mucopurulent material can be found in rabbits with ocular or nasal discharges. Examination of the fore and hind limbs may show evidence of ulcerative pododermatitis. An area of thin, hairless skin over the point of the hock is not unusual. It should be protected by thick fur that is directed across it. Rex rabbits are very prone to sore hocks due to the lack of protective guard-hairs in their coat.

Felts of densely matted hair are a cause of intestinal obstruction if the rabbit ingests them during grooming. Large felts can accumulate on the plantar aspect of the hind feet. Owners should be advised to groom these animals daily and ensure that loose felts of hair are removed. It is sensible to be careful when removing hair from the plantar aspects of the feet as this serves a protective purpose and removal of too much hair can cause hock sores. Rabbits with dental problems or long-haired breeds such as Angoras are especially at risk.

1.6.2.6 Examination of the perineum

Examination of the perineum confirms the sex of the rabbit and gives an indication of general state of grooming. Urine scalding, vaginal discharges, adherent caecotrophs, fly strike, perineal fold dermatitis or diarrhoea may be evident on examination of this area (see Figure 1.12).

The two deep folds of skin on either side of the anal orifice are the inguinal glands that are normally filled with a yellow-brown odiferous waxy secretion (see Figure 1.11B). These glands can become impacted and require the secretion expressing, or infected, causing production of pus.

The perineum is an extremely sensitive area in rabbits. Pain caused by infected, inflamed perineal skin can lead to urine retention, urethritis, cystitis and/or urinary incontinence. Urine scalding can also be due to urogenital disease or indicative of other problems such as vertebral spondylitis, sore hocks or arthritis,

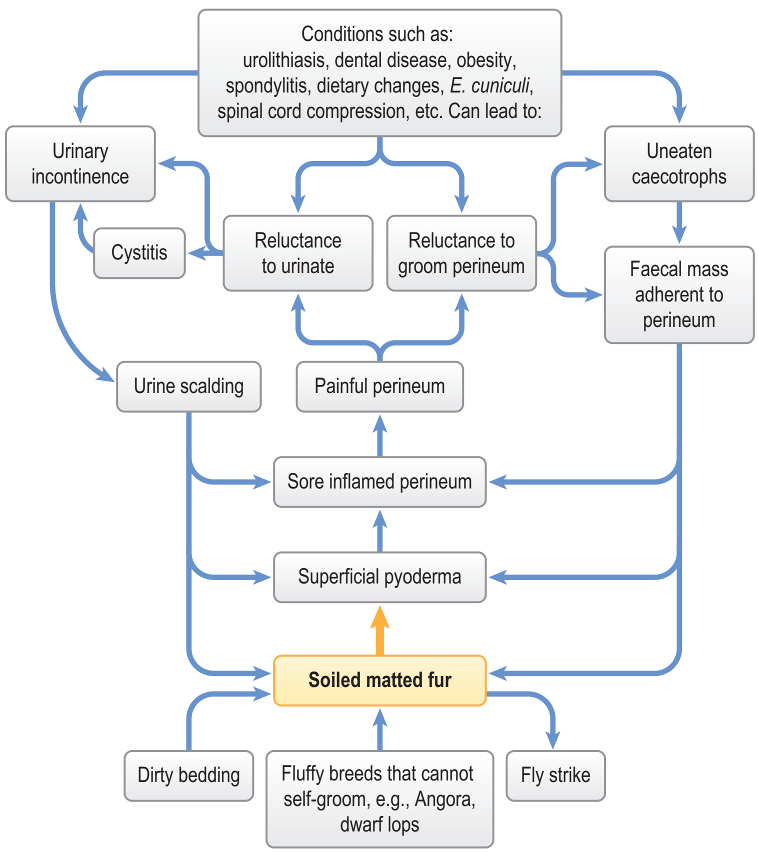

Figure 1.12 Causes of perineal soiling in pet rabbits. A healthy, short-coated rabbit will meticulously groom its perineum and keep it clean. There are many inter-relating factors that can prevent effective grooming of this area and result in matted, soiled fur with or without inflamed underlying skin.

which prevent the rabbit positioning itself correctly to urinate (see Section 12.4.3). Neurological deficits, abdominal pain or generalized weakness can also lead to urine scalding or perineal soiling. Skin inflammation in the perineal area may be caused by uneaten caecotrophs that have become adherent to the fur and caused superficial pyoderma of the skin beneath. Obesity, dental disease and arthritis prevent grooming around the perineum so the fur becomes matted, soiled and infected. This starts a vicious circle that can be broken by clipping and cleaning the perineal area and treating the painful dermatitis (see Figure 7.1 and Section 7.7.3). Clippers can be used to remove most of the fur. A sharp pair of curved, pointed scissors is useful for teasing out and cutting matted hair around the genitalia and under the tail. Dead and matted hair can be combed out with a flea comb. It is very easy inadvertently to damage the delicate skin. Patience and the correct equipment are required. Sedation may be needed. The underlying reason for urinary incontinence, cystitis, grooming difficulties or uneaten caecotrophs needs to be addressed to prevent recurrence.

The appearance of the vulva alters according to the state of sexual receptivity. When the doe is non-receptive, the vulva is pale pink and dry. During receptivity, the vulva becomes swollen, moist and red, becoming darker until it is purple at the end of the receptive period. If the doe is mated, the vulva returns to a light pink colour within 24 hours.

Inflamed or crusty skin around the genitalia can be associated with *Treponema paraluiscuniculi* (rabbit syphilis) or ectopic *Psoroptes cuniculi* (ear mite) infestation. Ear mites can be transferred from the ears to the perineal folds during grooming. Examination of the external ear canal of affected rabbits reveals thick crusty exudate caused by *P. cuniculi*. Rectoanal papillomas can cause crusty lesions that protrude through the anal sphincter.

The hydration status of the rabbit can be assessed during examination of the perineum. Dehydration can occur in the absence of obvious fluid loss because of the redistribution of water and electrolytes associated with alterations of gastrointestinal motility. Although rabbits do not take on a 'sunken eyed' appearance when dehydrated, the thin skin becomes wrinkled and loses its turgidity. The hairless scrotal skin of males is a useful site for assessing hydration status by tenting the skin. The inguinal skin can be used in females.

Mucous membranes can be examined by looking at the colour of the nose or by lifting the lip to see the gums and tongue. Cyanosis is evident in advanced cases of cardiovascular or respiratory disease. Mild anaemia is more difficult to elucidate, although extreme pallor is obvious. The mucous membranes can also be used to assess hydration; as long as they remain wet to the touch, the rabbit is well hydrated. Tacky or sticky mucous membranes indicate dehydration.

1.6.2.7 Rectal temperature

The rectal mucosa is thin and easily damaged. A thermometer can easily tear the rectal wall if a rabbit struggles during temperature taking. Many practitioners do not routinely take the rectal temperature as part of their clinical examination because of the risk of trauma and the limitations in interpreting its significance.

Key Points 1.14 Basic examination parameters

- The normal resting respiratory rate is 32–60 breaths per minute.
- The normal resting heart rate is 130–325 bpm. Murmurs, arrhythmias and pulse deficits should all be noted.
- The pulse may be taken using the central auricular artery.
- These parameters should be checked early in the clinical examination before stress of handling causes significant elevation.
- Capillary refill time is less than 2 seconds, and the mucous membranes should be pink.
- Gut movements may be heard every 30–45 seconds, but can be absent on examination.
- Immature rabbits can be sexed by everting the genital orifice. The female has a slit-like vulva. The male has a penis. Testicles descend at 10–12 weeks.

Key Points 1.14 Basic examination parameters—cont'd

- Female rabbits have a dewlap.
- It is difficult to age live rabbits with any degree of accuracy; the flexibility of the ear cartilages, the wear of the teeth and experience may all give clues.
- Examination of the perineum is an essential part of clinical examination. Urine scalding or faecal soiling may be indicative of other diseases.
- Normal rectal temperature is variable: < 38°C can be considered subnormal, whereas > 40.6°C is significantly high. Taking a rectal temperature can cause rectal tearing so it should be undertaken carefully.

Normal rectal temperature of rabbits is 38.5–40°C (103.3–104°F). It is affected by factors such as environmental temperature and restraint. There is a slight seasonal variation, with temperatures being higher in the autumn and winter than in spring and summer. Females have a slightly higher rectal temperature than males (Pericin and Grieve, 1984). Temperatures below 38.0°C (100.4°F) can be considered subnormal and temperatures in excess of 40.6°C (105°F) are significant and indicative of pyrogenic infection (Toth and Krueger, 1989) or heat stroke.

1.6.2.8 Abdominal palpation and auscultation

The normal topographical anatomy and relative position of the abdominal organs are illustrated in Figures 1.13–1.15. Radiography can be used to differentiate abnormalities detected during abdominal palpation. Ultrasound is also useful. Palpation of the abdomen should be done carefully and gently, as it is easy to traumatize the thin-walled viscera.

The spleen is too small to be palpable and the liver is not felt routinely during abdominal palpation. Both kidneys can usually be identified. They are mobile structures. The left kidney lies caudally to the right kidney, which lies close to the rib cage. The stomach cannot be palpated in the normal rabbit. In some cases of gastric stasis, the stomach may be felt as a hard round mass just behind the ribs on the right-hand side. Intestinal obstruction causes gross distension of the stomach with gas and liquid (see Box 1.8). The caecum may be felt as a soft pliable structure in the ventral abdomen. The size and contents vary with diet and time of day. A full caecum may be felt as a doughy mass. Caecal impactions are felt as a hard sausage-like structure. Gas distension of the caecum can result from gastrointestinal hypomotility. In these cases, the caecum may not be differentiated from other organs or can be felt as a gas-filled structure that makes a sloshing sound when palpated. The bladder can be felt in the caudoventral abdomen. It should be palpated with care as it can rupture easily, especially if the urethra is partially obstructed by a urolith. Rabbits suffering from urolithiasis or cystitis often strain in response to bladder palpation and may void small amounts of urine on to the consulting table.

Gut sounds are not always evident in the healthy rabbit; it is worth listening for at least a minute on each side to properly assess this and give the guts a chance to move during auscultation. Absence of gut sounds does not signify intestinal stasis. Tinkling sounds may be heard in distended gas-filled organs such as the caecum or stomach, indicating a gas/fluid interface.

The uterus lies in the ventral abdomen, caudal to the caecum. The broad ligament may contain large quantities of fat that can be seen radiographically. An enlarged uterus due to pregnancy or neoplasia may be felt. Twelve- to 14-day fetuses can be felt as olive-sized masses in the caudal abdomen. As the uterus enlarges it falls forward into the abdomen.

Abdominal masses may be neoplastic. Common neoplasms include uterine adenocarcinoma, lymphomas, liver and kidney tumours. Abdominal abscesses can occur, secondary to penetrating trauma or previous surgical intervention. Areas of fat necrosis may be felt as hard lumps, especially in the remnants of the broad ligament in spayed females.

The limbs, vertebral column and rib cage can be checked for any obvious fractures or deformities.

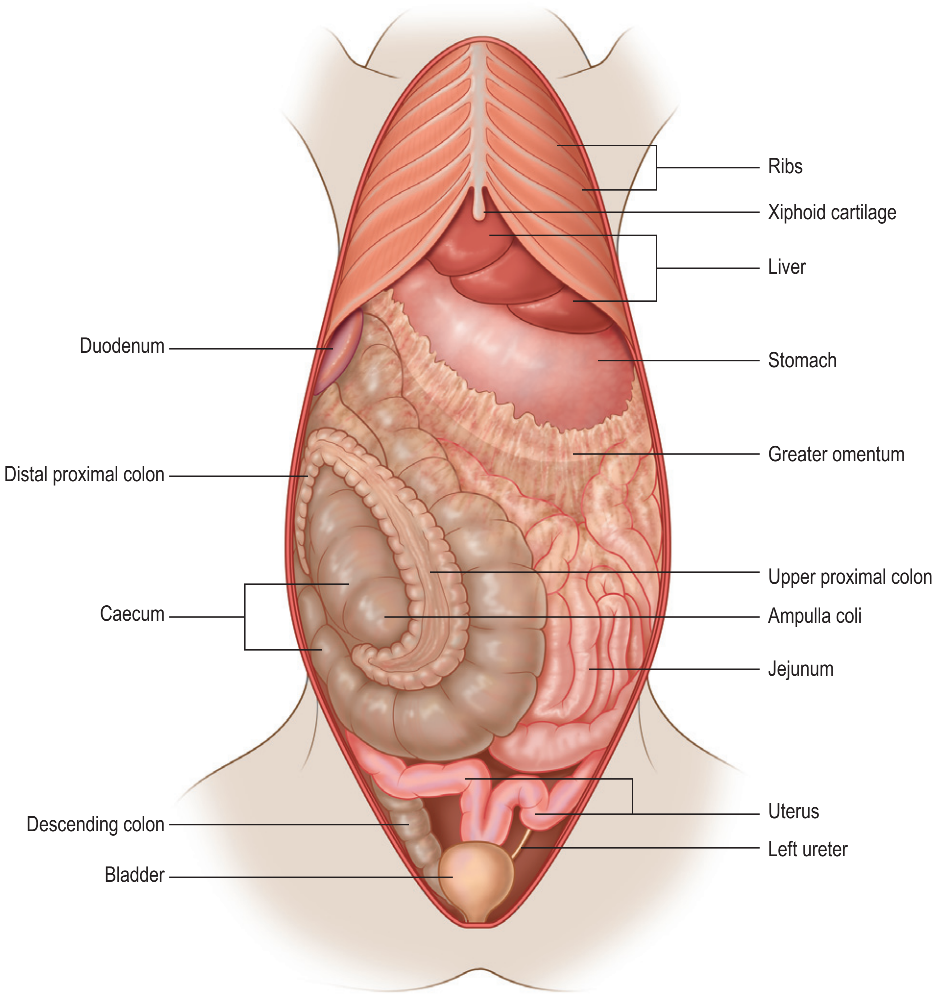

Figure 1.13 Topographic view of the abdomen, ventral view. The ventral abdominal wall has been resected to expose the viscera that are illustrated *in situ.* The diagram was drawn from post-mortem specimens using Barone *et al.* (1973) as a reference source.

