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Oral biology and disorders of chiroptera, insectivores, monotremes, and marsupials

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Chiroptera

The mammalian Order Chiroptera is subdivided into Microchiroptera and Megachiroptera. Although this classification implies "little" and "large" bats, there are some large microchiropterans (eg, the false vampire bat, *Vampyrum spectrum*, 145 g to 190 g) and small megachiropterans (eg, the dog-faced fruit bat, *Cynopteris brachyotis*, 30 g) [1].

The Megachiroptera includes a single family of fruit and blossum/nectar-feeding bats, the Pteropodidae, with 42 genera and 166 species that are confined to the Old World, east to Australia and the Cook Islands [2,3]. This group includes the largest bats known, which have weights of 1 kg, wingspans of 1.5 m, and body lengths of 40 cm. Their long snouts, large eyes, and pointed ears give members an attractive, "fox-like face" that is the basis for their common name "the flying fox" [4]. Microchiroptera consist of 16 highly diverse families that are found throughout the world.

Dentition

Bats' dentitions are closely related to the ancestral eutherian stock that had a full number of four premolars in each quadrant. Present-day species normally lack the second premolar in the maxilla and mandible. In *Myotis spp*, the presence of the third premolar tooth (P3) is also variable [5]; it is absent in 9.3% of the little brown myotis bat species (*M lucifugus*) [6]. In *M occultus* one or more P3 were reported to be absent from 68% of 91 skulls [7]. Also, all bats lack at least one of the three upper incisors of the primitive eutherians [5]. There is some controversy about which incisor has been lost in the course of evolution, but the traditional view is that it is the first

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incisor. On the basis of an abnormal supernumerary deciduous incisor in *M lucifer*, however, it has been postulated to be the second incisor [8].

Megachiroptean teeth are structurally unique among mammals. The incisors are small, the sexually dimorphic canines are always present, and the spaced-out brachydont molar cheek teeth are elongated and generally flat with a few prominent cusps [9]. The Megachiroptean bats have evolved to have dentitions that are highly efficient at extracting the liquid portion of their chosen foods. The bat uses the specialized flat molar teeth to pulverize bites of fruit; the juice is squeezed out and swallowed, and the remaining fibrous portion of the compressed pellet is spat out [4]. The dental formulae varies (Table 1) from $I^2{}_2{:}C^1{}_1{:}P^3{}_3{:}M^2{}_3 = 34$ in *Pteropus* spp and *Rousettus* spp to $I^1{}_0{:}C^1{}_1{:}P^3{}_3{:}M^1{}_2 = 24$ in *Nysctimene* spp and *Paranyctimere* spp [3].

Table 1
Dental formulas of the Chiroptera

Fruit bats *(Megachiroptera)*	(I1–2/0–2:C1/1:P3/3:M1–2/2–3)×2 = 24–34
Insectivorous bats *(Microchiroptera)*	(I0–2/2–3:C1/1:P1–3/2–3:M2–3/2–3)×2 = 22–38
Lionycteris robusta (Panama long-tongued bat)	(I2/2:C1/1:P2/3:M3/3×2 = 34
Lionycteris mordax	
Lionycteris spurrelli	(I2/2:C1/1:P2/3:M3/3)×2 = 34
Anoura geoffroyi (Geoffrey's tailless bat)	(I2/0:C1/1:P3/3:M3/3)×2 = 32
Glossophaga sorcina (Pallas' long-tongued bat)	(I2/2:C1/1:P2/3:M3/3)×2 = 34
Myotis plethodon (Barbados long-tongued bat)	(I2/2:C1/1:P2/3:M3/3)×2 = 34
Lionycteris sanborni (little long-nosed bat)	(I2/2:C1/1:P2/3:M2/2)×2 = 30
Lionycteris nivalis (big long-nosed bat)	
Lionycteris obscura (brown long-nosed bat)	(I2/0:C1/1:P2/3:M2/2)×2 = 26
Lionycteris degener	
Choeronyteris mexicana (Mexican long-tongued bat)	(I2/0:C1/1:P2/3:M3/3)×2 = 30
C inca	(I2/0:C1/1:P2/3:M3/3)×2 = 30
C godmani	
C minor	
Rhynchonycteris naso (proboscis bat)	(I2/0:C1/1:P2/3:M3/3)×2 = 30
Saccophteryx bilineata (greater white-lined bat)	
Peropteryx macrotis (lesser sac-winged bat)	
Balantiopteryx plicata (Peters' sac-winged bat)	
Bio (Thomas' sac-winged bat)	
Pteronotus personatus psilotis (moustached bat)	(I2/2:C1/1:P2/3:M3/3)×2 = 34
P davyi (Davy's naked-backed bat)	
Mormoops megalophylla (Peters' ghost-faced bat)	
Rousettus	(I2/2:C1/1:P3/3:M2/3)×2 = 34
Pteropus	
Nystctimene	(I1/0:C1/1:P3/3:M1/2)×2 = 24
Paranyctimere	
Desmodus (vampire bats)	(I1/2:C1/1:P2/3:M0/0)×2 = 20

Microchiropteran bats have multicusped teeth that consist of small incisors, large canines, and molars with two V-shaped ridges (dilambdodont) that have evolved for cutting up insects. The dental formulae are quite varied between species: $I^{0-2}{}_{2-3}$:$C^{1}{}_{1}$:$P^{1-3}{}_{2-3}$:$M^{2-3}{}_{2-3}$ = 22–38 [5].

The true vampire bats (suborder Microchiroptera, family Phyllostomatidae, subfamily Desmodontinae) are neotropical in distribution and include three monospecific genera: the hairy-legged vampire (*Diphylla ecaudata*), the white-winged vampire (*Diaemus youngii*), and the common vampire (*Desmodus rotundus*). All three species are obligate sanguivores with a severely modified dentition that is limited to 20 teeth. Of these, only the upper incisors and canines are notably developed. The medial incisors have long cutting edges that extend posterolaterally in the manner of a "V," and these teeth are used for making the incision for feeding. The upper canines are long and blade-like and are principally used in aggression and defense. All cheek teeth are reduced and nonocclusive and they lack grinding surfaces [10]. Wounds that are inflicted by vampire bats bleed for hours because their saliva contains antihemostatic agents, an active plasminogen activator, called "desmokinase," an inhibitor of platelet aggregation, and several anticoagulant substances [11,12].

Periodontal disease

Periodontal disease occurs in several bat species. Recession of the alveolar crest bone in Davis' long-tongued bat (*Glossophaga alticola*) is more common in old animals where the dentition is worn. But interestingly, no calculus is generally found on the teeth, nor is there evidence of food lodged between teeth or in gingival pockets in this species [13]. Periodontal disease also occurs in adult long-nosed bats (*Leptonycteris* spp) with dehiscences and fenestrations over the roots of upper teeth. A condition that is unique to bats, namely the invasion of the gingiva by protonymphs of mites (*Radforddiella*), where the mites penetrate the gingival margin on the palatal surface of the postcanine teeth, was reported [13]. A Central European species of bat (*Myotis daubentonii*) was also reported to be susceptible to periodontal disease [14]. It is clear that, for reasons unknown, periodontal disease is common in bats and deserves further study.

Caries

Dental caries is not a common feature in bats, although, the Central American spear-nosed bat, (*Phyllostomas hastatus*), is commonly affected. One study found that 40% of 52 skulls from a wide geographic range that included Venezuela to Panama and Trinidad had readily detectable caries [15]. The condition was more common in males. The lesions started in the developmental enamel pits on the buccal surfaces of the upper molars or in the depressions between the occlusal ridge-like cusps. On reaching the

dentine, the destructive process spread out, undermining enamel which then broke away leaving more than half of the crown destroyed. Caries started in sites where food stagnation was evident. An unusual, but not predominant, feature in this species is the presence of stained, often intersecting cracks in the enamel surface, that are unrelated to tooth wear [16]. There is probably something unusual about the environment or diet of *P hastatus*, combined perhaps with tooth morphology, that accounts for this condition.

Zoonoses

In the past, a great deal of concern has been directed at the numerous viruses that have been isolated from the salivary glands of bats as a source of zoonotic diseases, in particular rabies and the rabies-related diseases. These viruses are particularly dangerous to humans. They are members of the family Rhabdoviridae and the genus *Lyssavirus* [17]. Lyssaviral infection has probably existed for centuries, because there is indirect evidence of bat lyssaviral infection from the tenth century in Europe; knowledge of the problem in America predated fifteenth century European explorers [18]. Recent evidence showed that bats react to infection with rabies virus in the same manner as other animals; they either survive or die, and they usually show the paralytic form and rarely attack man (with the exception of the vampire bat who will attack a sleeping person to feed) [17].

Handling for oral examination

Handling some bat species requires care because they will struggle and either injure themselves or deliver a powerful defensive bite when restrained. Their thumbs and associated claws can also scratch and pull in a handler's finger close for a bite. When restraint is necessary, manual methods, caught by hand or net, are preferable to chemical ones. Long-sleeved, loose-fitting, soft leather gloves are recommended for the large species and vampires. When short-term, chemical restraint is required for an oral examination and the animal can be held safely, inhalation anesthesia using isoflurane (Forthane) by facemask, initially 5% in 500 mL/min O_2 then reducing to 2.5% in 200 mL/min, is recommended [1]. If longer-term chemical immobilization is required, a combination of ketamine (Ketaset), 10 mg/kg and xylazine (Xylazil-100), 2 mg/kg was reported to give 30 to 40 minutes of effective anesthesia in the island flying fox (*Pteropus hypomelanus*) [19]. Hypothermia can be avoided by wrapping the wings close to the body in bubble wrap. Venipuncture can be performed using a median artery on the lateral aspect of the humerus; the cephalic vein, which extends along the leading edge of the patagium; or the pedal veins. Handlers should be immunized against rabies and associated viruses.

Insectivora

The Order Insectivora contains eight families, about 70 genera, and approximately 400 species of small mammals that are found throughout all continents, except Australia and Antarctica [20–24]. Variations in appearance and habits in the different families, which include the hedgehogs, shrews, and moles, are marked. The mammals that make up the order are usually terrestrial, and nocturnal or active in subdued light. Aquatic forms eat fish, frogs, snails, aquatic insects, and crustaceans. The small elephant shrew prefers ants or termites. Many species eat snails or slugs. Anatomical characteristics of the insectivores include small, long, narrow snouts, usually five-digit feet, and a primitive tooth structure; there are variants, however. The short-tailed shrew (*Blarina* spp) and possibly some species of *Sorex* have a toxic bite that numbs small prey and is painful to larger vertebrates and man [25].

Dentition

The dental formula of insectivores is variable between families and within some of them; many have or nearly have, the primitive eutherian maximum of 44 teeth (Table 2). The incisors are modified forceps for picking up small prey. The canines often resemble the incisors or the most mesial premolars [5]. As in most mammalian groups, when the premolars are reduced in number, the most mesial are lost first [26]. The arrangement of cusps on the molars is close to the basic tribosphenic pattern.