1.6.2.9 Auscultation and assessment of respiration

Rabbits have a small rib cage and thoracic cavity. The diaphragm, rather than the intercostal muscles, brings about respiratory movement. Breathing takes place through the nose. Rabbits do not mouth breathe or pant effectively. Respiratory rate varies between 32 and 60 breaths per minute. Increased respiratory rates are indicative of stress, pain, hyperthermia, infection or respiratory disease. Metabolic acidosis can also be manifested by an increased respiratory rate. On occasion some rabbits appear to have a very rapid respiratory rate without significant disease. This circumstance is known as 'paradoxical breathing' and is related to reduced vagal tone causing increased

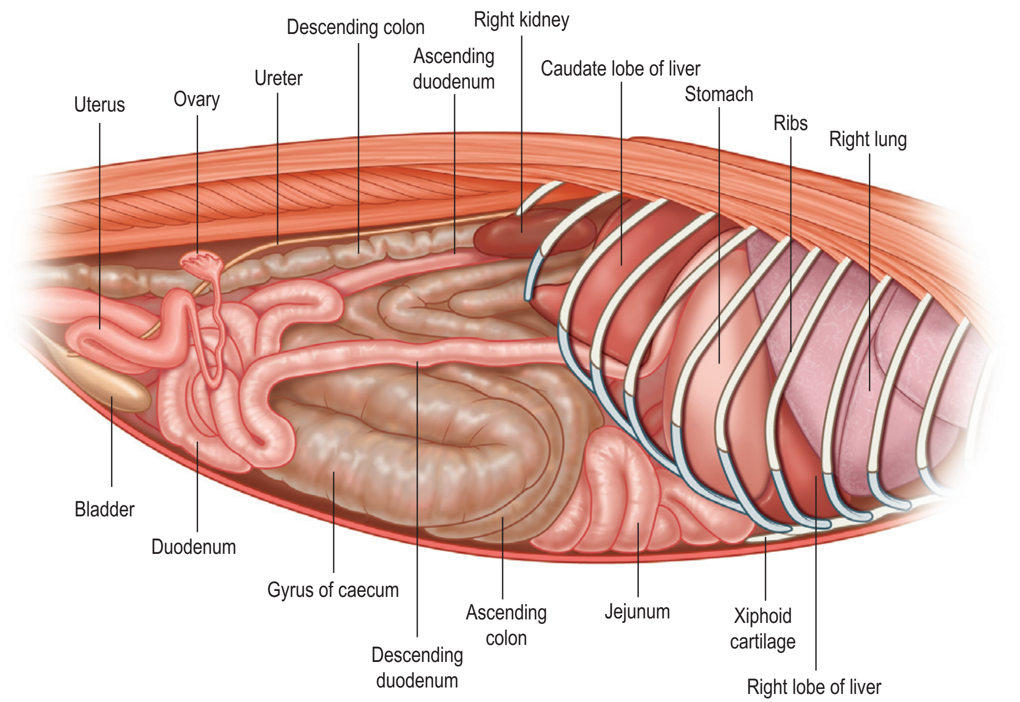

Figure 1.14 Topographic view of the abdomen, right lateral view. The abdominal viscera are illustrated *in situ* after resection of the right abdominal wall. The diagram was drawn from post-mortem specimens using Barone *et al.* (1973) as a reference source.

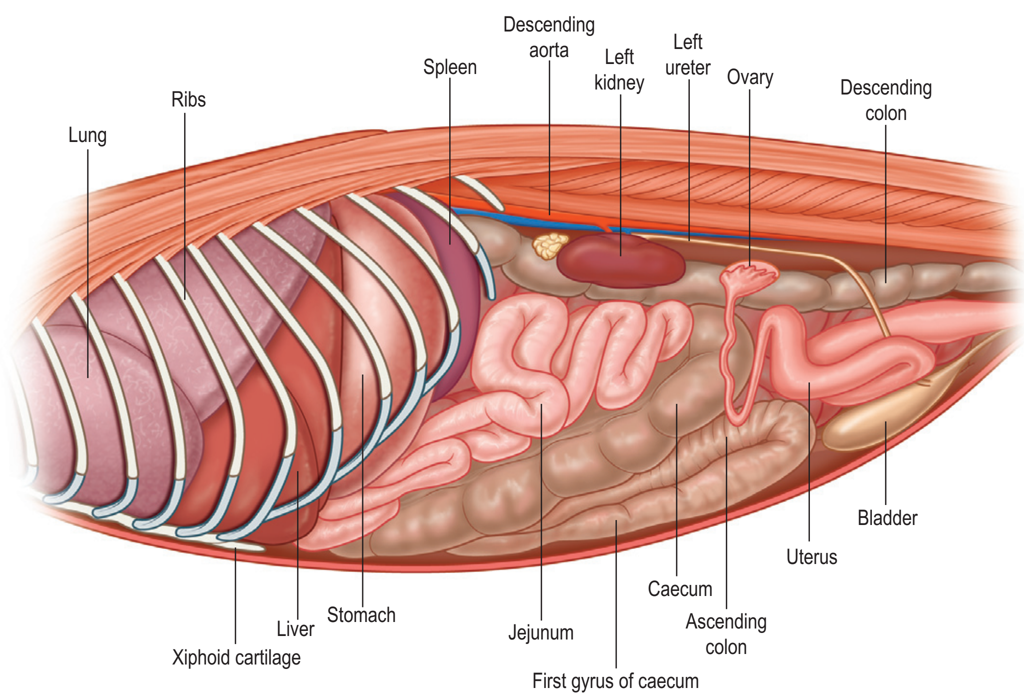

Figure 1.15 Topographic view of the abdomen, left lateral view. The abdominal viscera are illustrated *in situ* after resection of the left abdominal wall. The reproductive tract is not illustrated. The diagram was drawn from post-mortem specimens using Barone *et al.* (1973) as a reference source.

diaphragmatic activity and 'augmented' breaths (Whipp, 1987). Upper respiratory tract disease is common in rabbits (see Section 11.2.3). Occlusion of the nasal passage results in increased respiratory effort and may be accompanied by various snuffles, squeaks and whistles. Some short-nosed breeds always make this type of noise. The differentiation between upper and lower airway disease can be made by observation and auscultation and examination of the nose.

An increase in respiratory rate is brought about by an increase in diaphragmatic rather than intercostal movement and can give the impression of dyspnoea. Dyspnoea is manifested by cyanosis, mouth breathing, depression and distress and may be accompanied by an audible respiratory noise. Abnormal, absent or muffled lung sounds may be heard during thoracic auscultation of rabbits with lower respiratory disease. Chronic lung disease cannot be ruled out by auscultation of the chest, although use of a suitably sized paediatric stethoscope can be helpful as it allows more precise examination. Severe lung changes are a frequent incidental finding during post-mortem examination. Abnormal heart sounds can sometimes be detected, although cardiac disease is rare in rabbits in comparison with lung disease. The list of differential diagnoses of dyspnoea is similar to other species.

Key points 1.15 Abdominal palpation

- Care should be taken during abdominal palpation as the thin-walled viscera are easily traumatized.
- Both kidneys can be felt during routine abdominal palpation.
- The spleen is too small to be palpated.
- The stomach and liver are not usually palpable.
- The caecum may be palpated depending on nature of contents and time of day.
- Palpating the bladder can elicit straining and urination in rabbits with cystitis.
- The uterus cannot be palpated in the non-gravid, healthy animal. During pregnancy it may be felt in the ventral abdomen.

Normal heart rate varies between 130 and 325 bpm, which is too fast to differentiate heart sounds. Stress increases the heart rate markedly. A pulse can usually be felt in the central artery of the ear (Figure 1.16). A femoral pulse can sometimes be found, although it is not as easy to locate in the rabbit as in the dog or cat.

Key points 1.16 Thoracic auscultation

- The thoracic cavity of the rabbit is small.
- Breathing takes place through the nose.
- Respiration is brought about by movement of the diaphragm rather than the intercostal muscles.
- The lung field extends from the thoracic inlet to the 12th rib but is most easily heard between ribs 6 and 12 dorsally. Breathing should be quiet and crackles and wheezes are always abnormal.
- The heart in rabbits is small relative to body mass (0.2% of body mass compared with 0.76% in dogs); both sides of the heart should be auscultated. The first heart sound corresponds to closure of the atrioventricular valves, the second to closure of the pulmonic and aortic valves. Gallop rhythms are always abnormal and indicate structural heart disease.
- A pulse may be felt in the central artery of the ear.

1.6.2.10 Examination of the face, head and oral cavity

Some rabbits tolerate examination of the head and oral cavity with minimal restraint. Others jump and attempt to escape, so wrapping these individuals in a towel is safer. Sedation should be considered if the rabbit is very intolerant as it will almost always be safer and less stressful for everyone involved.Visual inspection of the external ear canal may reveal the typical crusty exudate associated with *Psoroptes cuniculi* infestation or the waxy exudate often encountered, especially in lop-eared breeds. There is a blind ending section of the external ear canal separated by a cartilaginous plate or

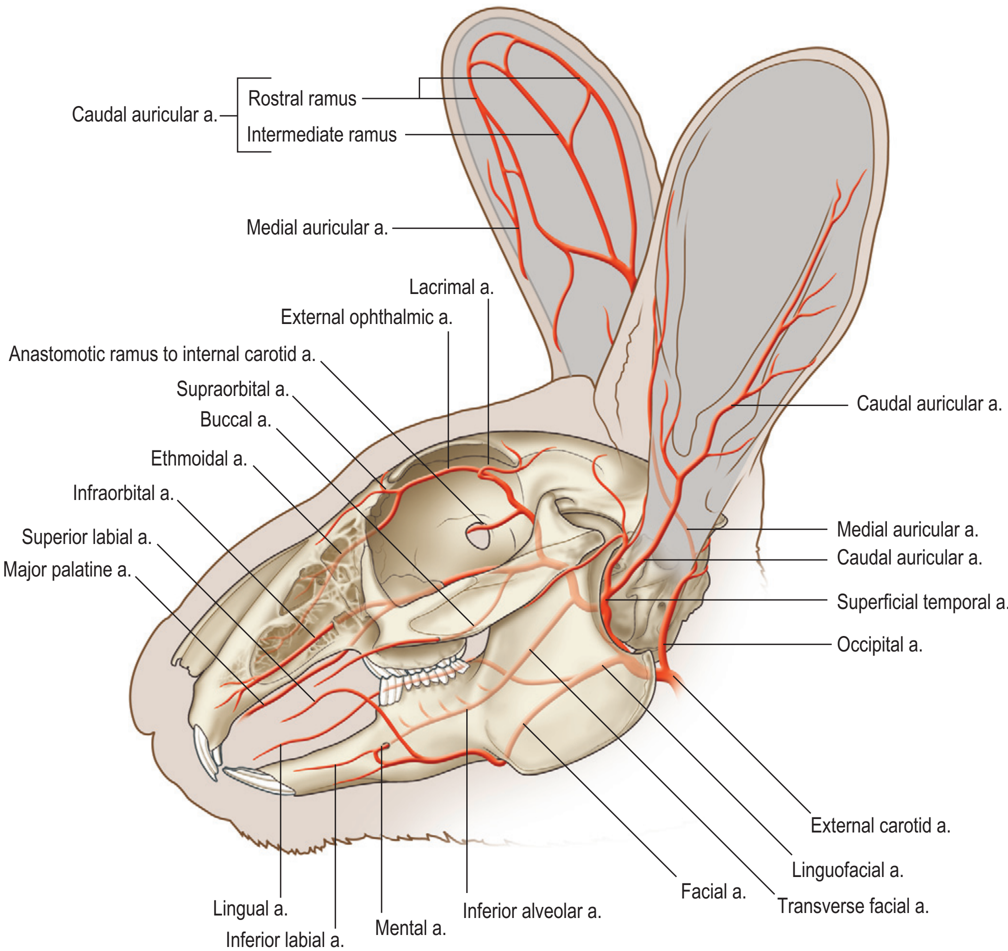

Figure 1.16 Arteries of the head. The arteries of the cheek may be encountered during surgery on facial abscesses in rabbits. The buccal and lingual arteries are in close proximity with the cheek teeth and can be inadvertently punctured during tooth trimming. The arteries of the ear are also illustrated. A pulse can often be detected by placing a finger on the intermediate ramus of caudal auricular (central) artery of the ear.

tragus. Examination of both sides of the tragus can be performed with an otoscope. Otoscopic visualization of the eardrum is difficult due to the length of the auditory canal and the presence of wax and debris. Using a narrow cone and gently directing it around the bend in the ear canal gives the best view; however, this technique can be uncomfortable.

The skin around the face and head is normally clean and free from debris. Sometimes it is a bonded companion, and not the patient itself, that keeps the head groomed and cleaned. The presence of small scabs in the fur is indicative of a rabbit not grooming perhaps due to pain around the face. Saliva staining on the chin or around the mouth is usually indicative of dental disease causing pain on swallowing or pus present in the oral cavity causing a bad taste. Moist dermatitis of deep skin folds under the chin occurs in some loose-skinned breeds. Epiphora causes tear staining and matted fur on the face beneath the medial canthus of the eye, which can lead to superficial pyoderma in that area. Occasionally this is associated with spurs on the upper premolars or molar teeth growing into the mucosa inside the cheek. Grooming the skin over the area becomes painful. The large ears of some lop-eared rabbits can sometimes impinge on the eye and surrounding structures causing trauma and irritation.

The head should be palpated and carefully examined for the presence of abscesses on the side of the face, under the masseter muscles or along the bottom of the jaw. One side of the face should be compared with the other and any asymmetry noted. It may be useful to view the head from above as soft tissue asymmetry may be subtle. Pain or bony swellings associated with elongated tooth roots can be detected by palpation of the ventral border of the mandible and the zygomatic area (see Section 5.7). The nares should be inspected for signs of nasal discharge.

The incisors are easily examined by retracting the lips. The molars and premolars can be visualized with the aid of an otoscope or vaginal speculum. With practice, normal and abnormal cheek teeth can be differentiated by this technique, although it is not always possible to determine the cause of an abnormality. Dental abnormalities can be missed on conscious examination alone as soft tissues impinge on the view. Rabbits that resent oral inspection often have problems with their cheek teeth. Excessive saliva, halitosis, presence of food, blood or pus is indicative of dental problems and general anaesthesia and preferably radiography is necessary to examine the mouth thoroughly.

1.6.2.11 Examination of the eyes

Exophthalmos or glaucoma can be seen by comparing the size and shape of the eyes. Fear can cause the eyes to bulge out of the sockets due to engorgement of the orbital vascular sinus (see Figure 1.17) (Eglitis, 1964). Retrobulbar abscesses, tumours or cysts can cause a unilateral exophthalmos. Thymoma or other mass lesions affecting venous return in the chest can also contribute to exophthalmos, which is usually bilateral (Vernau *et al.*, 1995). The eyelids should be examined for evidence of wounds, ectropion, entropion, meibomian cysts or myxomatosis. The eyes should be clean and free from purulent discharge. The rectus dorsalis muscle can be seen attached to the dorsal sclera when the upper eyelid is retracted. Applying pressure to the area just below the medial canthus of the eye may squeeze pus out of the opening of the nasolacrimal duct in cases with purulent dacrocystitis.

Key Points 1.17 Examination of the head and oral cavity

- Visually inspect the head for ocular and nasal discharges, areas of asymmetry and mass lesions.
- Examine the ears visually and using an otoscope. Wax and debris may obscure the view, particularly in lop-eared breeds. The tragus, a blind-ending section of the external ear, must also be carefully examined. Pus is a relatively common finding in the external ears of pet rabbits. It may not be associated with inflammation or clinical signs.
- Examine the eyes and surrounding structures visually and using an ophthalmoscope. Schirmer tear tests, fluoroscein dyes and ultrasonography are useful adjuncts to basic examination.
- Palpate the skull, paying particular attention to the ventral mandibles and the zygomatic area. Gently manipulate the lower jaw to assess its range of motion.
- The incisors can be examined by moving the upper lips sideways and back. Make certain all teeth are present. Pay attention to the occlusion and evidence of damage to the tooth enamel surface.
- The cheek teeth can be examined using an otoscope. This is inserted into the rabbit's mouth via the diastema and is used to visualize the buccal, occlusal and lingual surfaces of the cheek teeth. The view is limited by the oral soft tissues, saliva and movements of the patient. It is a good initial examination tool but definitve oral examination must be undertaken with the rabbit anaesthetized.

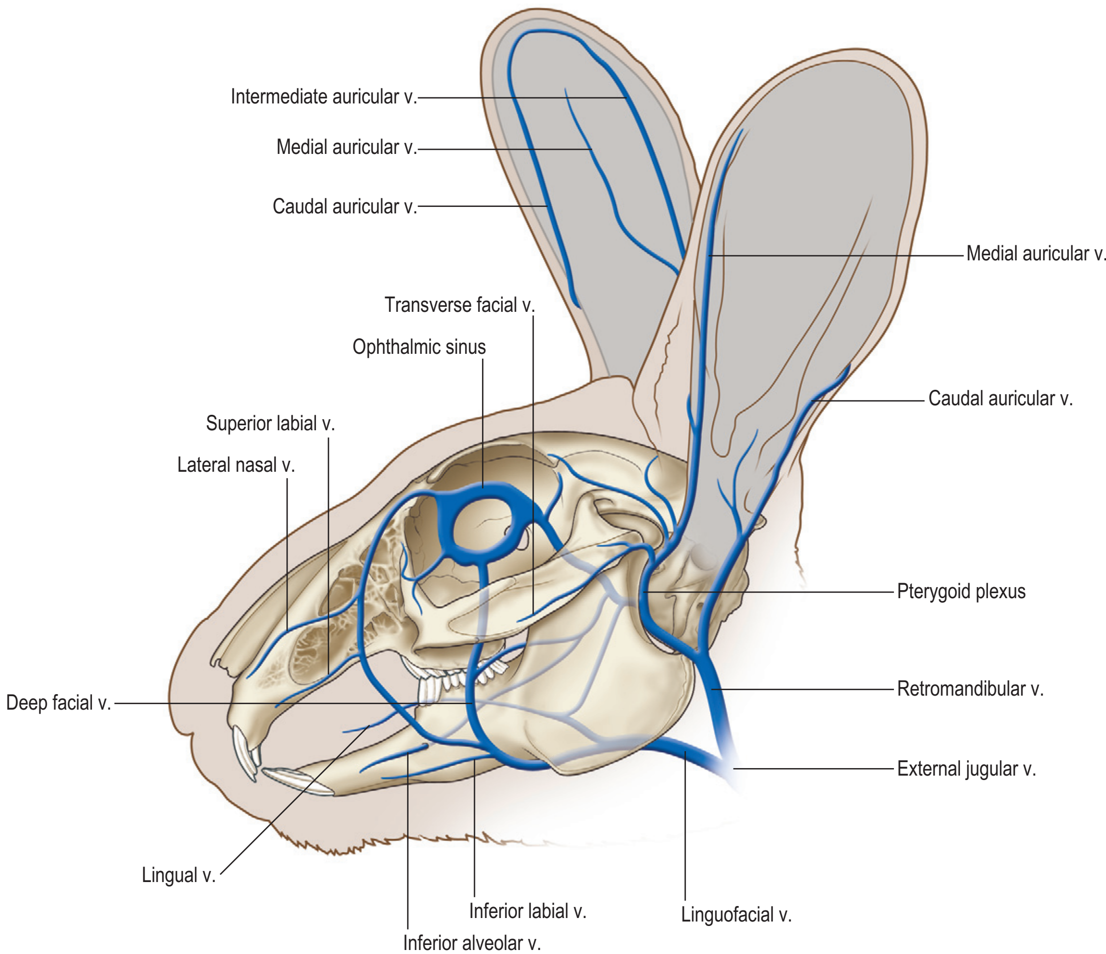

Figure 1.17 Veins of the head. The veins of the head include the marginal ear vein that is a convenient site for venepuncture. The large orbital venous sinus is also illustrated. This sinus may be encountered during enucleation of the eye and can be a source of serious haemorrhage.

Nystagmus may be observed by watching the movement of the eye for a few seconds. Occasionally slow nystagmus can be seen in pet rabbits at rest in association with nodding of the head. Affected individuals are usually seropositive for *Encephalitozoon cuniculi*.

Direct illumination of the eye may reveal pathological conditions of the cornea and uveal tract. Evidence of previous lens rupture and cataract formation is associated with *Encephalitozoon cuniculi*. Local anaesthesia with topical proxymetacaine drops facilitates examination of the cornea and third eyelid. The application of fluorescein will reveal corneal ulceration. Fluoroscein can also be useful to evaluate the drainage of the tear duct. In a normal rabbit the dye will not overflow onto the face and should appear at the external nares within a minute or so of application (although it takes longer to appear than it does in dogs and cats). Where the tear duct is blocked the dye will flow onto the face and fail to appear at the ispsilateral nostril although it may occasionally appear at the contralateral one, suggesting that in some rabbits there is a connection between the tear ducts. The Schirmer tear test has been evaluated in rabbits. The test paper is inserted into the lower conjunctival fold in the lateral third of the eyelid and is held in place for 1 minute. The amount of wetness is measured in millimetres. Topical anaesthesia is not used. Normal values range from 0 to 11.22 mm/min, with a mean of 5.30 + 2.96 having been determined. Low values are of doubtful significance (Abrams *et al.*, 1990), although absence of tear production can be a sign of dysautonomia. A low Schirmer tear test result indicates keratoconjunctivitis sicca in other species but this condition has not been reported to occur naturally in rabbits. Impaired tear drainage due to nasolacrimal duct disease can result in high Schirmer tear test results. Excessive tear production can also be associated with corneal irritation due to conjunctivitis, corneal abrasions, ulcerations or foreign bodies. Orbital pain may be due to uveitis, glaucoma or retrobulbar disease.

Ophthalmoscopic examination of the fundus and internal structures of the eye requires mydriasis. Rabbits produce atropine esterase, which can interfere with topical atropine eye drops in some individuals. One drop each of 1% atropine and 10% phenylephrine, three to four times during a 15-minute period, has been recommended for rabbits (Kern, 1995) or 0.5 or 1% tropicamide can be used. The optic disc lies above the horizontal midline of the eye and it is necessary to look upward into the eye with an ophthalmoscope to view the optic disc, which has a deep natural depression (see Section 9.3). The retina is merangiotic (partially vascularized).

1.7 Reproduction and neutering

1.7.1 Oestrus cycle

Rabbits are well known for their ability to reproduce quickly. Puberty occurs at 4–9 months (or when 70–75% of mature bodyweight is reached) with smaller breeds maturing earlier than larger breeds. Like the cat and the ferret, rabbits are induced ovulators. Although they do not show a regular oestrus cycle, they do vary in receptivity and a cyclic rhythm exists. Follicle stimulating hormone (FSH) stimulates ovarian follicles to develop and produce oestrogens that cause the female to be receptive. Follicular development occurs in waves with 5 to 10 follicles on each ovary being at the same stage of development at any one time. When the follicles reach maturity they produce oestrogen for about 12–14 days. If ovulation has not occurred during this period, the follicles degenerate with a corresponding reduction in oestrogen level and sexual receptivity. After about 4 days a new wave of follicles begins to produce oestrogen and the doe becomes receptive again. Many factors influence this cyclic rhythm including nutrition, light, temperature, sexual stimulation and individual variation. In general, the receptive period lasts 14–16 days with a period of non-receptivity for 1–2 days (Patton, 1994). This is slightly longer than the oestrogen dominant phase, and a good rule of thumb is that a doe will usually be receptive while the vulva is red and swollen. Mating stimulates ovulation approximately 10 hours post-coitus (Harkness, 1987). Ovulation can also be induced by proximity of an entire male, mechanical stimulation of the vagina or by the act of being mounted by another female. Some indiviuduals will continue to be sexually receptive throughout pregnancy, although superfoetation (maintenance of two pregnancies at different stages) does not occur.

Key Points 1.18 Social and reproductive behaviour

- Domestic rabbits are descended from the European rabbit, *Oryctolagus cuniculus*, and retain many behavioural characteristics of their wild ancestors.
- Wild rabbits live in groups of 6–8 with a well-defined social hierarchy. Males fight for dominance and females aggressively defend their nesting sites.
- Wild rabbits seldom become tame in captivity even if they are hand-reared.
- Rabbits are induced ovulators without a defined oestrus cycle. Females show a cyclic rhythm of sexual receptivity.

Key Points 1.18 Social and reproductive behaviour—cont'd

- Pseudopregnancy is the result of ovulation without fertilization. Ovulation can be stimulated in the absence of mating by the close proximity of a male, mechanical stimulation or mounting by another female.
- Lactating does remain in the vicinity of their nest and defend it but only return once or twice daily to suckle the young.

Biological data are summarized in Box 1.9.

1.7.2 Mating and gestation

Rabbits are induced ovulators without a defined oestrus cycle, although females vary in sexual receptivity and a cyclic rhythm exists (see previous section). The breeding season usually runs from January to October and is stimulated by increasing photoperiod. Full sexual receptivity occurs every 18 days and is manifested by restlessness and increased chin rubbing. Does are fertile immediately after kindling, especially during the summer months. Breeders usually take females to the buck for mating rather than vice versa as they can be territorial and attack the buck if he is put in her hutch. Sometimes the two are introduced on neutral territory. In general, females are mated for the first time at approximately 5 months old and are not bred from over the age of 3 years (Sandford, 1996). Mating takes place within a few minutes and can be accompanied by a scream from either party, which is deemed to be normal. Mating may be repeated after a couple of hours to improve the conception rate. Artificial insemination is a recognized technique in rabbit breeding. Pregnancy can be detected by abdominal palpation. The best time for pregnancy diagnosis is 10–14 days after mating when the fetal units can be felt as olive-sized masses. Fetal resorption can take place up to 20 days post-coitus. Mammary development occurs

Box 1.9 Basic biological data for rabbits

Physiological data

Life span:	6–13 years
Urine volume:	20–250 mL/kg/24 h. Usually about 130 mL/kg/24 h
Water intake:	50–100 mL/kg/24 h
Optimum environmental temperature:	15–20°C (65–70°F)
Rectal temperature:	38.5–40°C (101.3–104°F)
Subnormal:	38.0°C (100.4°F)
Raised:	40.6°C (105°F)
Heart rate:	130–325 bpm
Respiratory rate:	32–60 bpm
Erythrocyte life span:	50 days
Blood volume:	55–65 mL/kg
Tidal volume:	20 ml (4–6 mL/kg)
Gastro intestinal transit time:	4–5 h
Intraocular pressure:	5–23 mmHg

Reproductive data

Puberty:	4–5 months in small breeds 5–8 months in large breeds
Descent of testicles:	10–12 weeks
Age at which to neuter:	>3 months for males; >5 months for females
Interval between castration and infertility:	4 weeks
Pregnancy diagnosis:	Palpation: 10–12 days Radiologically after 11 days Ultrasonographically day 8 onwards
Gestation:	30–32 days
Litter size:	Average 5–8
Milk composition:	13–15% protein, 10–12% fat and 2% carbohydrate
Birth weight:	40–100 g
Eyes open:	7 days
Weaning:	4–6 weeks

in late pregnancy. Radiographically, pregnancy can be detected after the 11th day. Real-time ultrasound can be used for early pregnancy diagnosis, being reliable from day 8 onwards (Ypsilantis and Saratsis, 1999). Some does remain sexually receptive during pregnancy and will continue to be mated by a male companion; however, superfoetation does not occur. Does can be mated soon after giving birth and may be lactating and pregnant at the same time.

Gestation is maintained by progesterone that is produced exclusively by the ovarian *corpora lutea*. In the absence of fetuses, pseudopregnancy can occur after ovulation and is maintained by corpora lutea that degrade after approximately 17 days (Fekete and Huszenicza, 1993). In the wild, unfavourable winter conditions or lack of food suppress follicular activity. Gestation takes 31–32 days, with litter sizes on average being five to eight; larger breeds generally have larger litters (Sandford, 1996). It is possible for a doe to have six litters in a year and produce 40 to 50 offspring. During late pregnancy the doe may be seen carrying bedding material into her chosen nesting site. The nest is built from hay, straw or other bedding material. The quality of the nest varies between individual does and has a strong influence on the survival of the young. The doe will defend her chosen nesting site against potential intruders, especially if she is pregnant or lactating and can become aggressive towards owners, other rabbits or pets. Hair is pulled from the hip, dewlap and mammary glands to line the nest. She may consume less food at this point and should be tempted to eat, as pregnancy toxaemia is a risk during this period. Otherwise, the doe should be left undisturbed.