The eruption sequence varies a great deal in accord with the phylogenetically loosely knit nature of this order; some members of the order may be more distantly related than being placed in the same order suggests [27]. The sequence in the greater hedgehog tenrec (*Setifer setosus*) is m2, m3, m4, M1, M2, M3, P2, P3, P4. In many other insectivores, however, P4 is the first premolar to erupt. Probably the front to back eruption of the teeth broke down in the course of evolution, as the single-cusped P3, and especially P4, became progressively molarized and assumed more important functions in the increasingly heterodont dentition [27]. In many insectivores, the deciduous dentition is erupted and shed before birth [5], whereas, in the golden mole (Chyssochloridae) of South America, the teeth do not erupt until the animal is fully grown and they do so simultaneously [28].

Table 2
Dental formulas of the Insectivora

Hedgehog	(I2–3/2:C1/1:P3–4/2–3:M3/3)×2 = 34–40
Elephant shrew	(I1–3/3:C1/1:P4/4:M2–3/3)×2 = 38–44
Water shrew	(I3/3:C1/1:P3/3:M3/3)×2 = 40
Golden mole	(I3/3:C1/1:P3/3:M3/3)×2 = 40
Moles	(I2–3/1–2:C1/0–1:P3–4/3–4:M3/3)×2 = 32–42

Dental variations

Variations in the number, shape, or size of teeth are quite common in some groups. Approximately 2% of European hedgehogs (*Erinaceus europaeus*) [29] and 49.3% of 71 hedgehogs that were examined in New Zealand [30] lacked one or more teeth. Because all New Zealand hedgehogs descended from about a dozen animals that were introduced from Britain in the 1890s, this seems to be a good example of the spread of a genetic character in an island population. Dental anomalies are extremely rare in most species of North American moles (Talpidae), but in one study, 7.9% of 265 broad-footed moles (*Scapanus latimanus*) were missing at least one tooth [31]. In a detailed study of European moles (*Talpa europaea*) that examined 8803 skulls, variations in the number of upper premolars were rare, but variations in the lower premolars was common. Female bats from Eastern Europe were found to have more dental variations when compared to their male counterparts [32]. A malposition of P3 and absence of P2 from a skull of an African hedgehog (*E albiventris*) from the wild was also reported [33]. The primitive mole sometimes has rudimentary teeth in the diastema between I2 and P2; microscopic examination suggested that these are retained deciduous teeth [34].

Periodontal disease

Periodontal disease has been diagnosed in captive and free-ranging hedgehogs [35], as well as in American least shrews (*Cryptotis parva*) [36]. In one study, calculus was found on the crowns of the cheek teeth and incisors [37]. Gross calculus was also found on all surfaces of the teeth from skulls from hedgehogs that were killed on the road [38]. In *C parva*, 15 out of 27 shrews that were maintained as a laboratory colony for 8 months showed changes that ranged from gingival inflammation that was discovered histologically to gross periodontal destruction with calculus and tooth loss [39]. Culture demonstrated a mixed bacterial infection, which agreed with a study [40] that suggested that periodontal disease is related to oral microorganisms; the disease was controlled by the addition of oxytetracycline hydrochloride, 200 mg to 4.5 liters of drinking water. The addition of abrasive items, such as ground charcoal or bone, to the diet has been recommended to control periodontal disease [41]. Clinical and subclinical foot and mouth disease has also been described in European and African hedgehogs with vesicles; erythema; swelling of the lips, feet, and perineum; as well as hypersalivation [25].

Handling for oral examination

Hedgehogs will roll up into a tight ball when handled. This self-protective behavior makes these animals difficult to examine; therefore, a complete oral examination requires chemical restraint [42–44]. A combination of medetomidine hydrochoride (Domitor) 0.2 mg/kg, ketamine, 2.0 mg/kg, and

fentanyl, 0.1 mg/kg, given subcutaneously was shown to be effective [44]. Induction is rapid, the duration and degree of immobilization are sufficient for oral examination, and the animals can be effectively remobilized with a combination of atipamezole hydrochloride (Antisedan), 1.0 mg/kg, and naloxone hydrochloride (Narcan), 0.16 mg/kg, given subcutaneously. For procedures that require a longer duration, animals can be maintained using isoflurane by mask.

Monotremes

The monotremes (platypus and echidna) are unique; they are the only mammals that lays eggs. The platypus (*Ornithorhynchus anatinus*) is a small mammal that is found in unpolluted rivers and streams in eastern Australia. It is highly specialized for its aquatic environment by having webbed feet and a thick, short, fur-covered, paddle-like tail. The upper and lower jaws are modified to a 'duck-bill' shape with dorsal nostrils and a long palate (Figs. 1, 2) [45]. The echidna (*Tachyglossus aculeatus* and *Zaglossus bruijni*) has two genera and covers most of Australia and New Guinea. The echidna's sides and back are covered with spines. The upper and lower jaws are modified to form a long snout or beak (Figs. 3, 4) that contains a long, mobile tongue that is used for the collection of food, which are ants and termites [45]. In the immature platypus, the dental formula is: $i^0{}_5{:}c^1{}_1{:}p^2{}_2{:}m^3{}_3 = 34$ with at least one upper and one lower premolar on each side having replacement buds beneath; whereas in the adult, all the

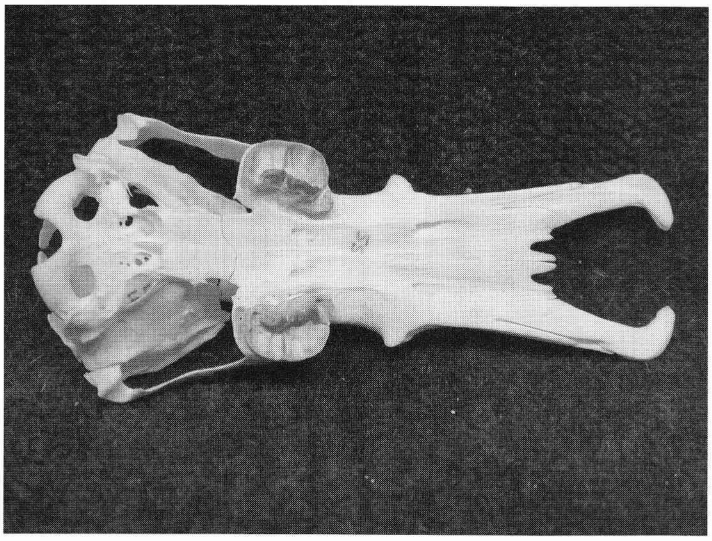

Fig. 1. The upper jaw of a platypus (*Ornithorhynchus anatinus*).

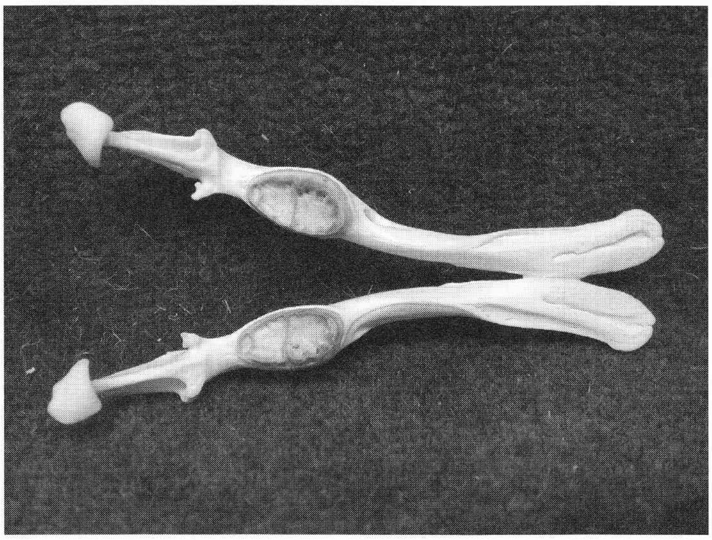

Fig. 2. The lower jaw of a platypus (*Ornithorhynchus anatinus*).

teeth are replaced by horny plates on the gum [46]. Neither the platypus nor the echidna possesses teeth as an adult.

In the wild, the platypus feeds on freshwater crustaceans, molluscs, insect larvae [mayfly (*Ephemeroptera*) and caddis fly (*Trichoptera*)], and earthworms. A lot of time is spent sifting benthic material with the aid of its highly sensitive bill. Food items are crushed and ground between the horny

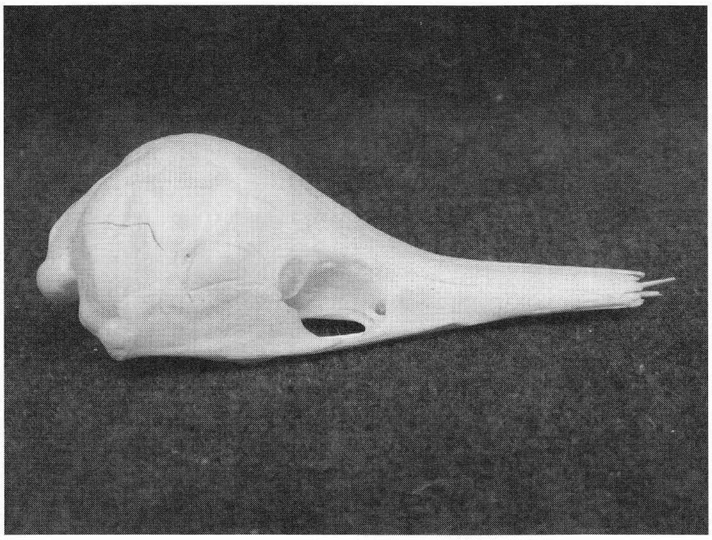

Fig. 3. The upper jaw of an echidna (*Tachyglossus aculeatus*).