1.7.3 Parturition

Parturition usually takes place in the morning and is completed in less than half an hour although, occasionally, young can be born hours or even days apart (Adams, 1987). The young are altricial and born bald, blind and helpless. Most passive immunity is obtained before birth, although some antibodies are present in the colostrum (Brewer and Cruise, 1994). When the entire litter has been born, the doe pulls more fur from her body to cover the litter in its nest. Does are particularly susceptible to disturbance in the first few days after parturition and may cannibalize the young. Inexperienced does sometimes mutilate them. The legs or ears may be attacked or the skin stripped over the neck, thorax or abdomen. Cannibalization and mutilation are most likely to take place on the day of parturition and may be an extension of eating the placenta. Sometimes young rabbits are born outside the nest or the doe rejects them. These kits will die from hypothermia unless they are warmed up and returned to the nest. The doe will usually accept them and the chances of survival are far greater if the kit is reared by its natural mother rather than being hand-reared by a human. It is advisable to remove other rabbits from the hutch during late pregnancy. Female companions can cannibalize the young and entire males will mate the doe within hours of her giving birth. Females can lactate and be pregnant at the same time and have a second litter within a few weeks of the first.

1.7.4 Lactation and maternal care

The doe stays in the vicinity of the nest but only feeds the young once or twice daily, taking 2–5 minutes each time, during which a baby rabbit can drink 20% of its bodyweight (Donnelly, 1997). Owners often think the young have been deserted and need reassurance that it is normal for the mother to be out of the nest and that she may be particularly aggressive and protective during this period.

In the wild, although the doe remains in close vicinity of the nest, she does not groom the young or keep them warm. Nests are hidden, well insulated and secure. The babies drink sufficient milk to last 24 h. It is possible for baby rabbits to survive for more than 24-h intervals between feeds, which explains why females can rear litters that exceed their number of nipples (Lang, 1981b). Suckling normally takes place in the early morning and, if the doe does return to the nest to feed the young for a second time, then it is usually in the first few days after giving birth. The baby rabbits spend most of the day buried in the warmest part of the nest, tightly grouped together conserving heat and energy. After about

22 h, the whole group becomes active and makes its way to the surface (McBride, 1988). When the mother arrives, she stands over the babies which suckle, changing nipples and position approximately every 30 seconds. After about 3 minutes, the doe leaves the nest and the babies urinate on the surface before digging themselves deep into the bedding to sleep for another 22 h. Young rabbits are totally dependent on milk until day 10. They are usually eating small amounts of solid food by day 15 (Kraus *et al.*, 1984) and start to leave the nest and be weaned at about 25 days of age.

The glucose reserve of neonatal rabbits lasts approximately 6 h postpartum. Hypoglycaemia results in rapid ketosis and death (Kraus *et al.*, 1984). Passive immunity is obtained through the placenta, although there is some evidence that neonates absorb antibodies from their intestine in the first few hours after birth (Brewer and Cruise, 1994). Rabbit milk has low lactose content, is concentrated and is of high nutritive value, containing 13–15% protein, 10–12% fat and 2% carbohydrate. The composition changes towards the end of lactation when protein and fat levels increase.

Rabbit owners are usually unaware of the natural lack of maternal behaviour by rabbits and become convinced that a nest of babies has been deserted. Constant interference and 'checking to see if they are alright' increases the likelihood of the mother cannibalizing the young in the first few days. There is also a misconception that all baby animals must be fed every 2–3 h, even during the night. If owners are concerned, the nest can be checked once a day and if the babies are warm, asleep and unwrinkled then they are being fed. Baby rabbits that are not being fed will be restless and crawling around on the surface of the nest. They take on a wrinkled appearance due to dehydration. It is possible to cross-foster orphaned rabbits to another lactating doe. It is not necessary to use any method for destroying the scent of the natural mother or human hand. Females do not make any distinction of young, even if they are of different colours or sizes (Cheeke *et al.*, 1982). Ideally, older rabbits should be introduced to a younger litter. The fostered babies should be placed at the bottom of the nest with the natural kits on top.

1.7.5 Rearing orphans

Abandoned or orphaned wild or domestic rabbits can be hand-reared, although the mortality rate is high. Baby rabbits can be fed on powdered cat milk replacers; however, these are often less calorie dense, and much higher in carbohydrate than rabbit milk. Johnson-Delaney (1996a) advocated the addition of egg yolk to milk replacer (in this instance Esbilac) in order to increase the fat and protein levels. They will drink 2–30 mL of milk per feed, depending on how old they are. Baby rabbits should be fed when they are restless. Milk replacers are a nutritional compromise and do not match the composition of rabbit milk. Therefore orphan rabbits may need feeding two to three times daily, but care should be taken not to overfeed or force-feed them. Holding newborn rabbits on their backs simulates the natural nursing position. Hypothermic or moribund rabbits can be given fluids or milk replacers by stomach tube to correct hypoglycaemia. The babies should be kept warm and dry in a quiet place with suitable bedding material in which to burrow. Shredded tissue paper or kitchen roll is satisfactory for making a nest that can be put in a hay-lined cardboard box and placed in a warm environment such as an airing cupboard.

Most suckling animals are stimulated to urinate and defecate by the mother licking the perineum and lower abdomen. People that have successfully hand-reared orphans usually advise that baby rabbits should also be stimulated by rubbing the genital region after each feed. Female rabbits do not stay with their young and do not groom them, so it may not be necessary to stimulate young rabbits in this way. However, it can do no harm and is therefore advisable.

Mortality can occur from aspiration pneumonia due to inhalation of milk replacer. A syringe with a teat or a small amount of tubing cut from a giving set is a satisfactory method of feeding orphans. Healthy babies suck the milk out of the syringe. Squirting milk into the mouth carries a risk of choking the rabbit. Enteritis is a potentially lethal complication of hand-rearing. Rabbits are unusual among young animals in having very few micro-organisms in the stomach and small intestine while suckling (Lang, 1981b). An antimicrobial fatty acid or 'milk oil' is present in the suckling rabbit. It is produced by an enzymatic reaction in the doe's milk that takes place in the suckling rabbit's stomach (Brooks, 1997). This milk oil controls the gastrointestinal microbial contents of suckling rabbits and protects them from enteric infection. Orphan rabbits that are fed on milk from other species do not develop this antimicrobial factor and are therefore more susceptible to bacterial infections introduced during feeding. It is important that boiled water and sterile syringes and feeding tubes are used to feed orphans and that each feed is made up just prior to being given. Overfeeding can cause digestive upsets. In general, it is preferable to underfeed than overfeed. Small babies can soon make up their weight once they are weaned and able to digest solid food.

Baby rabbits can be offered hay and fresh food from about 18 days of age. Caecotrophs collected from healthy adults may be fed during weaning to colonize the intestinal tract with healthy bacteria and protozoa, a practice known as transfaunation. It may be necessary to place an Elizabethan collar on an adult rabbit for a day or two to prevent them from eating the caecotrophs, so they can be harvested. Weaning is a danger period for any young rabbit, especially orphans. Diarrhoea can result from colonization of the gut by pathogenic bacteria. Probiotics can be useful in this period, especially if no caecotrophs are available.

1.7.6 Pseudopregnancy

Pseudopregnancy mimics true pregnancy. Pseudopregnant does pull fur from their abdomen and chest, make a nest, develop mammary glands and aggressively defend their nesting site. Pseudopregnancy lasts for 16–18 days, rather than the 31–32 days of true pregnancy. Because rabbits ovulate in response to sexual stimulation by another rabbit, proximity of a male or mating behaviour between two females housed together can stimulate ovulation and result in pseudopregnancy.

Key Points 1.19 Reproductive data

- The breeding seasons runs from January to October.
- The female will be receptive approximately every 18 days, and cycling starts at around 5 months of age.
- Males are fertile from around 4 months of age, depending on body size and breed.
- Pregnancy diagnosis:
  1. Manual palpation, day 10–14
  2. Radiography, day 11 onwards
  3. Ultrasonography, day 8 onwards
- Fetal resorption can occur up to 20 days post-coitus. Thereafter abortion will occur should the fetuses die.
- The gestation period is 31–32 days,
- Pseudopregnancy occurs after a non-fertile mating or after being mounted by a female. It lasts for around 16 days and is usually self-limiting.
- Parturition often occurs in the morning and is over rapidly. Dystocia is rare. Occasionally babies from the same doe can be born several hours to days apart and remain viable.

Key Points 1.20 Hand-rearing orphans

- Maternal care is limited in rabbits, and a doe suckles her young for 2–5 minutes twice daily.
- Kits that are asleep within the nest and do not have wrinkled skin have probably not been abandoned and should be left alone.
- Kits that are restless and at the top of the nest and whose skin is wrinkled and dry may need to be hand-reared.
- Kitten milk replacer can be used as a substitute; however, it is higher in carbohydrates than rabbit milk. Egg yolk can be added to increase the amount of fat and protein given.
- Kits should be fed several times a day, in response to increase in activity. A tiny teat or a measure of

Key Points 1.20 Hand-rearing orphans—cont'd

soft drip tubing attached to a syringe can be used. Kits should be regularly weighed to assess weight gains/losses.

- The stomach of baby rabbits is very susceptible to infection when being hand-reared. The addition of probiotics to the rearing milk should be considered.
- Baby rabbits should be offered access to hay and small pellets from day 10 onwards.
- Caecotrophs from a healthy adult rabbit can be used to colonize the gut with suitable bacteria at the time of weaning.

1.7.7 Advice on neutering

Neutering modifies sexual behaviour in rabbits but may not abolish it altogether. Increasing day-length can trigger social, sexual and even aggressive actions in neutered rabbits, although the behaviour is usually mild. In the spring, does may dig out a new burrow and males may have minor skirmishes. Copulatory actions can persist after neutering, as part of dominance or excitement behaviour. It is beneficial for rabbits to be neutered for similar reasons to the dog or cat. Neutering prevents unwanted pregnancies and pseudopregnancies and permits both sexes to be housed together. Male aggression is reduced or abolished, so fight and bite wounds are minimized. Neutering also modifies scent marking by spraying urine or depositing faeces. Female reproductive disorders such as uterine or mammary neoplasia and endometritis occur frequently in the middle-aged doe. Spaying is indicated to prevent these diseases. Aggressive behaviour towards owners can be modified by neutering, especially if it is hormone related. Male rabbits make better pets if they are castrated. Entire bucks can attempt to mate their owner's legs or mount toys, mats or other household objects.

Although rabbits can be spayed or castrated at any age, approximately 5 months of age is the best time for both sexes. It is advisable to spay females after puberty but before maturity when large amounts of abdominal fat can complicate the surgery. Prepubescent females can be more difficult to spay because of their tiny uterus and ovaries that can be hard to locate; however, the surgical incision can be very small, and if haemoclips or a ligasure device are used for haemostasis then surgery is extremely rapid. The benefits of a quick surgery, a small incision and less tissue manipulation must be weighed against the difficulty in visualizing the uterus. On a cautionary note, insufficient research has been done to allow certainty that early neutering will not cause adrenal disease in rabbits as it does in ferrets. Males should be left until the testicles have descended. Motile spermatozoa appear in the ejaculate from about 4 months of age. After castration, the male can be considered sterile after a period of 5–6 weeks.

1.7.8 Leg rings

Pedigree rabbits are identified by an aluminium ring placed over the hock at 8–10 weeks of age. Some breeders use right or left legs according to the gender. Rings are purchased from the British Rabbit Council, who keep records of the numbers. Different sizes are needed for different breeds, which are denoted by a letter that prefixes the ring number. The year of birth is also recorded on the ring. These rings should be removed as they serve no purpose in the pet rabbit and can trap hair and debris beneath them. Skin necrosis and secondary infection can set in (see Figure 1.18). In severe cases, the blood supply to the foot is cut off, so the leg becomes gangrenous and has to be amputated or the rabbit euthanased. If the rings are not removed, owners must be advised to check them daily.

Ring removal may prove difficult in the conscious animal, although in calm rabbits instruments made for ring removal in birds may be safely used as long as they are cooled with water during use. Sedation or general anaesthesia is required if the ring has caused soft tissue damage or if some form of power tool is to be used to cut the ring off. Part of a wooden tongue depressor can be slipped between the ring and the leg to keep the fur out of the way and give some protection to the skin before removing the ring with a hack saw or small saw attachment on a power drill. Care is

Figure 1.18 Identification ring occluding the blood supply to the hind foot. Pedigree rabbits are identified by aluminium rings slipped over the hock when the rabbit is 8–10 weeks old. The rings are supplied by the British Rabbit Council in a range of sizes. Each ring has the year of birth and a unique number from which the rabbit can be identified. Occasionally, rabbits with identification rings are sold as pets. It is advisable to remove the rings because hair can become entrapped beneath the ring and occlude the blood supply to the foot. This rabbit was euthanased.

required to prevent the metal ring from overheating. Cotton wool soaked in water can be used periodically to cool the ring during removal.

1.8 Vaccination and preventive medicine

1.8.1 Vaccination

1.8.1.1 Myxomatosis vaccination

Myxomatosis is a common disease present in wild rabbits that can be spread to pet rabbits via insect vectors such as fleas and mosquitoes as well as by direct contact (Chapuis *et al.*, 1994; Houlihan and Lawson, 1945) (see Section 14.6.1). Those rabbits that are kept in gardens visited by wild rabbits are most at risk. Myxomatosis is a member of the poxvirus family and is almost universally fatal in unvaccinated rabbits. Outbreaks of myxomatosis occur seasonally, reaching their peak in the late summer. Historically in the UK a live vaccine (Nobivac Myxo) prepared from attenuated Shope fibroma virus grown on cell line culture has been used. Shope fibroma virus naturally affects the cottontail rabbit *Sylvilagus floridanus* that is native to North America. It is antigenically related to myxoma virus and cross-immunity occurs. Shope fibroma virus is transmissible to the European rabbit *Oryctolagus cuniculus* in which it produces localized benign fibromas. The disadvantage of this vaccine is that it is less immunogenic than attenuated myxoma virus vaccines, and the duration of immunity is short. With the introduction of a novel combined myxomatosis/viral haemorrhagic disease (VHD) vaccine, this stand-alone myxomatosis vaccine is likely to be withdrawn from sale. In other parts of Europe modified live myxoma virus vaccines have been used; however, these are known to cause immunosuppresion, which can cause significant disease problems in large rabbitries.

The new combined vaccine (Nobivax Myxo-RHD; rabbit haemorrhagic disease (RHD) is analogous to VHD) has been manufactured from a laboratory-derived attenuated strain of myxomatosis and a capsid protein from a German VHD virus. During efficacy testing 100% of vaccinated rabbits were protected from challenge with field strain myxomatosis ($n = 11$), although some developed mild pyrexia. All rabbits were also protected from challenge with VHD, and none of these rabbits demonstrated any clinical signs, while all unvaccinated rabbits died within 72 hours. All vaccinated rabbits showed a significant haemagglutination inhibition titre against VHD when compared to the naive unvaccinated rabbits. The vaccine has been shown to be safe and effective for use in farmed rabbits where there is commonly an endemic underlying respiratory disease within facilities that can become clinically apparent after use of some vaccines. The vaccine is also safe for use in dwarf breeds (Spibey *et al.*, 2012). The vaccine is licensed for use in rabbits over 6 weeks of age with a duration of immunity of 12 months. It must be given by subcutaneous injection into the scruff of the neck to healthy animals. Some individuals may show a 1- to 2-cm swelling at the injection site during the week following vaccination. These generally resolve without treatment. Nobivac Myxo-RHD should not be used in the first 14 days of pregnancy, and its safety was not tested in breeding males, so use in breeding stock is not yet supported.

1.8.1.2 Viral haemorrhagic disease

Viral haemorrhagic disease (or rabbit haemorrhagic disease) is a highly infectious lethal disease of rabbits. It is caused by a host-specific calicivirus (see Section 14.6.2). VHD virus is spread by oral, nasal and parenteral transmission and is present in urine and faeces from infected rabbits. The virus can survive for long periods outside the host. It is thought that wild birds carried infection across the channel from Europe to wild rabbits in this country. Wild hares form the wildlife reservoir in this country, carrying the virus without clinical effect. VHD may be transmitted directly from contact with wild rabbits and hares or carried on footwear and clothing. Contaminated foods, such as grass or weeds picked from areas grazed by wild rabbits, can be a source of infection. Hutches and cages that have been occupied by an infected rabbit require thorough disinfection before a new rabbit is introduced. Ideally, only vaccinated animals should be brought in to infected premises. VHD virus can survive outside the host for 10–19 months at room temperature. Exposure to 2% potassium peroxymonosulphate (Virkon) for 2 h does not inactivate the virus, although a 4% solution is effective; 1% sodium hydroxide or 10% household bleach is also an effective disinfectant (Goodly, 2001; Gorski *et al.*, 1994).

There are two vaccines against VHD available in the UK (Cylap, Fort Dodge; Lapinject, CEVA). They are both inactivated, adjuvanted virus vaccines. Rabbits over 10 weeks can be vaccinated with a single dose. It is safe to vaccinate pregnant animals with VHD vaccine. Boosters are given annually.

The whole 1 mL dose should be given subcutaneously. Inadvertent intradermal injection can result in tissue reaction (to humans as well as rabbits). After subcutaneous administration, it is advisable to massage the vaccination area thoroughly and advise the owner to do the same periodically over the next few hours. In this manner, the vaccine is dispersed in the subcutaneous tissues and is less likely to cause a reaction. Some judges penalize show rabbits that have an area of dermatitis or a scar, so it is important to make sure the owners are aware of the risk. According to the datasheet, accidental self-injection with the vaccine can cause a severe reaction in humans that could result in the loss of a finger.

1.8.1.3 Simultaneous administration of myxomatosis and VHD vaccine

It is tempting to administer both the myxomatosis and VHD vaccines during a single consultation. There are data to support the efficacy of simultaneous vaccination but no firm conclusions can be drawn because of differences in the type of vaccine.

At the present time, the manufacturers of both the myxomatosis and the VHD vaccine advise against simultaneous immunization. It is common practice to leave 2 weeks between the injections. Because both vaccines can cause a skin reaction, it is wise to vaccinate a rabbit in consistent places in order to verify to which vaccine a rabbit has reacted.

1.8.1.4 Combined myxomatosis and VHD vaccine

A novel recombinant vectored vaccine for the control of myxomatosis and VHD has been produced (Nobivac Myxo-RHD, MSD-Animal Health). This vaccine allows once-yearly vaccination with proven duration of immunity to both components. Recombinant technology has allowed insertion of a capsid protein gene from the VHD virus into a laboratory-attenuated strain of myxomatosis, giving dual immunity. This vaccine has not been associated with adverse side effects, nor has it been shown to exacerbate underlying conditions. It is considered safe for use in both young and intensively farmed animals. Occasionally small local skin reactions (plaques of thickened skin without scabs) are noted at the site of injection (1–2 cm in diameter, around 1 week post-injection); however, these resolve without treatment within a few days. There is evidence that rabbits who have been previously vaccinated with a myxoma virus-derived vaccine or who have survived myxomatosis may demonstrate a lack of response to the VHD component of this vaccine. In the UK these cases are likely to be rare as myxoma-derived vaccines are not used; however, rabbits imported from Europe may be affected. The current suggestion is to vaccinate these rabbits with another form of VHD vaccine initially.

Key Points 1.21 Vaccinations

- Pet rabbits in the UK can be vaccinated against both myxomatosis and viral haemorrhagic disease (VHD).
- Myxomatosis vaccine can be given to rabbits over 5 weeks of age. VHD vaccine is given to rabbits over 10 weeks of age.
- Myxomatosis vaccine should not be given to pregnant does. VHD vaccine can be given during pregnancy.
- VHD vaccine must be given entirely subcutaneously and dispersed by massaging the injection area thoroughly.
- It is not advisable to administer both myxomatosis and VHD vaccine at the same time. At least 2 weeks should elapse between vaccinations.
- Myxomatosis vaccine administered during late spring offers protection over the summer months when the disease is prevalent in wild rabbits.
- A novel recombinant myxomatosis/VHD vaccine is now available, giving a year-long duration of immunity against both diseases.

1.8.2 Health risks from keeping rabbits

For a healthy human, the risk of serious infectious zoonotic disease from pet rabbits is negligible. The main health risks are associated with handling the animal. Rabbits can inflict nasty bites and scratches that can become infected. Owners can develop an allergy to rabbit dander.

Parasites can be transmitted from rabbits to humans. Fleas can be found on pet rabbits, although they are not usually the rabbit flea (*Spilopsyllus cuniculi*) but the cat or dog flea (*Ctenocephalides felis* or *canis*) caught from other pets in the household. *Cheyletiella parasitovorax* is transmissible to humans who handle infested rabbits. The mite causes erythematous pruritic lesions in humans, especially on the arms. Ringworm is occasionally encountered in pet rabbits. Asymptomatic infections have been reported (Vangeel *et al.*, 2000).

Protozoal infections such as giardia (Johnson-Delaney, 1996b) can affect both rabbits and humans but transmission between species does not appear to occur. *Toxoplasma gondii* also affects both rabbits and humans but is only transmitted by eating undercooked rabbit meat. It is not transmitted through rabbit faeces. *Encephalitozoon cuniculi* has caused illness in humans but only immunocompromised individuals such as AIDS patients, or those on chemotherapy. There are isolated reports of human infections with organisms such as *Salmonella*, *Pasteurella multocida* or *Bordetella bronchiseptica* after contact with infected domestic rabbits (Gueirard *et al.*, 1995). Other zoonotic infections can occur in wild rabbits such as tularaemia (*Francisella tularensis*; Gill and Cunha, 1997), plague (*Yersinia pestis*; Cleri *et al.*, 1997) and listeriosis (*Listeria monocytogenes*; Broderson and Gluckstein, 1994).

1.9 Stress

1.9.1 Stress

The effects of stress upon rabbits are significant (see Box 1.10). Catecholamines are released in response to stress and can initiate a number of problems. In extreme cases, catecholamine release can cause heart failure and death. Stress due to overcrowding has been used to induce cardiomyopathy in laboratory rabbits (Weber and Van der Walt, 1975). This is important because travel to and handling/manipulation whilst at the veterinary surgery is intrinsically stressful to most rabbits and can result in the measurable physiological changes detailed below.

Stimulation of the sympathetic nervous system inhibits activity of the gastrointestinal tract. Gut motility is reduced, which can have a knock-on effect on caecal microflora and digestive function. Enterotoxaemia or gut stasis can result from any stressful situation. Mucoid enteropathy is associated with stressful situations such as weaning, parturition or re-homing.

Stress reduces renal blood flow in rabbits. In a study by Kaplan and Smith (1935) into the effects

Box 1.10 Stress in rabbits

Causes of stress of rabbits

- Pain and disease
- Unfamiliar surroundings
- Transport
- Rough handling
- Proximity of potential predators: dogs, cats, ferrets, birds of prey and, for wild rabbits, humans
- A dominant companion and no means of escape
- Inability to exhibit natural behaviour patterns, e.g., to forage, make a nest or interact socially
- Poor husbandry: insufficient food, water and indigestible fibre, excessively high or low environmental temperature (see Section 1.2.1 in this chapter regarding 'Five Freedoms' of animal welfare).

Effects of stress in rabbits

Many of the effects of stress are linked to the release of catecholamines or corticosteroids and can be life-threatening:

- Catecholamine release can cause heart failure and death. Stress due to overcrowding has been used to induce cardiomyopathy in laboratory rabbits.
- Stimulation of the sympathetic nervous system inhibits activity of the gastrointestinal tract. Gut motility is reduced, which can have a knock-on effect. Gut stasis, trichobezoar formation (hairballs), enterotoxaemia and mucoid enteropathy can all be linked with stress.
- Stress in rabbits causes a marked decrease in urine flow, renal plasma flow and filtration rate. Oliguria can last from 30 to 120 minutes.
- Stress can increase gastric acidity and cause gastric ulceration in rabbits.
- Stress is immunosuppressive. Rabbits suffering from dental disease have lymphocyte counts significantly lower than those of healthy rabbits.
- Stress affects carbohydrate metabolism. Handling alone can cause an increase in blood glucose to the order of 8.5 mmol/L. Blood glucose levels can be very high (20–25 mmol/L) in association with intestinal obstruction and other stressful diseases.
- Stress causes anorexia that, in combination with disruption to normal carbohydrate metabolism, can lead to hepatic lipidosis, liver failure and death.

Ways to minimize stress in rabbits undergoing veterinary treatment

- Use analgesics in any situation where the rabbit may be experiencing pain.
- Use quiet, gentle handling and sedate or anaesthetize rabbits for painful or uncomfortable procedures.
- Wrap rabbits in a towel for examination or procedures such as blood sampling.
- Keep rabbits away from the sight, sound and smell of predators, e.g., barking dogs, ferrets.
- Provide hay as bedding material for rabbits awaiting or recovering from surgery. Hay smells familiar and provides security for timid animals. It is also a source of indigestible fibre and foraging material.
- Consider hospitalizing a bonded companion with a sick rabbit.
- Minimize stressful procedures or devices, e.g., Elizabethan collars or nasogastric tubes.

of diuresis and urine flow, a single dose of 50 mL/kg of water was given to rabbits before subjecting them to unpleasant or painful stimuli. In all cases the disturbing stimuli were immediately followed by a marked decrease in urine flow, renal plasma flow and filtration rate. Oliguria was frequently severe, lasting from 30 to 120 minutes. Some rabbits died in convulsions. The control group of rabbits that were not stimulated and remained undisturbed could withstand diuresis by increasing urine flow.

Stress increases gastric acidity. Gastric ulcers are a common post-mortem finding in rabbits, especially in those that have been anorexic prior to death. In a survey of 1000 post-mortem examinations by Hinton (1980), 7.3% were found to have ulceration of the gastric mucosa that was related to the stress of the associated illness. Experimental stress ulcers have been induced in the gastric mucosa of laboratory rabbits by administering intraperitoneal injections of adrenaline (Behara *et al.*, 1980).

Stress can alter the differential white cell count in any species. Rabbits are particularly susceptible to the effects of stress. A car journey to the surgery, a period in the waiting room next to a barking dog or the excitement of handling can be reflected in the blood picture. Adrenaline and cortisol affect the distribution of lymphocytes throughout the body. Administration of exogenous adrenaline to rabbits results in redistribution of lymphocytes from spleen and bone marrow to peripheral blood, lungs and liver (Toft *et al.*, 1992a). Conversely, exogenous corticosteroid administration results in a redistribution of lymphocytes from the peripheral blood, bone marrow and spleen to the lymphatic tissue in rabbits (Toft *et al.*, 1992b). Prolonged periods of stress cause lymphopenia. Rabbits suffering from clinical symptoms of dental disease have significantly lower lymphocyte counts than healthy rabbits kept under free-range conditions (Harcourt-Brown and Baker, 2001) (see Figure 2.1).

Carbohydrate metabolism is affected by stress. Handling alone can cause an increase in blood glucose to the order of 8.5 mmol/L. Blood glucose levels can rise to 20–25 mmol/L in critically ill rabbits, such as those with an intestinal obstruction (Harcourt-Brown and Harcourt-Brown, 2012). Disruptions in carbohydrate metabolism have potentially serious consequences that can result in hepatic lipidosis, liver failure and death.

As a prey species, rabbits have many physiological and behavioural responses to adrenal hormones. The response to danger is either to 'freeze' or to jump and flee. Although the majority of pet rabbits are used to being handled by their owners and are not particularly stressed by clinical examination, there is always potential for them to suddenly spring up and attempt to escape. Broken bones or fractured teeth can be the consequence of a leap off the consulting table. Struggling rabbits can inflict injury by scratching with the hind legs or, very occasionally, biting.