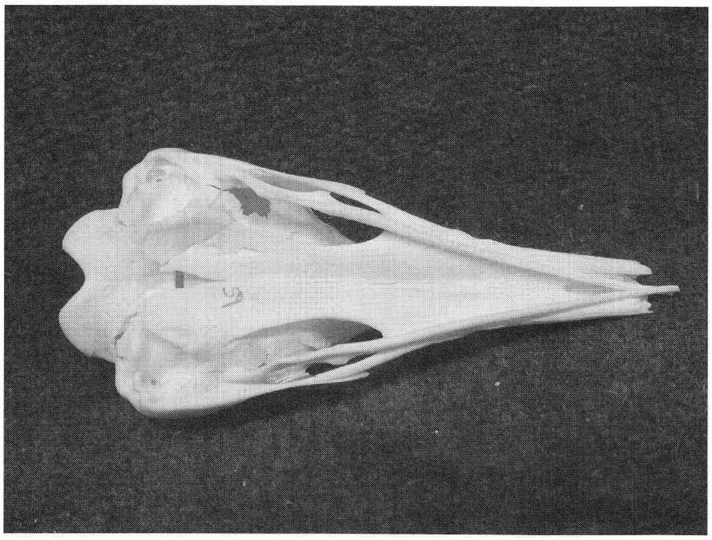

Fig. 4. The lower jaw of an echidna (*Tachyglossus aculeatus*).

ridges toward the rear of the buccal cavity [47]. The natural diet of *T aculeatus* consists almost entirely of ants and termites; the proportions depend on the local availability. The insects are seized by a long, sticky, distensible tongue, then they are crushed by the grinding action of a group of spines at the base of the tongue against groups of transversely arranged ridges on the hard palate. *Z bruijni* feeds almost solely on earthworms and the larvae of the scarab beetle [47]. The mouthparts are adapted to these food items; the tongue has backward-pointing spines over the distal third, which extends 2 cm from the end of the beak during feeding. Prey is hooked onto the exposed spines by a slight forward and upward movement of the beak and then jerked back into the mouth where it is ground as in *T aculeatus* [48].

Handling for oral examination

Male platypuses, by 9 to 12 months of age, have a prominent elongated, sharp, keratinous spur that is 1.0 cm to 1.5 cm long on the medial side of each tarsus. Females have an insignificant spur, which is shed by 11 to 12 months of age. The hollow spur of the male is ducted to a crural gland that secretes a toxin, which makes them potentially dangerous. The spurs are rapidly embedded in soft tissues by aggressive thrusts and may be impossible for an unassisted handler to remove. Pain caused by trauma is severe, is accentuated by the toxin, and swelling and dysfunction of the envenomated part last days to weeks.

A detailed oral examination of the platypus may require chemical restraint although much can be achieved without it. The handler should

approach the animal from above and behind, taking a firm grasp of the tail without allowing the fingers to curl around to the ventral pelvic region to reach the spurs. Examination of the external bill and intraoral examination can be performed through slits made in a cloth bag in which the platypus is wrapped and additionally immobilized on a polyurethane foam pad [49].

Males and some female echidnas have a hollow spur that is 0.5 cm to 1.0 cm in length on the medial side of each tarsus. The spines and the strong, clawed feet deter casual handling, but the spurs are not dangerous. To handle the echidna, which is covered in spines, it should be driven into a hard surface and picked up by the hind legs. If the echidna has already dug in, a gloved hand should be used to protect it during excavation, because the beak is vulnerable to trauma [49].

Anesthesia

In the monotremes, the anesthesia of choice is gaseous inhalation because injectable anesthesia is unpredictable. A clear plastic 60 L box using 5% isoflurane in 10 L/min O_2 for about 5 minutes can be safely used for induction; the animal can be maintained on 1% to 3% isoflurane in 500 mL/min O_2 using a T-piece from a small face mask. Anesthetic complications include cyclic apneas. Following recovery, platypuses can be returned to water in 4 hours. If injectable anesthesia is used in platypuses, a mixture of alphaxalone and alphadolone acetate (Saffan), 15 mg/kg, IM, gives surgical anesthesia for 60 minutes but recovery often takes more than 4 hours. In echidnas, a combination of ketamine, 15 mg/kg, and xylazine, 5 mg/kg, IM, produces heavy sedation; maintenance can then be achieved using 1% to 3% isoflurane in 500 mL/min O_2 using a T-piece with a small facemask [49].

Oral problems

Many infectious agents have been isolated from monotremes, but their significance in the oral cavity is doubtful or uncertain because most seem to be well adapted to their host and cause little obvious pathology. Platypuses suffer from few problems, apart from punctures, lacerations, and cuts on the bill from trauma, eels, water rats, or fighting among males. Abrasions on the bill in captivity may result from digging in an attempt to get out of the enclosure. Treatment is generally unwarranted. In contrast, minor injuries to the echidna's beak can be serious, because the beak, which contains bony prolongations of the premaxilla and mandibles, is a delicate organ and is prone to trauma. The nares and mouth are located in the tip of the beak; therefore damage affects respiration, prehension of food, and olfaction. Soft-tissue injuries that result from cat, dog, or fox bites are occasionally seen and should be treated appropriately [49]. Fibroma of the beak (neoplasia) has been reported in echidnas [50].

Marsupials

This order of mammals is large and diverse; there are 262 living species in 16 families that are found mainly in the Australian region. One anatomical feature that distinguishes marsupials from other mammals is the possession of a pouch [45].

In the past, marsupials were divided into two suborders on the basis of the dentition: the Polyprotodontia with small, unequal incisors and large canines, and the Diprotodontia with large first incisors and the other incisors and canines are reduced or absent. The marsupials are usually now divided instead into five superfamilies, the Phalangeroidea, Permeloidea, Dasyuroidea, Dipelphoidea, and Caenolestoidea, on the basis of nondental characters, particularly limb morphology [5].

The basic marsupial dental formulae seems to be $I^5{}_4$:$C^1{}_1$:$p^3{}_3$:$M^4{}_4$ = 50 (Table 3) [46]. There are, however, difficulties with nomenclature and homology [51]. Although rudimentary precursors of other teeth occur in some species, such as the brush-tailed phalanger (*Trichosurus vulpecula*) and the short-tailed wallaby (*Setonyx biachyurus*) [52,53], usually it is only one of the apparently permanent teeth, the third premolar (P3) that replaces a deciduous precursor. The functional marsupial dentition can, therefore, either be thought of as a permanent one, with a deciduous dentition that has been almost completely suppressed [54], or the whole dentition, apart from P3, can be regarded as homologous with the eutherian deciduous dentition plus the permanent molars, in which case, the adult formula would be: $I^5{}_4$:$C^1{}_1$:${}^{mmPm}{}_{mmPm}$:$M^3{}_3$ [55]. Although it is probably best to follow the late-nineteenth century pioneer paleontologist, F. Ameghino, and consider the postcanine teeth (P.C.) as a single series with the basic formula: $I^5{}_4$:$C^1{}_1$:P.C.$^7{}_7$ [51,56].

In the different marsupial species, the number of teeth varies greatly. The opossums (Dipelphidae) have the formula that was given above, but, in the other families, the number of incisors, canine, and postcanine teeth are reduced in various degrees. The reduction in numbers is most extreme in the wombats (Vombatidae) with only one large, rodent like incisor in each quadrant, which, because there is no canine, is separated from the first of the postcanine teeth by a long diastema (Fig. 5) [46].

Superfamily Phalangeroidea (kangaroos, wallabies, bettongs, and potaroos)

Dentition

In the family Macropodidae, which includes the kangaroos, wallabies, bettongs, and potaroos, the dental formula is: $I^3{}_1$:$C^{0\text{-}1}{}_0$:$P^2{}_2$:$M^4{}_4$ = 32–34 [5]. The single, large, lower incisor is procumbent and is of continuous growth. The upper incisors are arranged in an arch, which are separated from the

Table 3
Dental formulas of the marsupials

Basic metatherian tooth formula	(I5/4:C1/1:P3/3:M4/4)×2 = 50
Macropus rufus (red kangaroo)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Macropus giganteus (Eastern grey kangaroo)	
Macropus rufogriseus (red-necked wallaby)	
Macropus rufogriseus bennetti (Bennett's wallaby)	
Macropus eugenii (Dama wallaby)	
Macropus irma (western brush wallaby)	
Macropus dorsalis (black-striped wallaby)	
Petrogale penicillata (brush tailed rock wallaby)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Lagorchestes conspicillatus (spectacled hare-wallaby)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Lagorchestes leporides (eastern hare-wallaby)	
Dorcopsulus macleayi (Papuan forest wallaby)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Dendrolagus bennettianus (Bennett's tree kangaroo)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Dendrolagus lumholtzi (Lumholtz' tree kangaroo)	
Dendrolagus ursinus (Vogelkop tree kangaroo)	
Bettongia penicillata (brush-tailed bettong)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Bettongia gaimardi (Eastern bettong)	
Bettongia lesueuri (boodie)	
Potorous tridactylus (potaroo)	(I3/1:C0–1/1:P2/2:M4/4)×2 = 34–36
Schoinobates volans (greater glider)	(I0–2/1–3:C1/0–1:P1–3/1–3: M3–4/3–4)×2 = 24–42
Petaurus australis (fluffy glider)	
Dactylopsila trivirgata (common striped possum)	
Dactylopsila megalura (large-tailed possum)	
Pseudocheirus fobesi (moss-forest possum)	
Pseudocheirus albertisii (d'Albertis' ringtail)	
Pseudocheirus peregrinus (common ringtail possum)	
Trichosaurus vulpecula (brush-tailed possum)	
Trichosaurus caninus (mountain possum)	
Phalanger maculates (spotted phalanger)	
Phalanger ursinus (bear phalanger)	
Phalanger orientalis (common phalanger)	
Acrobates	
Distoechurus	
Cercatetus	
Phascolarctidae (koala)	(I3/1:C1/0:P1/1:M4/4)×2 = 30
Vombatidae (Wombat)	(I1/1:C0/0:P1/1:M4/4)×2 = 24
Peramelidae	(I4–5/3:C1/1:P3/3:M4/4)×2 = 46–48
Isoodon auratus (golden bandicoot)	
Rhynchomeles	
Macrotis	
Echymipera	
Peroryces	
Chaeropus	
Perameles	
Dasyurus	(I4/3:C1/1:P2/2:M4/4)×2 = 42
Dasyurus maculates (tiger cat)	
Dasyurus geoffroii (chuditch)	
Phascolosorex dorsalis (narrow-striped marsupial mouse)	(I4/3:C1/1:P3/3:M4/4) × 2 = 46

Table 3 (*continued*)

Phascolosorex doriae (red-bellied marsupial mouse)	
Myoictis	
Antechinus flavipes (yellow-footed antechinus)	
Phascogale tapoatafa (tuan)	
Myrmecobius fasciatus (banded anteater)	(I4/3:C1/1:P3/3:M5–6/5–6)×2 = 50–54
Dipelphys marsupialis (common opossum)	(I5/4:C0–1/1:P3/3:M4/4)×2 = 50
Dipelphys azarae (s. American opossum)	
Metachirus nudicaudatus (brown four-eyed opossum)	
Philander opossum aztecus (grey four-eyed opossum)	
Caluromys philander (woolly opossum)	
Lutreolina crassicaudata (little water opossum)	
Monodelphia maraxina (short-tailed opossum)	
Monodelphia domestica (grey short-tailed opossum)	
Marmosa robinsoni (mouse opossum)	
Caenolestoidea	(I5/4:C0–1/1:P3/3:M4/4)×2 = 50

cheek teeth by a long diastema (Fig. 6), that may contain a small canine [57]. In the mandible, the incisors and cheek teeth are also separated by a long diastema, but no canine is present. In the bettongs (*Bettongia* spp), the upper first incisor also grows continually. The cheek tooth rows are curved with the convexity buccally. The other cheek teeth are broad and quadritubercular or bilophodont in keeping with the herbivorous diet [57].