Owners are often unaware of the stressful effect or the physical danger posed to their rabbit if it is sitting on their knee in full view of other animals

Key Points 1.22 Creating a rabbit-friendly surgery

- Rabbits are a prey species. In threatening situations catecholamine release prepares them for flight.
- Catecholamines can have negative physiological effects on rabbits. These can include causing gut stasis, oliguria, flare-ups of subclinical infection and in extreme cases death.
- It is desirable to ensure that any interaction with a rabbit is as stress-free as possible.
- Potential stressors include:
  1. *The journey to the vets*. Owners should try and minimize travel time, make certain that the rabbit does not become too hot or cold, provide suitable food for the rabbit, consider bringing the bonded companion and cover the rabbit's cage whilst in transit to reduce visual stimuli.
  2. *The waiting room*. Veterinary staff should try to avoid having rabbits exposed to potential predators for long periods; an alternative waiting area is preferable. In cases where the proximity of dogs and cats is unavoidable, waiting times should be kept to the minimum and the rabbit perhaps kept under supervision outside in the car, or taken into a preparation room or quiet ward until the consultation.
  3. *The consultation*. Rabbits that are handled calmly and gently are much less reactive. Pain relief should be given promptly for any condition that is potentially painful, and examination under sedation considered. Some rabbits will need to be restrained using a towel; however, many respond to just a gentle covering of the eyes and stay still.
  4. *Hospitalization*. Ideally rabbits should be housed separately from cats, dogs and ferrets. Finding a quiet place in the clinic is beneficial; however, staff must be able to perform adequate observations. Rabbits should be provided with familiar food, litter and bedding materials. Any medical treatments should be carried out in the least stressful manner possible. Use of sedatives such as midazolam at very low doses can be considered when an animal appears very distressed in hospital.

in the waiting room. They may be next to potential predators such as ferrets, dogs, cats or birds of prey. Even the sound or smell of predators such as ferrets can be stressful. Loud noises, unfamiliar surroundings and car journeys all add to the stress levels of rabbits that are visiting the surgery. The effects of stress can be minimized by encouraging owners to leave their rabbits in the carrier in the waiting room, quiet gentle handling in the consulting room and the routine use of analgesics to all animals that may be in pain.

1.9.2 Behaviour problems and aggression

Like other species, rabbits respond to handling from an early age. A rabbit that associates humans with pleasurable experiences is less likely to be timid, scared or aggressive than a rabbit that is left to its own devices for most of the time and is chased or handled roughly when it does have human contact. A study into the effect of early handling has suggested that baby rabbits that are picked up and handled between the ages of 26 and 42 days are more willing to approach humans and will remain closer to them (Der Weduwen and McBride, 1999).

Owners frequently seek advice about aggressive tendencies in their rabbits. Sometimes the reason for the aggression is obvious. Two entire males that are kept together are likely to fight and will need to be separated or castrated. Female rabbits are strongly influenced by their hormones and will vigorously defend their ‘nesting site’, i.e., a hutch or a run, and attack intruders, including other rabbits and humans. These rabbits may be quite docile when they are out of their hutch. For this reason, it is advisable to clean out hutches when they are unoccupied. Spaying usually cures this type of aggression, although it may take some weeks to settle down. Female rabbits can vigorously protect their young and aggressive behaviour can be extended to include the protection of a bonded companion.

Straightforward aggression is not the only reason for rabbits biting their owners. Occasionally fingers are mistaken for food, especially if the fingers smell of sweets or biscuits. Overzealous grooming can result in a nibbling response. Young rabbits nibble objects as part of their development and can extend this exploratory behaviour to include their owners. People that smell of other rabbits or animals can be attacked as part of defensive territorial behaviour. In general it is preferable to approach nervous or aggressive rabbits from above. As in other species, pain can result in aggressive behaviour. A rabbit that is normally docile but starts to be aggressive should be examined carefully for a source of pain. Dental disease and the formation of sharp hooks on the molars can be extremely painful. Rabbits are also prone to painful musculoskeletal disorders such as arthritis or vertebral spondylitis.

Deafness has been reported as a cause of aggression in rabbits (*Rabbit Health News* 1991a, 1993). Deaf rabbits may be startled by owners coming up on them unexpectedly and sometimes their response is to bite. Deafness can be caused by *Psoroptes cuniculi* infestation occluding the external auditory canal with mites and exudate. Many lop-eared rabbits have external ear canals full of wax and debris anyway. In some rabbits, the tympanic bullae are full of inspissated pus as a result of ascending *Pasteurella multocida* infection from the nasal cavity. Inspissated pus in the horizontal ear canal is a common post-mortem finding in many pet rabbits. Granulomatous encephalitis caused by *Encephalitozoon cuniculi* could also cause deafness (see Section 10.4).

1.10 Hospitalization and clinical techniques

1.10.1 Hospitalization of rabbits

There are many advantages to hospitalizing rabbits. Conditions such as digestive or respiratory tract disorders require more intensive nursing than many owners are willing or able to provide at home. As rabbits are good at hiding, illness and significant alterations in condition may pass unnoticed without regular knowledgeable observation. Medication in the form of intravenous fluids, daily injections or nebulization may be necessary. Regular syringe feeding, clipping and bathing may be required. Observation of behaviour, appetite, faecal and urine output is easier if the rabbit is kept on its own under the careful eye of competent nursing staff. A stress-free environment is required. Accommodation needs to be away from barking dogs and the sight and smell of predators. Ideally rabbits would be housed in a separate quiet room, where the nursing staff are able to spend time observing their patients as well as performing tasks such as assist feeding and medicating. Hospitalized rabbits should be provided with a bed of good-quality hay to nibble and lie on. The familiar smell of hay gives them security. All rabbits should be provided with some kind of hide, such as a cardboard box or short length of plastic drainpipe. House rabbits can be very particular in their choice of litter material and may be reluctant to use a tray that does not contain the correct type of litter. Most owners are willing to bring in the correct type of material for their rabbit's litter tray. Fresh water needs to be provided in a drinking container that the rabbit is familiar with. Some rabbits will not use a sipper bottle. It is worth considering hospitalizing a bonded companion of a sick rabbit as rabbits can become stressed if they are separated. The decision should be based on the welfare of the well rabbit, as hospitalization must be less stressful than separation.

1.10.2 Euthanasia

Euthanasia is defined as 'an easy or painless death' (Blood and Studdert, 1999). The traditional approach of an intravenous overdose of barbiturate can be difficult to accomplish easily in rabbits. The marginal ear vein is accessible but many rabbits will jump up suddenly in response to venepuncture, which can be distressing for owner, vet and rabbit. The application of a transdermal local anaesthetic cream (EMLA) may be sufficient to allow intravenous injection in very sick animals. Sedation prior to intravenous barbiturate injection is preferable if the owner wishes to be present. The owner may wait with their rabbit until the sedative has taken effect. A combination of acepromazine and butorphanol (0.5 mg/kg acepromazine plus 0.1 mg/kg butorphanol) can be given by subcutaneous injection and has the advantage of vasodilation that facilitates venepuncture. Alternatively, fentanyl/fluanisone (0.3–0.5 mL/kg) (Hypnorm, Janssen) can be used but it is given by intramuscular injection, which is more distressing to patient and owner than a subcutaneous injection. Subcutaneous (50 mg/kg) ketamine with or without other agents can be used. Medetomidine is an effective sedative but causes peripheral vasoconstriction, which can make the lethal intravenous barbiturate injection difficult. Medetomidine in combination with buprenorphine results in rapid loss of consciousness with little peripheral vasoconstriction. This combination needs to be given intramuscularly.

1.10.3 Clinical techniques

1.10.3.1 Chemical restraint

Chemical restraint is useful for the diagnosis and treatment of many conditions in pet rabbits. It is easier to collect a blood sample or take a well-positioned diagnostic radiograph if the patient is immobile and compliant. Soiled, matted fur or maggots can be removed from sedated rabbits and a period of sedation and analgesia allows time for inflamed skin to respond to treatment. Rabbits with gastrointestinal disease that results in gas-filled viscera such as the caecum or stomach can benefit from a period of analgesia. Intravenous fluid therapy is much easier in a sedated animal.

The properties of sedatives and tranquillizers are described in Section 4.4. Fentanyl/fluanisone (0.2–0.3 mL/kg) (Hypnorm) is a particularly useful for rabbits and is the only product licensed for rabbits in the UK. Fentanyl/fluanisone is vasodilatory, which, in conjunction with its sedative properties, makes venepuncture for the blood sampling or intravenous therapy simple. It is a satisfactory method of chemical restraint for radiography, dematting or maggot removal. An alternative to fluanisone/fentanyl is a combination of acepromazine and butorphanol (0.5 mg/kg acepromazine plus 0.1 mg/kg butorphanol). This combination is also sedative and vasodilatory. However, it should be used with care in dehydrated animals or those with cardiovascular disturbances (Flecknell, 2000).

The use of subcutaneous midazolam can be helpful for rabbits that are very stressed in hospital. The use of very low doses (0.25 mg/kg) can be enough to facilitate intravenous catheterization, supportive feeding and in some cases radiography. The added advantage is that this drug is very safe.

There are many other combinations that can be used as chemical restraint in rabbits, especially in the USA where fentanyl/fluanisone is unavailable (Mason, 1997). Anaesthesia and analgesia are discussed in Chapter 4.

1.10.3.2 Blood sampling

There are several superficial veins that can be used to collect blood from rabbits. Sites for venepuncture and intraosseous fluid therapy are illustrated in Figure 1.19. Although laboratory rabbits are sometimes bled by cardiocentesis, this procedure is not suitable for a pet rabbit. Rabbit blood clots extremely fast and must be collected quickly but in a manner which does not cause haemolysis. Heparinizing the syringe and needle can be helpful. As a rough guide, it is safe to take up to 1% of the animal's bodyweight of blood (Ramer *et al.*, 1999).

The marginal ear vein is easily visualized and accessible but is too small in some breeds for the blood to flow freely. Blood can be taken quickly from the central ear artery, but this procedure carries a small risk of permanent damage to the blood supply to the pinna if the artery is damaged. Part of the pinna may subsequently slough off. Conscious rabbits can jump suddenly and dislodge a needle from an ear vein in response to venepuncture. This response can be avoided by the application of a local anaesthetic cream (EMLA, Astra). EMLA is a mixture of lidocaine and prilocaine that produces anaesthesia of full skin thickness. The cream is applied over the marginal ear vein before covering the site with an occlusive dressing or clingfilm. After 45–60 minutes a blood sample can be taken (Flecknell, 2000).

The jugular vein is a satisfactory site for the collection of good-quality samples in most rabbits. The dewlap of female rabbits does not pose a problem. It may be difficult to visualize the vessels in obese animals. The rabbit should be wrapped in a towel and held securely by an assistant. The head is extended backwards and the hair over the throat clipped off. The jugular vein can usually be visualized in the jugular furrow and is raised by occluding the vessel by a finger at the thoracic inlet. Up to 10 mL of blood can be safely collected from any sized rabbit from this site. Difficulties can arise with short-nosed breeds such as the Netherland dwarf or animals with upper respiratory tract problems that can become distressed or even cyanosed when the head is extended backwards. Alternative sites such as the cephalic or lateral saphenous veins can be used instead. The lateral saphenous vein is more easily accessible and is often a larger size than the cephalic vein. The vessel is very superficial and collapses easily if too much negative pressure is applied. Large haematomas can occur if adequate pressure is not applied after the blood sample has been taken. It is a good idea to make a blood film in addition to placing the blood in sample tubes. The film can be quickly stained and examined for a differential white cell count, which, in addition to a PCV, will give an immediate assessment of the rabbit's health status in the absence of sophisticated laboratory equipment. Analysers such as the I-Stat (Heska) require heparinized blood but are useful pieces of equipment in the assessment of critically ill rabbits as they can measure parameters such as electrolytes, glucose and urea, using only a few drops of blood.

1.10.3.3 Urine collection

Urinalysis is covered in Section 2.5. Urine samples can be collected from house rabbits and from many hutch rabbits by providing a clean but empty litter box placed in the site where the rabbit usually urinates. Cystocentesis is an alternative method of urine collection if the bladder can be easily palpated and differentiated from other structures such as a gravid or neoplastic uterus or an abdominal abscess. Care must be taken not to puncture the gut inadvertently.