Tooth eruption

In marsupials, only P3 replaces a deciduous precursor; in macropods, P3 replaces m3 and the tooth that is immediately mesial to it (m2, P2, or P.C.2,

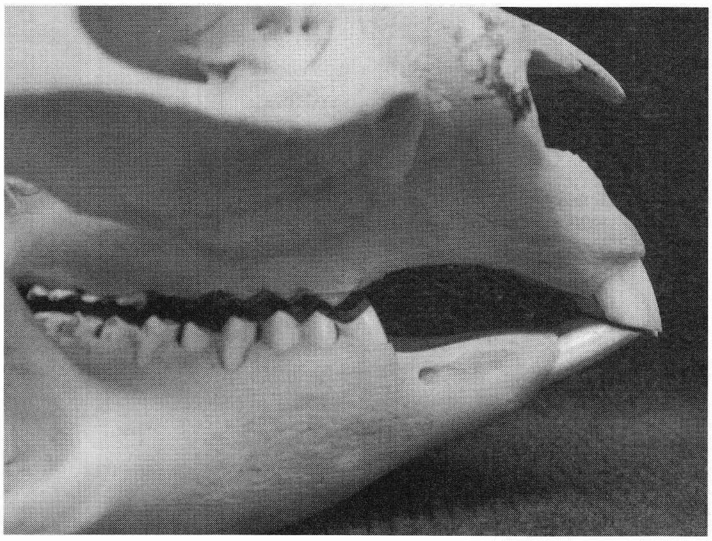

Fig. 5. Lateral view of a wombat jaw (*Vombatus* sp).

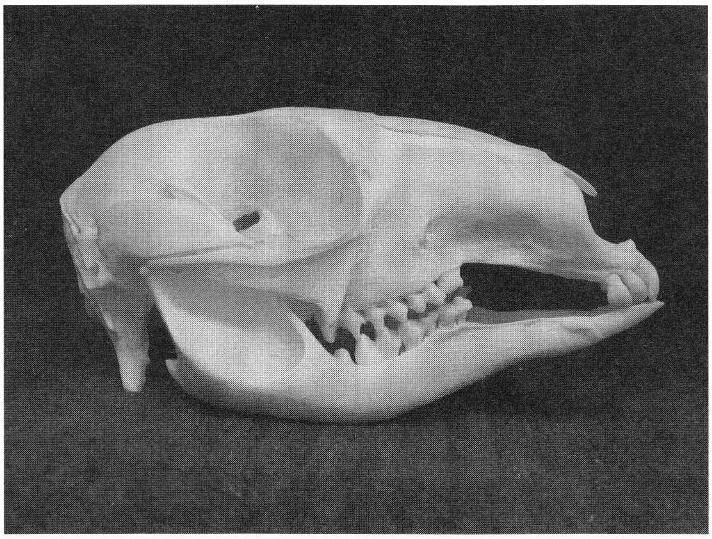

Fig. 6. Lateral view showing long diastema between incisors and cheek teeth of an Eastern Grey kangaroo jaw (*Macropus giganteus*).

depending on the terminology used). In the red kangaroo (*Macropus rufus*) and eastern gray kangaroo (*M giganteus*), M3 erupts at the same time as P3 but, in the wallaroo (*M robustus*) and red-necked wallaby (*M rufogriseus*), P3 erupts between the early-erupting M4 and the later-erupting M3 [58]. Occasionally, P3 replaces only one of them and the other is retained, as in the banded hare-wallaby (*Lagostrophus fasciatus*) [58]. In macropods where P3 is unerupted, the deciduous molar persists, as has been recorded in 18 of 300 gray kangaroos [59].

Irregularities in tooth position in the macropods are rare [57]. The position of P3 in the upper jaw can be variable, but it is usually in line with the molar series so that its buccal surface forms a continuous curve with the molars.

Molar progression

The macropods demonstrate the phenomenon of molar progression [60], where worn molars are shed anteriorly and new molars erupt behind the remaining two molars in the area of occlusion. This maintains a sharp and efficient dental mill throughout life [61]. In young animals, M1 is opposite from the root of the malar process with the developing teeth projecting well back into the infratemporal fossa. In old animals, M4 is just posterior to the malar process with a considerable interval between the tooth and the end of the maxilla. As a result of this anterior movement, in old animals, the molars may be reduced to one in each quadrant [59]. M1 is always disproportionally worn, namely more than its eruption. In animals in which

there has been partial or complete loss of teeth from fracture or excessive attrition, the anterior movement of the arch on the injured side is usually less than on the opposite side [57]. Specimens in whom the molar is absent show that the developing teeth at the posterior end of the rows are important factors in molar progression.

Periodontal disease

The idea that animals living in their natural habitat are unlikely to suffer from periodontal disease is challenged when the macropods are studied. Skulls from 119 wild Eastern gray kangaroos established that they suffered from localized alveolar crest destruction associated with food packing between teeth as well as from gross depositions of calculus on the crowns of teeth [62]. In many specimens, the remains of fibrous food were still in situ between the teeth. Western gray kangaroos from the Taronga Zoo collection were also found to suffer from periodontal disease, with calculus build-up, gingival recession, and alveolar bone loss (Fig. 7). It seems that the deposition of calculus begins while the teeth are erupting because it was found on the occlusal surfaces of the erupting teeth; however, as soon as the teeth come into occlusion the calculus is worn away from the occlusal surfaces, and, thereafter, is found on the lingual and buccal surfaces only [28]. In a 1989 survey, 35% of the major problems that were reported in tree kangaroos (*Dendrolagus* spp) were related to periodontal disease; these ranged from receding gums to abscesses of the teeth and surrounding tissue [63]. In a recent study, black-pigmented bacteria were cultivated from the plaque from 32 of 90 marsupials [64]. Most isolates were identified as *Porphyromonas gingivalis*-like species, with the higher prevalence of isolation from the oral cavity of the kangaroos and wallabies. This finding

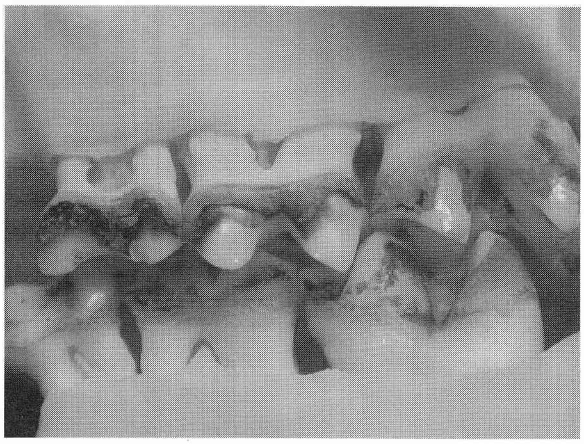

Fig. 7. Periodontal disease, calculus deposition, alveolar bone loss and root exposure in a Western Grey kangaroo.

supports Wallach's [65] hypothesis "that there is an association between periodontal disease and lumpy jaw in macropods, the periodontal lesions providing portals of entry for the organism." Periodontal disease treatment involves systemic antibiotics and surgical intervention to remove the severely affected teeth and provide drainage. Captive animals' teeth with exposed roots can be salvaged if the tooth remains solid, can be thoroughly root planed, and attention to diet and oral care are instigated.

Lumpy jaw

The endemic character of lumpy jaw in Australian marsupials seems to be of ancient lineage; evidence of it was found in six Pleistocene fossil macropod mandibles from a site that was estimated to be 26,000 years old [66]. In Australia, *Fusobacterium necrophorum* is most commonly isolated from lesions in pure culture [67–70]. They are necrotizing or purulent or both, and there is acute inflammation of soft tissue, severe necrosis and lysis of the bone, with resorption of the tooth roots (Figs. 8, 9). In many cases, necrosis is so severe that teeth fall out or can be easily extracted (Fig. 10). Affected animals are unable to masticate because of the inflammation and pain in the soft tissue. Pathological fracture of the mandible is common. Secondary sites of infection occur in the lungs, liver, and gastric mucosa as a result of aspiration of infected saliva or pus [67–69] a foul, fetid odor accompanies infections.

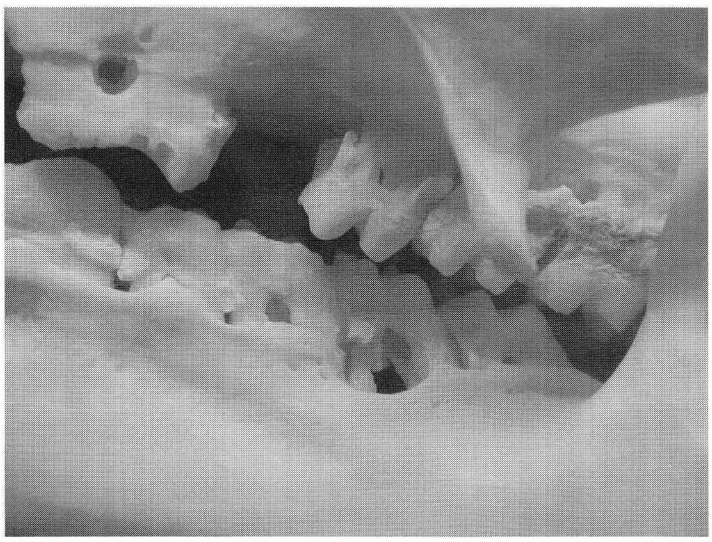

Fig. 8. Lumpy jaw, calculus deposition, bone loss and root exposure jaw in a Good Fellow's tree kangaroo.

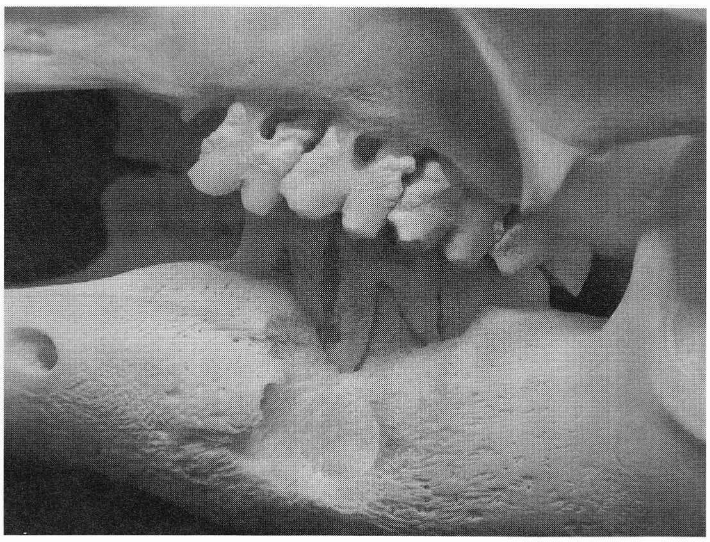

Fig. 9. Lumpy jaw, calculus deposition, advanced bone loss, and root and furcation exposure in a red-necked wallaby (*Macropus rufogriseus*).