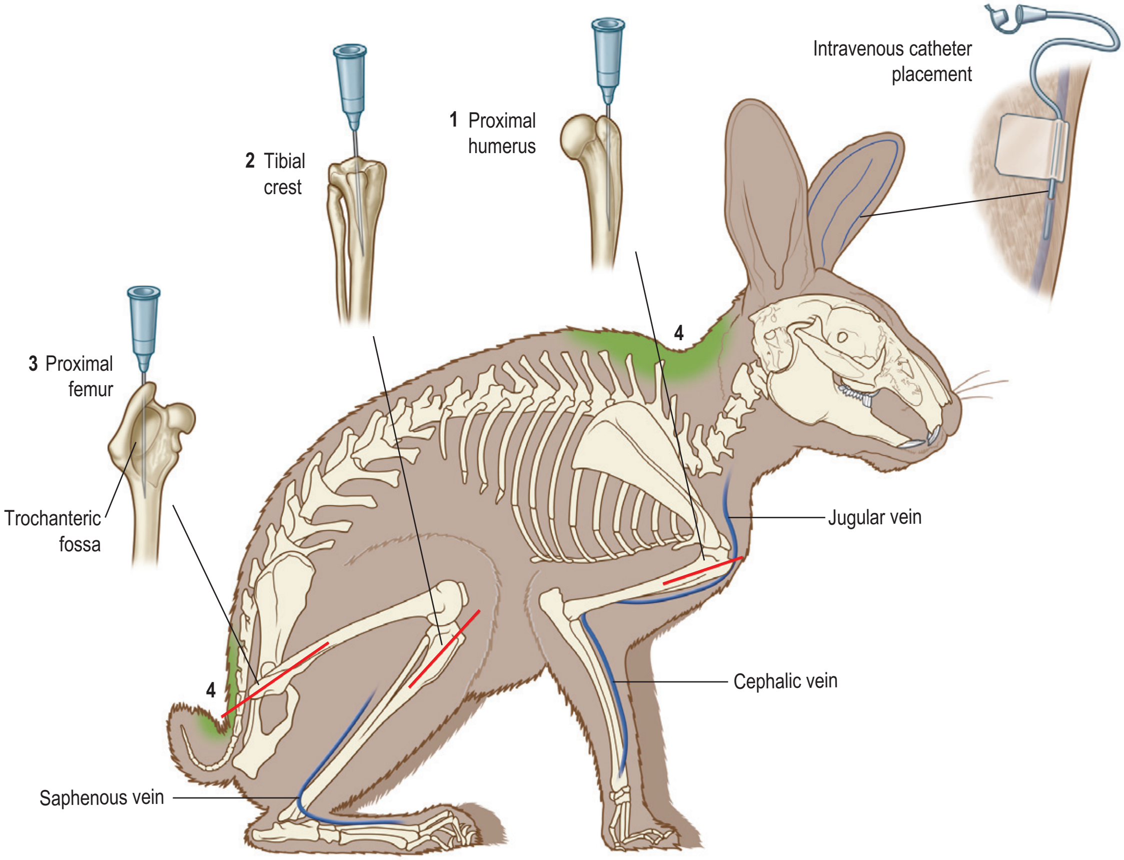

Figure 1.19 **Sites for venepuncture and intraosseous fluid therapy plus difficult-to-groom areas.** The jugular, cephalic and saphenous veins are in similar positions to those of other domestic animals such as dogs and cats. All these sites can be used for blood sampling and intravenous injections in rabbits. The jugular vein is the greatest in diameter and is the best site for taking blood samples. The ear vein is also satisfactory in large breeds or for collecting small volumes. The needle and syringe may need to be heparinized as rabbit blood clots very quickly. **Suggested techniques** (Further information is given in Section 1.10.3). Jugular blood sampling: good restraint is required for taking blood from the jugular vein. The rabbit should be wrapped in a towel, placed on the edge of a table and held by an assistant. The head is raised and held back, either by the assistant or by the person collecting the blood. It is important to ensure that the head is held straight. The fur over the jugular furrow is clipped off. Usually, the vein is easily visualized and can be raised by placing a finger at the thoracic inlet. A good-quality sample of 5–10 mL of blood can be collected quickly from this site without either haemolysis or clotting. **Intravenous fluid therapy.** A simple method of venepuncture for intravenous fluid therapy is to use a 21- or 23-gauge butterfly catheter (see Section 1.10.4.2). One wing is removed before inserting the needle, bevel up, into the marginal ear vein (caudal auricular vein). The remaining wing is 'superglued' to the fur on the ear after the needle has been inserted into the vein. The wing provides a large surface area of contact with the ear. In sedated or moribund rabbits, no bandaging is necessary to keep the needle in place, although a piece of bandage tied around the rabbit's neck can be used to hold the giving set out of the way. An intravenous catheter may be used instead of the butterfly set, but is not as satisfactory because the wing does not have as large a surface area for the bonding agent. Alternative sites for intravenous fluid therapy are the cephalic and saphenous veins. **Intraosseous fluid therapy**. In all intraosseous sites, a spinal needle is preferable because the stylet prevents bone clogging the needle. A spinal needle is stronger and more able to penetrate the bone. Possible sites for intraosseous administration: 1. **Proximal humerus:** this is the easiest site for access to a medullary cavity. An imaginary straight line is made using the greater trochanter of the humerus and the elbow joint as landmarks. The needle is inserted through the greater trochanter and directed along the imaginary line to penetrate into the medullary cavity. 2. **Tibial crest:** an intraosseous catheter can be inserted just caudoproximal to the tibial crest. However, the lateral wall of the tibial cortex curves medially and the needle must be directed towards the medial aspect of the tibia in order to penetrate the medullary cavity. If the needle is mistakenly inserted along an imaginary straight line towards the hock joint, it will go into the cortex of the tibia and miss the medullary cavity. 3. **Proximal femur:** this is the least satisfactory site for intraosseous fluid therapy because of the well-developed trochanteric fossa. This can be seen on the caudal view of the femur. The path of an intraosseous catheter must pass through this fossa to gain access to the medullary cavity. Therefore, to gain access to the medullary cavity three layers of cortical bone must be penetrated. 4. **Difficult-to-groom areas.** The areas of skin that are difficult for a rabbit to reach and groom are shown as green shading. Obesity or other flexibility problems hinder grooming in these areas and allow dead hair, skin debris and parasites to accumulate. Signs of skin disease often begin at these sites. The area between the tail and the dorsum can become contaminated by urine, faeces and is often the site that flies choose to lay their eggs. These are the areas that owners should pay particular attention to when grooming their pet.

Ultrasound can be used to identify the bladder. Repetitive puncture of the bladder can cause inflammation and subsequent stone formation. Rabbits are more prone than other species to developing calculi along a cystotomy suture line (Kaminski *et al.*, 1978).

Key Points 1.23 Hospitalization facilities

- Hospitalization facilitates administration of medication and food and permits observation of demeanour, appetite, thirst and urinary and faecal output.
- A stress-free environment is required for hospitalized rabbits.
- A bedding of hay provides a familiar smell, a sense of security and a source of indigestible fibre.
- Some house rabbits will only use a litter tray containing a familiar substrate.
- Peaceful euthanasia can be accomplished by the administration of 0.5 mg/kg acepromazine +1.0 mg/kg butorphanol given subcutaneously 10–15 minutes prior to intravenous barbiturate injection.
- Rabbit blood clots quickly. The marginal ear vein can be used for blood collection in large rabbits. The jugular and cephalic veins may also be used.
- Although cystocentesis can be used to collect urine samples, repetitive puncture can cause calculus formation.

Urine can sometimes be collected by manual expression of the bladder, although this procedure is not without risk. The bladder is thin-walled and can rupture during manual expression, especially if there is a urethral obstruction. Chronic cystitis causes thickening of the bladder wall, making it less susceptible to rupture. Rabbits with cystitis or urolithiasis often urinate in response to palpation of the bladder and void urine that can be collected, if a suitable container is easily available.

1.10.4 Administration of medication

1.10.4.1 Subcutaneous injections

The subcutaneous route is suitable for the administration of most parenteral medications with the exception of some anaesthetic agents. Subcutaneous injections are well tolerated and even owners can inject their rabbit without problems. Occasionally subcutaneous injections of antibiotics or vaccines can result in a skin reaction that may not be noticed until a few days later. These reactions can be minimized by making sure that the needle has penetrated the skin and the medication is injected subdermally rather than intradermally. Massaging the area after giving the injection is also useful. The loose skin over the scruff is the usual subcutaneous injection site. Older rabbits may have a thick dermal shield that can affect the ability to inject in this area. Subcutaneous fluids (10–20 mL/kg) can be administered into either the scruff or the loose skin over the chest.

1.10.4.2 Intramuscular injections

There are a few products that need to be given intramuscularly to rabbits. Large volumes (> 0.5 mL/kg) should be divided and given in two sites. The cranial muscle mass (quadriceps) of the hind leg is the preferred site. The caudal muscle mass can be used, but the sciatic nerve must be avoided by palpating and identifying the semimembranosus, semitendinosus and biceps femoris muscles and ensuring that the injection is given into the muscle. Self-mutilation of the foot has been reported in rabbits as a result of nerve damage during intramuscular injection of ketamine and xylazine into the caudal muscle mass (Beyers *et al.*, 1991). Tissue damage and muscle necrosis were found at the injection site. The lumbar musculature is an alternative site for intramuscular injection.

1.10.4.3 Intravenous injections

The usual site for intravenous injection is the marginal ear vein that is accessible and easily visualized in rabbits (see Figure 1.19). Rabbits can be restrained by wrapping them in a towel. Topical local anaesthesia with EMLA cream (see Section 1.10.3.2) or chemical restraint can be used to prevent head shaking and the needle being dislodged. Placing a catheter will make intravenous injections safer and less stressful.

Small-gauge needles or catheters, adequate light and good eyesight are required, especially in dwarf breeds. An alternative site is the cephalic vein similar to the dog or cat. The rabbit's short legs sometimes make raising the vein difficult. Other veins such as the jugular, lateral saphenous or femoral veins can be used (Malley, 1996) and the choice is largely a matter of individual preference.

The choice of sites is limited for intravenous catheterization and fluid therapy (see Figure 1.19). The femoral and jugular veins are impractical. Usually the marginal ear vein or cephalic vein is used because of the ease of keeping the rabbit in the correct position for intravenous fluids to run once the drip is set up. Intravenous catheters can be held in place with adhesive tape or a few drops of skin glue (Vetbond) or superglue. A simple method is to cut one wing off a 21-gauge or 23-gauge butterfly set before placing it in the marginal ear vein. The remaining wing can be superglued to the fur on the pinna to keep the needle in place. No bandaging is required to keep the needle in place in sedated or moribund patients, although a piece of bandage tied around the rabbit's neck can be used to hold the giving set out of the way. Most rabbits tolerate the procedure well. Superglue is not as satisfactory for keeping intravenous catheters in place because they have a smaller wing that does not provide a large surface area for the bonding agent. In this case making a butterfly of tape around the hub of the intravenous catheter facilitates wither gluing or securing the catheter using tape.

1.10.4.4 Intraosseous route

This route introduces fluids and drugs into the medullary cavity of long bones so they are absorbed into the venous circulation. Anything that can be administered intravenously can be given intraosseously. There are several advantages to this technique, which avoids the necessity of cannulating a small collapsed vein in moribund patients. The intraosseous route is often used for small exotic animal patients such as birds, reptiles, guinea pigs and pot-bellied pigs where it is difficult to find a peripheral vein. Most rabbits are large enough and have sufficient accessible veins to use the intravenous route but there are occasions when intraosseous administration of drugs and especially fluids can be life-saving. Some practitioners prefer this method of fluid administration and use it routinely. Disadvantages include the risk of introducing infection and causing osteomyelitis. The rate of administration can be slow. These problems can be overcome by using careful aseptic techniques and multiple sites. Immature bones with active growth plates and diseased or fractured bones are not suitable. A needle is used to bore a hole through a bony prominence into the marrow cavity. Direct penetration of the marrow cavity is easier in the tibia or humerus of the rabbit than the femur. The anatomy of the head of the femur requires penetration of the trochanteric fossa so the cortical bone is penetrated three times instead of once (see Figure 1.19). The humerus is the preferred site. In conscious animals, local anaesthetic is infiltrated around the injection site, which is clipped and aseptically prepared prior to the introduction of the needle. A 20- to 22-gauge needle that is about half the length of the bone is required, i.e., 4–6 cm (1.5–2.5 in.). Spinal needles with a stylet that prevents a plug of bone clogging up the bore are most suitable but ordinary hypodermic needles can be used with a smaller gauge needle, catheter stylet or a length of wire acting as the stylet. The bone is penetrated by using the needle as a drill. The needle should be kept straight when boring the hole in the bone; this is easier to achieve if the needle is attached to a syringe that is then used as a handle. Moving the needle from side to side results in a larger hole than is required and leakage of fluid around the injection site. Penetration of the cortex can be felt as a sudden lack of resistance. The needle may need to be redirected slightly to push it down the medullary cavity. It is important to be certain that the tip of the needle is in the medullary cavity and not pushed against or penetrating the cortex. At this point the stylet is removed and a syringe attached to the needle to aspirate bone marrow which confirms correct placement of the needle. If there is any doubt, radiography is indicated. If the needle is not placed correctly, it should be withdrawn and a different bone selected to attempt the procedure again. Once the needle is placed it can be glued or sutured in place. Dressings and antiseptics can be used for protection and to reduce the likelihood of infection. Heparin should be introduced into the catheter every 4–6 h. The needle should not be left in place for longer than 72 h. When it is removed a light dressing and some antiseptic can be applied to the site (Anderson, 1995).

1.10.4.5 Intraperitoneal route

This route is seldom required for the treatment of pet animals and is more often used in laboratory rabbits. Ideally the bladder should be empty and care is needed to avoid the thin-walled caecum that lies in the right ventral abdomen (see Figure 1.13). The injection should be given caudal to the umbilicus so there is little chance of penetrating the liver, kidneys or spleen. The inguinal quadrant is the site described by Malley (2000). It is important to draw back on the syringe to check for intestinal contents, blood or urine, in which case the syringe should be withdrawn and another attempt made. This method should not be viewed as acceptable if an alternative is available; however, it can be life-saving in moribund patients.

1.10.4.6 Oral administration

There are therapeutic agents that need to be given by the oral route. Medicating the drinking water is unsatisfactory as many preparations flavour the water and make it unpalatable. Adding sucrose to the water has been advocated as a means of overcoming this problem. It is also difficult to ensure the correct dosage when medication is given in the drinking water and there is experimental evidence to show that antibiotics administered by this route are ineffective (Okerman *et al.*, 1990).

Rabbits can be given tablets, which can be placed in the mouth or administered with a pill giver. Placing tablets in food such as breakfast cereals can be successful and the occasional rabbit will eat tablets voluntarily. Crushing tablets and mixing the powder with honey or baby cereal can also be successful. Powders such as vitamin and mineral supplements can be given with food. Most rabbits will readily accept a piece of bread that has been sprinkled with powder. Liquids can also be given in this way.

Many rabbits are easy to dose with oral liquids. In fact many of them enjoy sweet compounds and will readily accept paediatric syrups or medication mixed with honey or fruit juice such as Ribena. Otherwise the rabbit can be wrapped in a towel and the liquid slowly squirted into the mouth using a syringe inserted in the diastema. Owners can be shown how to do this and most manage well. One note of caution is that overenthusiastic oral dosing can lead to trauma of the soft tissues inside the mouth or hard scabby lesions at the lateral commissures, both of which are painful and can discourage a rabbit from eating and grooming.

1.10.5 Nutritional support

Nutritional support can be life-saving in rabbits. Their metabolism is geared to a constant supply of nutrients from the digestive tract. Anorexia can have dire consequences, especially in fat rabbits as ketoacidosis and hepatic lipidosis can develop rapidly as a result of mobilizing fat reserves. Oral liquids soften and lubricate impacted stomach contents. In the short term, nutritional support is required to provide calories, nutrients, fluids and electrolytes. A readily available source of carbohydrate is required to provide glucose for absorption from the stomach and small intestine and prevent hypoglycaemia and the mobilization of the free fatty acids. In the long term, indigestible fibre and fermentable fibre are required to maintain gut motility and optimal conditions in the caecum for bacterial fermentation. Although fermentable fibre can be administered through a syringe, it is not possible to provide indigestible fibre in this way because it has to be ground down to a fine powder in order to pass through the nozzle. The beneficial effect of long indigestible fibre particles is lost by being ground down to a size smaller than 0.5 mm because particles below this size are moved back into the caecum to undergo bacterial fermentation rather than passing into the colon and stimulating gut motility. Therefore, it is important to encourage sick rabbits to eat as soon as possible.