A study of 144 skulls from kangaroos in German and Australian museums concluded that red kangaroos in captivity are particularly liable to suffer from lumpy jaw that commences as a focal periodontitis, involves the teeth, and leads to their loss [71]. Another study reported that 21% of macropods from the San Diego Zoo and Wild Animal Park were affected,

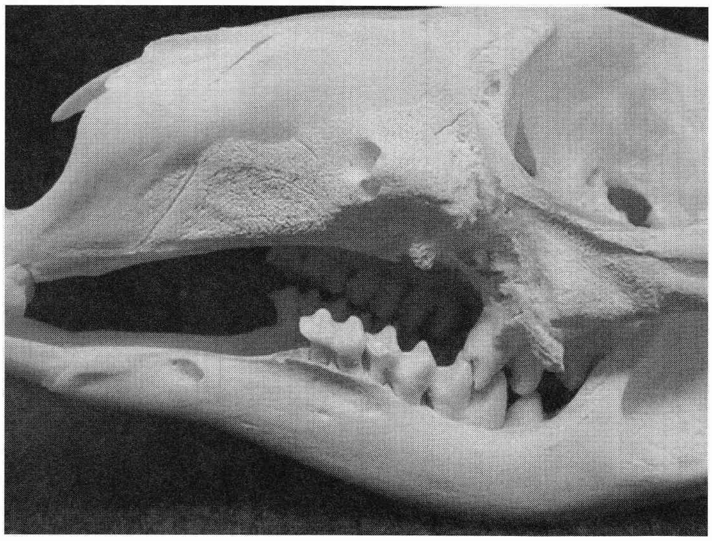

Fig. 10. Lumpy jaw, advanced destruction of bone and tooth loss in a bilby.

but the New Guinea scrub wallabies (*Thylogale brunii or T stigmatica*) and a red-necked wallaby that were kept on open parkland were hardly affected [72]. Further studies from Canberra, Australia reported that the red-necked wallaby and the red kangaroo showed a greater susceptibility to the disease than the Eastern gray kangaroo and the wallaroo [73]. Many of the lumpy jaw cases reviewed from Melbourne Zoo, Australia, seemed to develop at the site of erupting molars [74].

Treatment of lumpy jaw

Treatment, although not rewarding in advanced cases, consists of debriding the affected area, by removal of affected teeth and curettage of necrotic bone. It was reported that local treatment of the abscess with hydrogen peroxide or a preparation that contains an iodine antiseptic may help, followed by long-term parenteral antibiotic treatment for 3 to 6 weeks [74].

Treatment recommendations at Melbourne Zoo, Australia [75] involves flushing the extraction site and affected area with sterile saline, benzylpencillin solution (BenPen), or metronidazole solution (Metrin solution). The site may be left open or packed with a protective paste (Orabase) or, if the defect is large, cotton umbilical tape that is coated in zinc-oxide eugenol paste. Parenteral antibiotics, including long-acting penicillin (Aquacaine), 1mL/10 kg, IM, and clindamycin phosphate (Antirobe) 11 mg/kg, IM, and pain relief, ketoprofen (Ketofen), 1–2 mg/kg, and buprenorphine (Temgesic), 0.01 mg/kg, subcutaneous (SC), are also recommended. Affected animals should be housed in an off-limits enclosure during the treatment course, to minimize contamination of the display enclosure environment with causative organisms. Animals are anesthetized once weekly for reassessment until resolution of infection or healing of the extraction site has occurred; antibiotics are continued during this time. In cases of severe and extensive osteomyelitis, or when animals have had repeated episodes of disease, euthanasia is considered appropriate.

At Taronga Zoo, Sydney, Australia, a similar protocol is followed, but with the addition of either antibiotic-impregnated artificial bone matrix or antibiotic-impregnated polymethacrylate beads (AIPMMA) to permit a prolonged action of the antibiotic in the site and to reduce the side effects of systemic antibiotics. The encapsulated nature of these lesions makes systemic antimicrobial therapy difficult, because antibiotic penetration into the site of infection is poor [76]. These chronic infections generally necessitate long-term antibiotic therapy and given the incidence of bacterial resistance, there is often a need to rely on aminoglycosides, which may have toxic side effects when given systemically. Thus, a high and reliable concentration of antibiotic at the site of infection with reduced systemic side effects can be achieved with the use of AIPMMA beads [76].

Lumpy jaw case study (case 1)

A nine-year-old female Bennett's Wallaby (*M rufogriseus frutica*) was treated for a swollen and inflamed left mandible (Fig. 11) using AIPMMA beads [77]. The affected tooth was extracted and because adequate exposure was not available for thorough curettage of the diseased bone, an incision was made through the subcutaneous tissue and muscle over the enlarged osteomyelitic area. The necrotic tissue was thoroughly and completely debrided, a sample was collected and sent for culture and sensitivity, and the area was flushed with a solution of 5% enrofloxacin (Baytril) under high pressure. AIPMMA beads, that were impregnated with gentamycin (Gentapex-50) and clindamycin, were placed into the lesion (Fig. 12), and the muscle and subcutaneous tissues were sutured with 2/0 polyglactin 910 (Ethicon) to hold the beads in place, followed by suturing the skin with 3/0 polyglactin 910. A collar was placed on the animal to prevent it from interfering with the wound for 24 hours. The animal was retained in the hospital for 5 days and received carprofen (Rimadyl), 4 mg/kg, buprenorphine, 0.01 mg/kg, and enrofloxacin, 12 mg/kg, daily by SC injection. The animal returned to the collection; no further treatment was necessary although significant swelling of the mandible was still evident (Fig. 13).

Lumpy jaw case study (case 2)

A red-necked wallaby (*M rufogriseus*) was treated for a swollen face that involved the left lower incisor (Fig. 14). The affected area was radiographed and there was significant loss of bone with evidence of osteomyelitis present (Fig. 15). A culture was sent off and a mixed growth of bacteria was found.

Fig. 11. Left mandibular swelling and inflammation in a Bennett's wallaby (*Macropus rufogriseus frutica*).

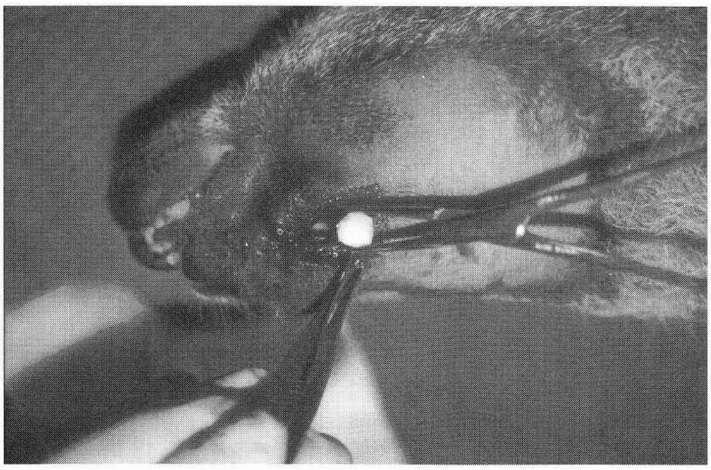

Fig. 12. Use of antibiotic impregnated beads in the wallaby from Fig. 11.

The tooth was extracted followed by curettage and debridement of the surrounding bone. Synthetic bone graft particulate (Consil, Nutramax, Baltimore, MD), that was impregnated with doxycycline powder (Psittavet, Vetafarm, Sydney, Australia), was placed into the lesion, followed by suturing the gingiva with 3/0 polyglactin 910 (Figs. 16, 17). The animal was retained in the hospital for 5 days and received carprofen, 4 mg/kg; buprenorphine, 0.01 mg/kg; and enrofloxacin, 12 mg/kg; daily by SC injection. The animal returned to the collection, became anorexic, and with further treatment continued to decline, which resulted in euthanasia 6 months later.

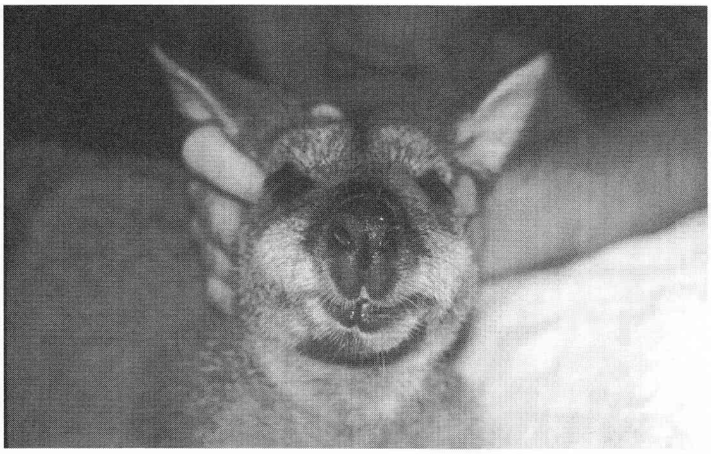

Fig. 13. Postoperative photograph showing the wallaby from Fig. 11, 3 months after surgery.

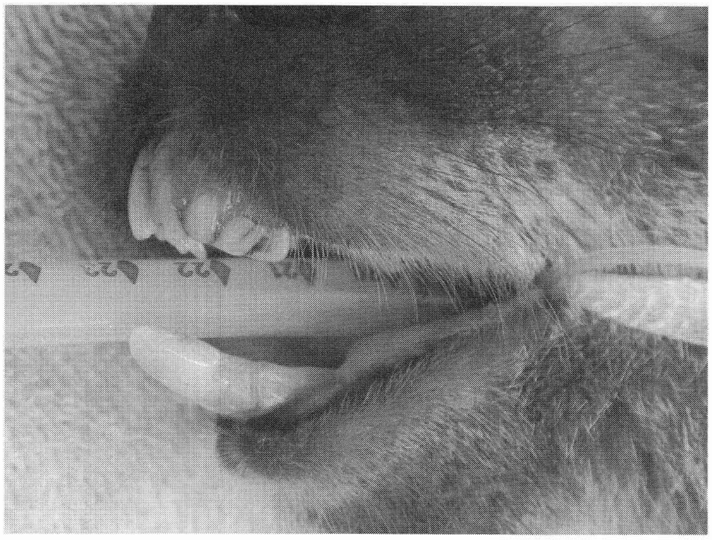

Fig. 14. Lumpy jaw associated with a lower left incisor tooth in a red-necked wallaby (*Macropus rufogriseus*).

Prevention of lumpy jaw

The basic diet that is fed to macropods at the Melbourne Zoo [75] is as follows: tray/trough, 3% macropod pellets / 66% chopped hard vegetables (carrot, sweet potato) *ad lib.* high quality meadow hay; fresh green lucerne

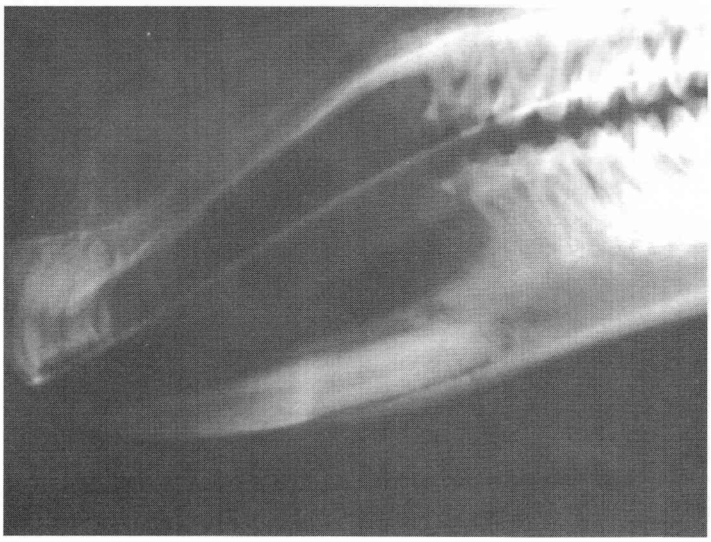

Fig. 15. Lateral radiograph showing increased space in periodontal ligament and radiolucency around tooth apex of lower incisor tooth of wallaby from Fig. 14.

Fig. 16. Postoperative photograph showing sutured extraction site of wallaby from Fig. 14.

once weekly; and browse once daily (mainly *Eucalyptus* spp). It was proposed that "lumpy jaw" can be minimized with careful husbandry, by reducing environmental stress (cold stress, overcrowding, increasing interaction with visitors), as well as keeping enclosures free from heavy fecal contamination, not overcrowding, and avoiding floors that are too wet or muddy [73–75,77].

Tooth fractures

Fracture of the delicate, long, procumbent incisor teeth is a common hazard in the wild and captive states, and may commonly lead to dentoalveolar abscesses [78]. In kangaroos and wallabies, the basal ends of the lower incisors are near the mental foramen; therefore, when the

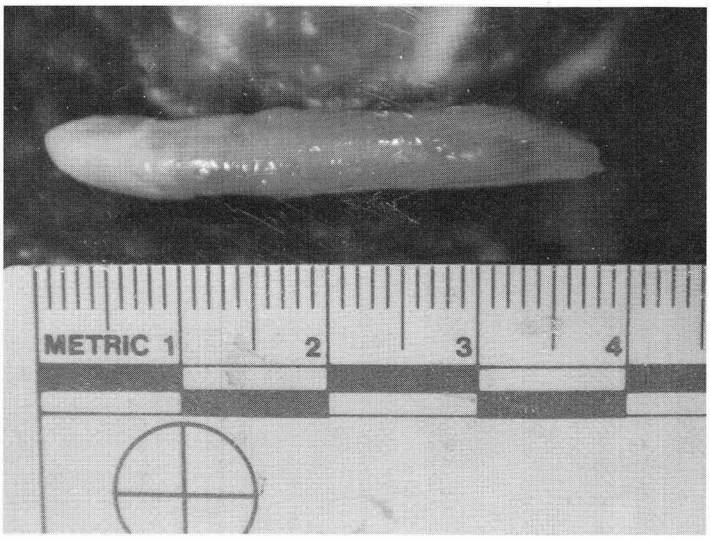

Fig. 17. The extracted tooth of wallaby from Fig. 14.

incisor is abscessed, the pus often comes to the surface through the mental foramen. In the much smaller potaroo (*Potorous tridactylus*), however, the root of the incisor extends back to the medial side of the first tooth of the molar series where it produces a slight elevation of thin bone on the inner surface of the mandible (Fig. 18). If the incisor becomes abscessed, the pus forms an opening there and may furthermore secondarily involve the molar, leading to its loss. A variety of organisms, from a single, localized abscess in the mandible of kangaroos and wallabies, generally of the genera *Fusobacterium*, *Bacteroides*, and *Actinomyces* have been isolated [79].

Attrition

Trichobezoars are not an uncommon finding in the stomach of older tree kangaroos and may indicate impaired mastication or excessive grooming [63]. They may be diagnosed by abdominal palpation and radiography. It is important to check for worn or excessively abraded teeth and to consider a change in diet, but trichobezoars generally do not cause clinical signs.

Nutritional secondary hyperparathyroidism

Nutritional secondary hyperparathyroidism occurs in tree kangaroos with the mandible becoming so soft that it becomes pliable (rubber jaw) [80]. The loss of the radiographic lamina dura causes loosening of the teeth and subsequent dental pain. If the disease progresses to fibrous osteodystrophy, there will be facial deformity that occurs because of the enlargement of

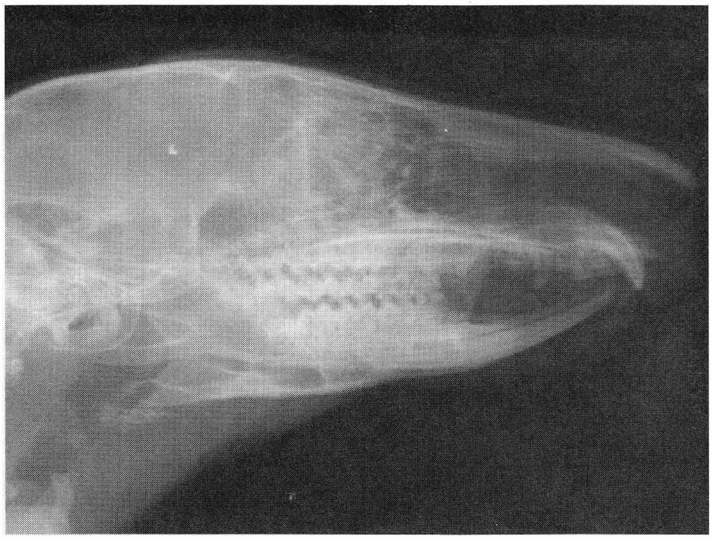

Fig. 18. Lateral radiograph showing the root of the incisor extending back to the medial side of the first tooth of the molar series of a potaroo (*Potorous tridactylus*).

facial, maxillary, and mandibular bones; the animal will be unable to prehend and masticate solid food because of an inability to close the jaws.

Handling for oral examination

Capture of macropods in zoo enclosures for purposes of relocation or treatment can be difficult because they tend to panic when pursued and cornered; this may result in injuries to the animal from attempts to leap through, or over, fences, or to the unwary or unskilled handler [81]. Red and Eastern gray kangaroos are capable of delivering a powerful forward kick with their hindlegs while balancing on their tail, or causing lacerations with their powerful sharp claws on their forelimbs. Wallabies will kick and have been known to bite.

Larger macropods may be caught in a loosely strung twine net that is placed across an enclosure; the animal will become entangled in it as it proceeds along its habitual pathway. Chemical restraint of the red kangaroo can be achieved by darting using etorphine hydrochloride (M-99), 0.04 mg/kg, and acepromazine (ACP), 0.4 mg/kg [81]. In other macropods etorphine and acepromazine can be unreliable, therefore, anesthesia can be achieved using medetomidine, 0.05 mg/kg, and ketamine, 3 mg/kg [81]. Smaller macropods may be caught with a small hand-held hoop-net.

Oral examination in most macropods is difficult because the mouth does not open wide; the clinician's sense of smell is important in detecting

infected teeth. A periodontal probe and radiography can enhance dental examination.

Family Phalangeridae (possums, gliders, and phalangers)

Dentition

The family Phalangeridae includes the possums, gliders, and phalangers. The dental formula of the phalangers is quite varied: $I^{2-3}{}_{1-3}$:$C^{1}{}_{0-1}$:$P^{1-3}{}_{1-3}$/3:$M^{4}{}_{3-4}$ = 26–42.

In the ring-tailed possums (*Pseudocheirus*), the maxillary premolars vary in size and in their distance from each other. In the mandible of the phalangerids, between the long, procumbent first incisor and P3, there are a variable number of small teeth, that are termed "intermediate teeth," because it is not certain which, if any of them, are the canines [82]. The number of intermediate teeth in the mandible varies [5].

In the brush-tailed possums (*Trichosurus vulpecula*), the upper canines are connate, and divided into larger mesial and smaller distal parts by grooves that separate the tips of the crown (Fig. 19) [5]. There are two premolars in each maxilla, P1 and P3. In *Trichuris* var. *fuliginosis*, P1 is a large tooth that is about the same size as the canine but is sometimes absent [83]; in *T caninus* (mountain possum) P1 is always present but P2 is often missing.

There are differences in the length of the muzzle in the various species of ring-tailed possum; in those with long muzzles, the upper incisors form a small, horseshoe-shaped arch, which occludes just labially to the procumbent I1. The canine in the upper jaw is widely spaced between I3 and the straight continuous row of cheek teeth. In the lower jaw, there is a long diastema between the procumbent I1 and the compact row of three premolars together with the four molars, the canine, P1, and P2 being absent. Thus, the upper canine and P1 are not in functional occlusion. In species with short muzzles, the spaces between the upper teeth are considerably less and the teeth are sometimes in contact. In the mandible, there is no diastema and no canine or P1, so the row of cheek teeth, beginning with P2, is usually in contact with the recumbent I1. With less space available for the premolars, the tendency is for P1 to be squeezed out of the arch [5]. Phalangerid molars are quadtribucular, usually with rounded cusps.

Black-pigmented *Bacteroides* species have been isolated from 5 of 21 phalangers [64], but no significant oral infectious diseases have been recorded in this species.

Oral examination

When a thorough oral examination is required, capture can be achieved by quickly grasping them by the tail from behind, lifting the phalangers from the substrate, and dropping them into a burlap bag. The phalangers

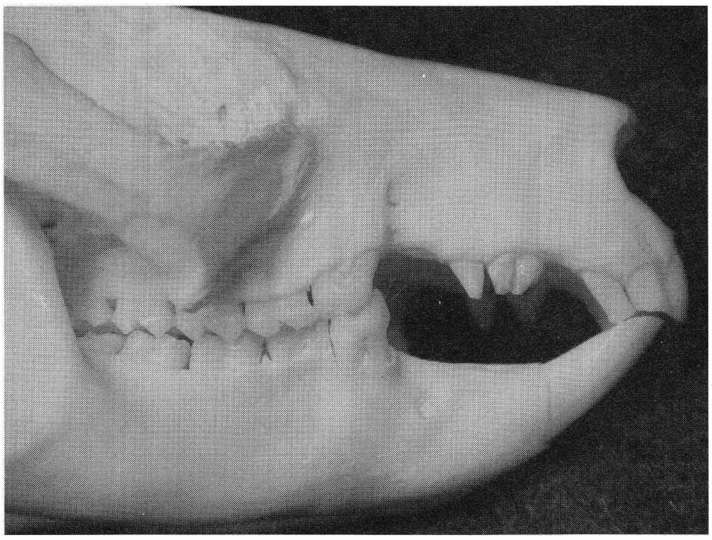

Fig. 19. Lateral view showing connate canine teeth and the intermediate teeth from a brush-tailed possum (*Trichosaurus vulpecula*).

have sharp and powerful claws on all feet, and they will defend themselves vigorously with these [81]; therefore, chemical restraint is needed in all but a tame or ill animal. Anesthesia can be achieved in smaller marsupials, such as *T vulpecula*, with ketamine. 15–30 mg/kg, IM or a combination of ketamine, 30 mg/kg, and acepromazine, 2 mg/kg [81], and in the smaller marsupials, (less than 250 grams), with isoflurane in a plastic chamber.