They need a source of palatable indigestible fibre, even if they do not appear to be eating. Hay, grass or dandelions are often the first item to be eaten voluntarily and are often eaten in preference to other foods.

In most instances, nutritional support can be given by syringe feeding three or four times a day. Liquid food (10–20 mL/kg) can be introduced into the mouth through a syringe with or without a small section of tubing attached. Several commercial foods are made for this purpose (Supreme Recovery/Recovery Plus, Oxbow Critical Care/Fine grind). Baby foods can also be used; however, the fibre content is too low and the sugar content too high for prolonged use. Meat or dairy-based products and those designed for dogs and cats should be avoided. They are useful in the short term as an immediate source of energy and digestible fibre. Alternatively, extruded monocomponent rabbit food (Supreme Selective, Supreme Petfoods, Alstoe VetPet Rabbit food, SupaRabbit Excel, Burgess) can be moistened and mashed to a paste for syringe feeding, although the fibrous particles tend to block the syringe. This can be avoided by mixing a small amount of puréed babyfood to this paste. The food needs to be ground to a powder, which detracts from its motility stimulatory properties. Many anorexic rabbits, especially those suffering from dental problems, will eat softened nuggets of extruded food from a dish. Eaten in this way, the food is a source of indigestible fibre.

1.10.5.1 Nasogastric tubes

Very occasionally a situation can arise where syringe feeding is impossible and it becomes necessary to place a nasogastric tube to provide nutrition. This technique should be used as a last resort because nasogastric tubes stress rabbits and stress reduces gastrointestinal motility and impairs digestive function. An Elizabethan collar is required to prevent a rabbit removing a nasogastric tube and this is not only stress provoking but also prevents caecotrophy. In most cases, syringe feeding is satisfactory and nasogastric tubes can be avoided.

It is easier to place a nasogastric tube in a moribund or anaesthetized rabbit as the nasal mucosa is sensitive and the introduction of a tube can cause sneezing and distress. In the conscious animal, local anaesthetic can be sprayed (Intubeze, Arnolds) or dropped (Opthaine, Ciba) into the nostril. Sufficient time (2–3 minutes) should be allowed to elapse for the anaesthetic to take effect before the tube is introduced. Paediatric tubes (4–8 French) are suitable for this purpose or customized veterinary products are available in varying sizes (Cook Veterinary Products). The tube is measured against the rabbit and marked to give an idea of the position of the tip as the tube is being placed: 3FR–4F urinary catheters can be used if a nasogastric tube is not available but holes need to be cut in the side and these can catch on the nasal mucosa as the tube is introduced. To place a nasogastric tube, the rabbit's head is grasped and elevated and the tube introduced into the ventral meatus and directed slightly ventrally (see Figure 1.20). The head is then flexed as the tube passes through the nasopharynx into the oesophagus and down into the stomach. Occasionally resistance is encountered in the nasal passage due to an elongated tooth root. In this instance, the other nostril can be tried.

It is possible to pass a nasogastric tube through the larynx and into the trachea and it is important to ensure that the tube is not placed in the trachea before introducing food. Keeping the head flexed minimizes the risk of tracheal intubation. If the tube has been measured up against the patient prior to placement, the length of the tube that has been passed will indicate whether the end is in the trachea or in the oesophagus. Palpation of the oesophagus, listening for breath sounds in the tube or instilling a few drops of water or saline can be helpful to confirm the correct placement of the tube in the stomach. If in doubt, a radiograph can be taken to check the tube's position. The nasal end is secured to the skin of the nose and between the ears using tape butterflies and sutures or superglue. Alternatively it can be secured to the Elizabethan collar, which is required to prevent the rabbit removing or damaging the tube. Nasogastric tubes can be left in place for several days. The rabbit is able to eat with the tube in place.

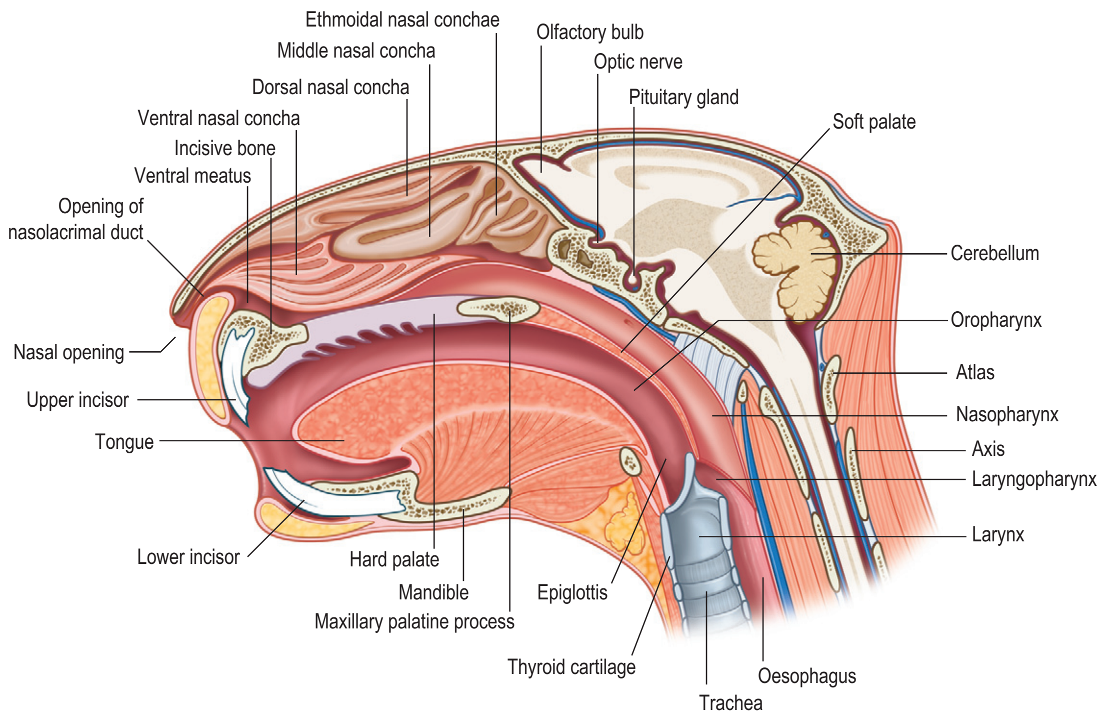

Figure 1.20 Sagittal section through head. This diagram was drawn from a prepared sagittal section of a rabbit's head using Barone *et al.* (1973) as a reference source. The structures of the nasal cavity and the position of the ventral meatus can be seen. The larynx is difficult to visualize through the oral cavity because of the large base of the tongue that occupies most of the nasopharynx and obscures the view.

Complications associated with nasogastric tubes include inadvertent introduction of the tube into the trachea and iatrogenic damage to the mucosa. The nasal mucosa is the primary site for *Pasteurella multocida* bacteria to reside and trauma to the tissues can stir up infection. Epistaxis can also result from the passage of a nasogastric tube.

1.10.5.2 Stomach tubes

There are occasions when it is necessary to pass a stomach tube. The most common indication is to decompress the stomach of rabbits with intestinal obstruction. These patients are usually either moribund or sedated. Some clinicians use stomach tubes for nutritional support or to administer medication. The technique carries a risk of inadvertently traumatizing the larynx or passing the tube into the trachea, causing breathing difficulties or aspiration pneumonia. It is also possible for the rabbit to chew through the tube and inhale or swallow a section. A gag can be used to prevent the rabbit from chewing the tubing. A piece of wood with a hole drilled through it can be placed in the diastema.

Despite the difficulty of endotracheal intubation in anaesthetized rabbits it is surprisingly easy to pass a stomach tube into the trachea. Selection of a large tube should prevent this happening. The tube can be measured against the animal and an estimate of the length required to reach the stomach made. It is then lubricated before it is passed over the tongue into the oesophagus. After placing the tube, the animal's respiration should be watched for a moment or two and the colour of the mucous membranes checked. A small amount of water can be introduced before giving any medication or food. If in doubt, a radiograph can be taken to check the placement of the tube. In rabbits with gastric dilation, gas and liquid readily pass up and out of the tube as the stomach decompresses.

1.10.5.3 Pharyngotomy and gastrotomy tubes

There are clinical situations where syringe feeding is impossible and a nasogastric tube inadvisable: for example, rabbits with skull injuries or a purulent nasal discharge. A technique for placing a pharyngotomy tube has been described for laboratory rabbits (Rogers *et al.*, 1988). Under general anaesthesia a 1-cm incision is made 5 mm from the midline just anterior to the larynx on the left-hand side. A tube is passed through the oral cavity into the oesophagus and down to the stomach. The tube is grasped with artery forceps through the mouth and pushed against the wall of the pharynx to cause a bulge under-the-skin incision. The muscle overlying the bulge is carefully incised using the hard tip of the artery forceps in the pharynx as a guide. The pharyngeal wall is incised and the oral end of the stomach tube exteriorized through the incision. The tube is then anchored at the pharyngeal incision before being run through the subcutaneous tissues to emerge at the base of the ear where it is anchored with skin sutures. Pharyngotomy tubes placed in this manner have been left in laboratory rabbits for 6–12 months to ensure accurate doses of the drugs that were being tested. The catheters were well tolerated and the rabbits continued to eat and drink without losing weight. This technique could be applied to pet rabbits. Soft feeding tubes designed for oesophagostomy in cats (Cook Veterinary Products) would be suitable for this purpose.

Percutaneous endoscopical gastrotomy (PEG) tubes have been used to administer enteral nutritional support to rabbits (Smith *et al.*, 1997). This technique does not appear to be as useful in rabbits as it is in dogs and cats. It is difficult to pass an endoscope through the rabbit's mouth and pharynx. In order to have a good endoscopic view, the stomach should be empty, which is difficult to achieve in rabbits even if they are prevented from eating caecotrophs. Elizabethan collars or bandages are required to prevent the patient from removing the tube once it is placed and these are not well tolerated. In the long term significant intra-abdominal adhesions can develop following the use of PEG tubes. These will in turn affect long-term gut motility and cause discomfort.

1.10.6 Elizabethan collars

Elizabethan collars are used in other species to prevent interference with surgical incisions, wounds, catheters or dressings. There are circumstances when collars need to be fitted to rabbits but there are serious disadvantages. Rabbits fitted with Elizabethan collars can become depressed or even anorexic. The collars are stressful and are most likely to be fitted at a time when it is important to minimize stress levels such as after surgery or during periods of anorexia. Significant elevations in plasma glucose levels have been found in rabbits fitted with collars (Knudtzon, 1988). Elizabethan collars also prevent a rabbit from consuming caecotrophs. Caecotrophs are rich in amino acids and vitamins and necessary for optimum nutrition and wound healing. Collar edges also damage the external pinnae of all but the shortest-eared rabbits, and this can contribute to discomfort. Good surgical technique, buried subcuticular sutures and the correct choice of suture material reduces the need for Elizabethan collars postoperatively. If collars are deemed necessary, then padding the edges to avoid ear damage, having supervised periods without the collar to allow caecotrophy and considering the use of clear collars to maintain field of vision can be helpful. For some areas (for example, to dewlap or rostral third of the body) soft collars are suitable for preventing self-trauma.

1.10.7 Nebulization

Nebulization has been described as an adjunct to treatment of upper and lower respiratory tract disease in rabbits (Callaghan and Raftery, 1998). A variety of medications, such as antibiotics, mucolytics and antiseptics, can be mixed with warm saline (38°C) and administered twice a day, via a nebulizer, into the air space of a small cage containing the rabbit. It is important to use isotonic saline as the vehicle. Experimental nebulization of rabbits with hypertonic saline (3.6%) caused extravasation of water into the sub-epithelial tissue of the airway wall. The formation of oedema was associated with a decrease in compliance and gas exchange (Hogman *et al.*, 1997).

Key Points 1.24 Fluid therapy and nutritional support

- Subcutaneous injections are well tolerated by rabbits, and in rabbits that are not massively dehydrated large volumes of fluids can be given subcutaneously. The maximum volume in a single site is 10 mL.
- Intravenous fluids can be given into the marginal ear vein. A butterfly cannula can be superglued to the pinna for easy administration; intravenous catheters can also be secured and are well tolerated. The fluid rate for maintenance is 100 mL/kg/24 h, but ongoing losses and illness factors also need to be accounted for.
- The proximal end of the humerus is the preferred site for intraosseous fluid therapy. The trochanteric fossa at the head of the femur precludes direct penetration of the marrow cavity of the proximal femur. Anything that can be administered into a vein can be administered intraosseously. Rabbits may show signs of pain on intraosseous injection.
- Nutritional support is life-saving in rabbits and is preferably given by syringe feeding.
- Formulations for nutritional support should include carbohydrate as a source of glucose that can be absorbed from the small intestine to prevent hypoglycaemia and mobilization of free fatty acids.
- Powdered formulations given through a syringe cannot provide indigestible fibre to stimulate gastrointestinal motility. It is long particles of indigestible fibre, not small particles of fermentable fibre, that stimulate gut motility. Prokinetic drugs may be necessary until the rabbit starts feeding voluntarily.
- Powdered formulations can be a source of fermentable (digestible) fibre as a substrate for caecal microflora.
- A tempting palatable source of indigestible fibre should be available for all sick rabbits. Grass is ideal; however, dandelion leaves and coriander are also favourites.
- Any rabbit not definitely seen eating for 12 h should be assessed and support feeding initiated, except where intestinal obstruction or bloating are concerns.

1.10.8 Cerebrospinal fluid (CSF) collection and myelography

The increase in status and popularity of rabbits as companion animals has resulted in greater owner expectations of veterinary treatment and there are times when myelography and spinal surgery are required. Cerebrospinal fluid analysis can also be helpful in the differential diagnosis of neurological disease. Cisternal puncture in the rabbit is widely used in laboratory rabbits and the procedure is similar to that for dogs and cats.

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