Family Phascolarctidae (koala)

The koala (*Phascolarctos cinereus*) is an arboreal folivorous marsupial, that derives food, water, and shelter almost exclusively from selected Eucalyptus trees [84]. It has adapted, specialized dentition and digestive processes to overcome the toxic oils that are found in the leaves of these trees. The dental formula is: $I^3{}_1{:}C^1{}_0{:}P^1{}_1{:}M^4{}_4 = 30$ [5] (Figs. 20–22) [5].

A high incidence of neoplasia and opportunistic infections suggests that koalas may be immunodeficent in comparison with eutharians [85]; in vitro and in vivo tests suggested delayed humoral immune responses to a range of antigens, whereas another study demonstrated prolonged IgM production [86]. Severe tooth wear in old age is the principal factor that limits the longevity of otherwise healthy koalas. The age at which tooth wear becomes incompatible with effective mastication varies from approximately 10 to 19 years [84].

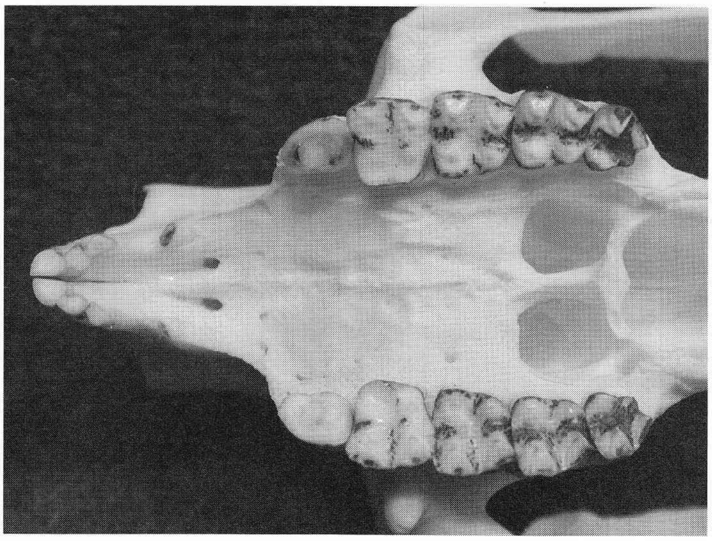

Fig. 20. The upper jaw of a koala (*Phascolarctos cinereus*).

Oral infection and trauma

Pharyngeal inflammation and regional lymph node enlargement (mandibular, facial) has been reported as a result of primary or secondary microbial infection from several organisms, including, but not limited to, *Bordetella bronchiseptica*, *Pseudomonas aeruginosa*, and *Pseudomonas spp*

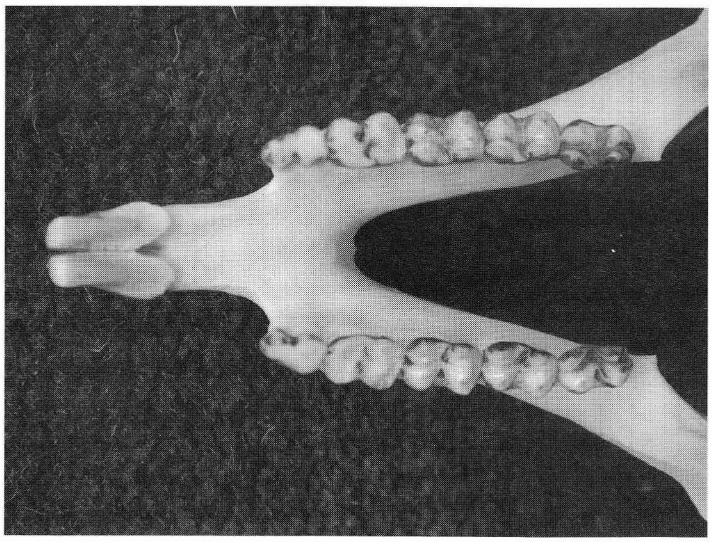

Fig. 21. The lower jaw of a koala (*Phascolarctos cinereus*).

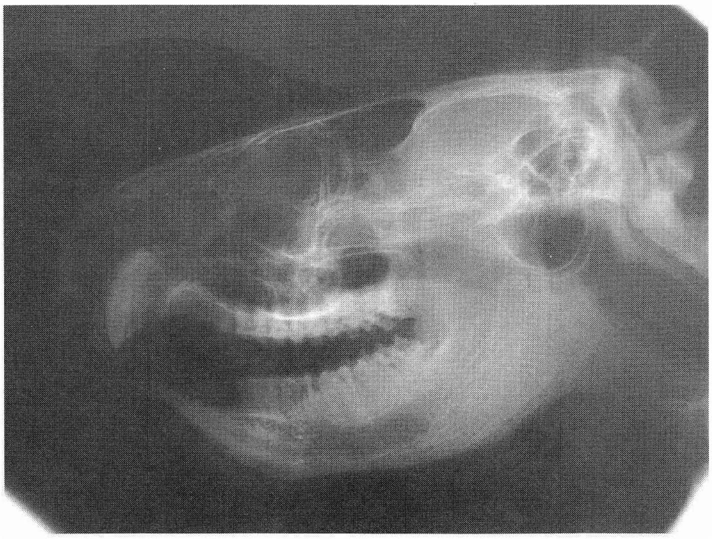

Fig. 22. Lateral radiograph of a koala jaw (*Phascolarctos cinereus*).

[84]. Culture and sensitivity testing is advised before an appropriate antibiotic is chosen. Extensive ulcerations of the gingiva and dorsum of the tongue, with histology revealing a mixed bacterial population in shallow ulcers, has been reported [87].

Oral thrush with shallow erosions or white curd-like accumulations on the tongue and palate is common in hand-raised young koalas; this is caused by *Candida albicans* [84]. Nystatin (Nilstat Oral) 5000 IU/kg, three times a day by mouth, is used as treatment. Koalas also suffer oral trauma, tooth fractures, and pulp exposure.

Oral neoplasia

Neoplasia accounted for 7.5% of 253 captive and free-living koala mortalities in New South Wales (NSW) over a 9-year period, or 12% of wild mortalities [88]. The C-type retrovirus that may cause immunosuppressive or oncogenic changes has been isolated from affected and normal koalas [89]. The most commonly reported neoplasms are lymphoid neoplasia, craniofacial tumors of mixed cartilage and bone, and serosal proliferations. In lymphoid neoplasia, the clinical signs may include anorexia, lethargy, variable body condition, localized or generalized lymphadenopathy, swelling of the face, neck and hindlegs, and spontaneous hemorrhage [90]. There is no successful treatment. Koalas who have craniofacial tumors of mixed cartilage and bone may have nasal or naso-ocular discharges, epistaxis, facial distortion, or palatine swelling (Fig. 23). Tumors typically

Fig. 23. Left facial distortion due to a craniofacial tumor in a koala (*Phascolarctos cinereus*). (*From* Canfield PJ, Perry R, Brown As, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

involve the bones of the nasal cavity and paranasal sinuses and have been described as benign and expansive (Fig. 24). Histologically, the masses consist of irregular compartments of hypertrophying chrondrocytes embedded connective tissue, with varying degrees of calcification and ossification (Figs. 25–27). Radiographically, the tumors appear as dense masses with speckled appearance and distinct, rounded outlines (Fig. 28). Tumors that have been surgically removed have reoccurred [90].

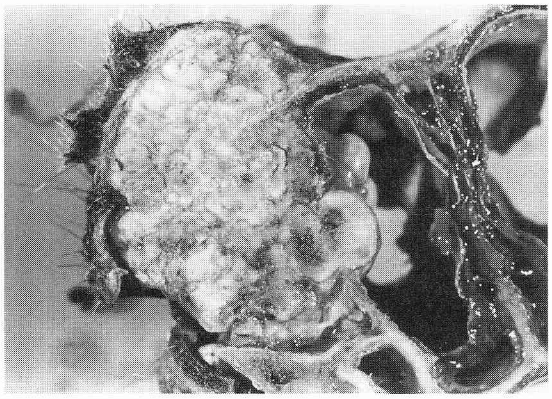

Fig. 24. Nodular, lobular appearance of an exposed craniofacial tumor viewed caudorostrally. (*From* Canfield PJ, Perry R, Brown As, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

Family Vombatidae (wombat)

Dentition

Wombats (*Vombatus* and *Lasiorhinus*) have teeth that are highly adapted to a herborious diet, but in a different way than the macropods. The dental

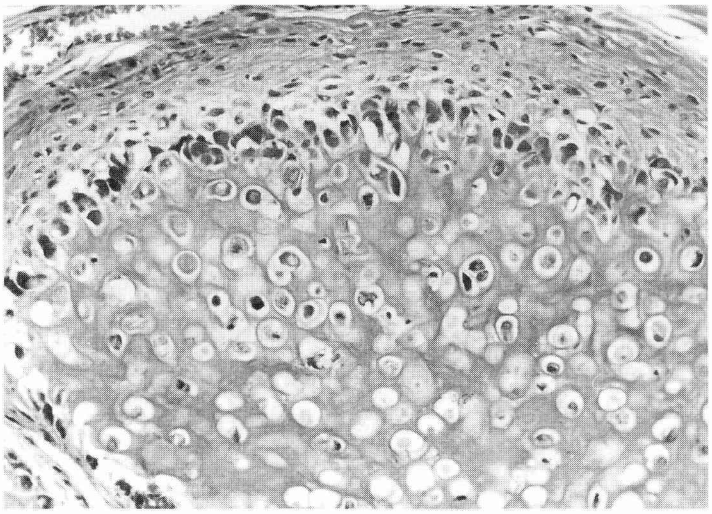

Fig. 25. Rim of a compartment of a craniofacial tumor showing perichondrium-like connective tissue and chondroblasts. Haematoxylin (H) and Eosin (E) ×125. (*From* Canfield PJ, Perry R, Brown As, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

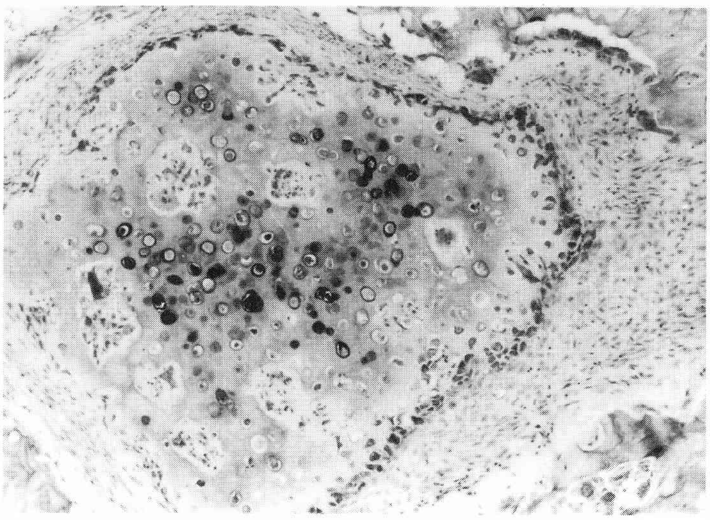

Fig. 26. Compartment (lobule) showing centrally retained, hypertrophied chrondrocytes. Toluidine blue ×62. (*From* Canfield PJ, Perry R, Brown As, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

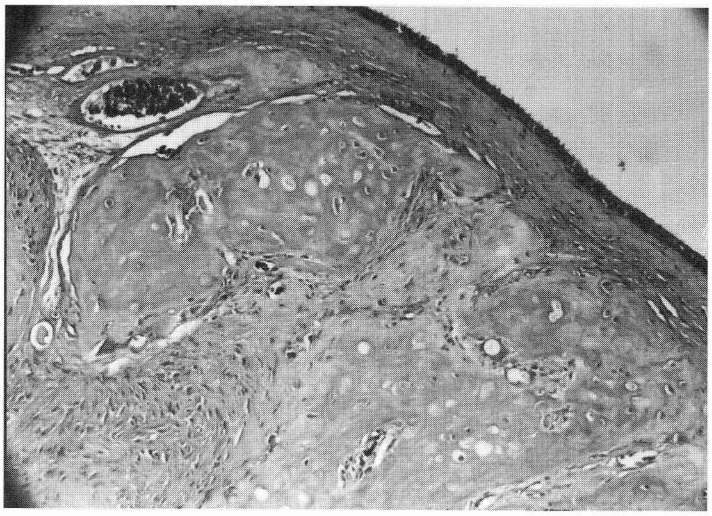

Fig. 27. Nodular proliferations of a craniofacial tumor adjacent to nasal mucosa. The nodules are composed of mature bone. H and E ×80. (*From* Canfield PJ, Perry R, Brown As, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

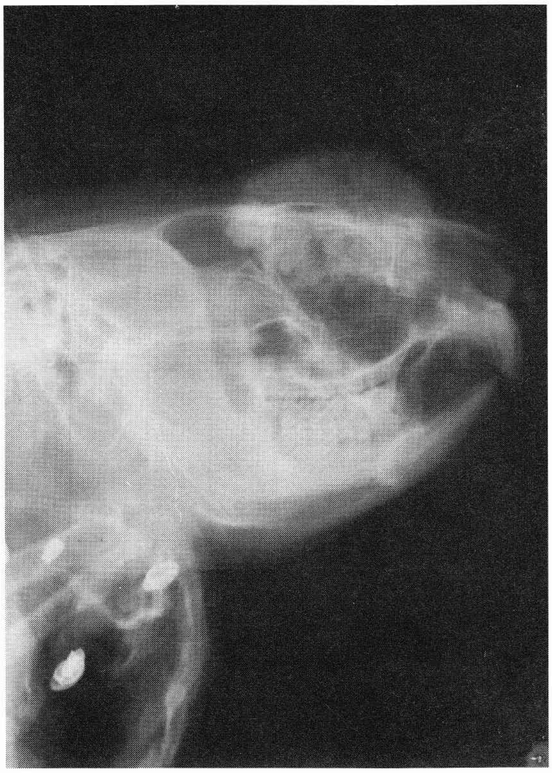

Fig. 28. Lateral radiograph showing the extent of the craniofacial tumor depicted in Fig. 23. (*From* Canfield PJ, Perry R, Brown AS, et al. Cranio-facial tumours of mixed cartilage and bone in koalas (*Phascolarctos cinereus*). Aust Vet J 1987;64(1)20–2; with permission.)

formula is: 1/1:0/0:1/1:4/4 = 24 [5]. They have only a single pair of upper and lower incisors, which, together with the other teeth, are rootless and grow continuously throughout the animal's life. This characteristic is unique among the marsupials. The molars and incisors of wombats wear in such a way as to maintain extremely sharp shearing faces on the buccal side of the lower molars and on the palatal surface of the upper molars [91] (see Fig. 5; Figs. 29, 30). This efficient dental mill is used to break up their highly fibrous food, principally grasses and sedges. The effectiveness of the dental mill of the wombat is seen in the greater proportion of fine particles in their feces compared with the feces of kangaroos [92].

Oral diseases and conditions

Caries is not a common finding in marsupials, but has been reported in the literature, on the incisive edge of an upper incisor in a captive wombat (*V ursinus*) [16]. There has been no significant oral infectious diseases

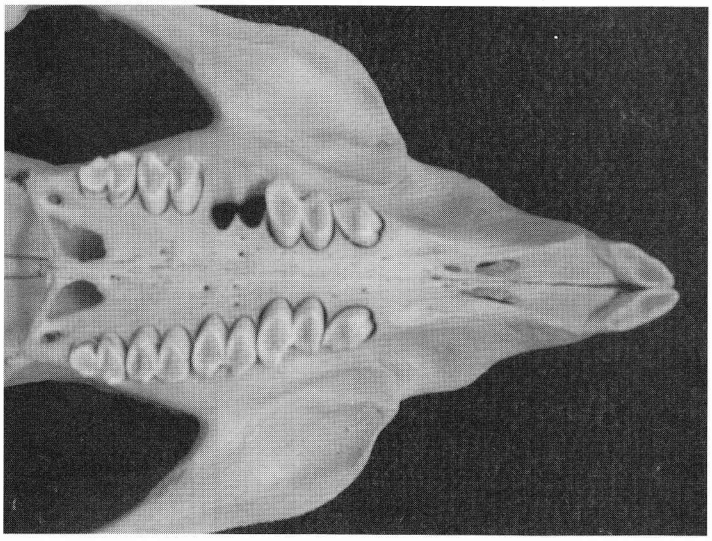

Fig. 29. The upper jaw of a wombat (*Vombatus* sp).

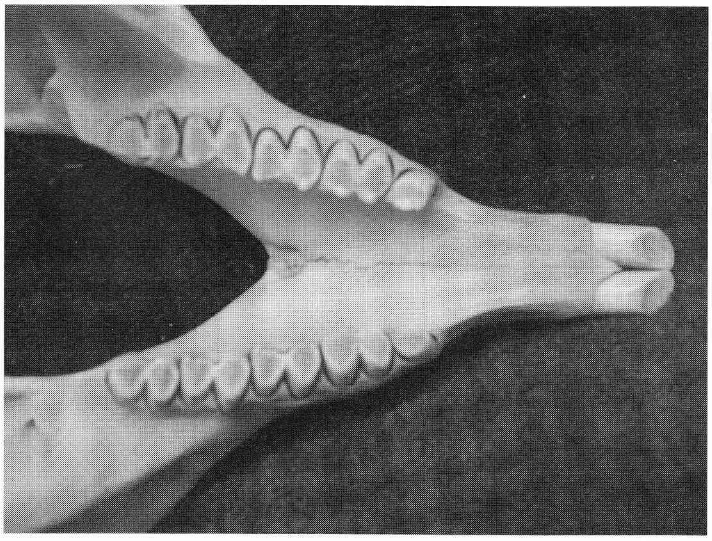

Fig. 30. The lower jaw of a wombat (*Vombatus*).

recorded in this species, but a wombat from Taronga Zoo, Australia had a significant malocclusion of the mandible, or wry mouth, which resulted in its eventual euthanasia (Figs. 31–33).

Handling

Male wombats will charge with their mouth wide open and lower incisors pointing forward as tusks at an unwary intruder in their enclosure. Wombats may be approached from behind and grasped with both arms around the thoracic region immediately behind the forelegs [81].

Superfamily Permameloidea (bandicoots)

Bandicoots in the wild are omnivorous but have a preference for insects. The dental formula is: $I^{4-5}{}_{3}{:}C^{1}{}_{1}{:}P^{3}{}_{3}{:}M^{4}{}_{4}$ = 46–48 [5]. The lower incisors are more or less equal in size and are not procumbent; the canines may be large or as small as the incisors, and the molars are tribercular or quadtriburcular. The muzzle is long and narrow and the canines and premolars are widely spaced [5].

Periodontitis, a frequent disease in captive bandicoots that are fed a predominantly soft food diet, is also found in wild bandicoots that scavenge the food that the picknickers leave behind in Australian national parks [93]. Clinical signs of periodontitis include calculus formation, bleeding and recession of the gums, and in chronic cases, loss of teeth and body condition [94].

Superfamily Dasyuroidea (marsupial cats and marsupial mice)

In Dasyuridae, which includes the marsupial cats and marsupial mice, the muzzle is fairly short but the canines and premolars are slightly spaced. In a series of 30 skulls of captive-bred kowari (*Dasyuroides byrnei*) from the Queensland Museum, a higher incidence of brachycephaly and malocclusion was found compared with wild animals [95]. The dentition is adapted for an insectivorous or carnivorous diet. The incisors are not procumbent, the canines are well-developed, and the molars are tritubercular. The dental formula is: $I^{4}{}_{3}{:}C^{1}{}_{1}{:}P^{2}{}_{2}{:}M^{4}{}_{4}$ = 42 [5]. In *Dasyurus*, the two premolars are regarded as P1 and P3 [83].

The larger dasyurids have powerful jaws and sharp claws that they use for defense; the small dasyurids will also bite hard if the occasion warrants such action.

In the genera *Phascolosorex*, *Myoictis*, *Antechinus*, and *Phascogale* the dental formula is: $I^{4}{}_{3}{:}C^{1}{}_{1}{:}P^{3}{}_{3}{:}M^{4}{}_{4}$ = 46 [5]. In tuan (*Phascogale tapoatafa*) the P3 is occasionally small, single-rooted, and varies in size [5].

The Tasmanian devil (*Sarcophilus harrisii*) has a dentition that has evolved for its carnivorous diet (Figs. 34–36). The dental formula is: $I^{4}{}_{3}{:}C^{1}{}_{1}{:}P^{2}{}_{2}{:}M^{4}{}_{4}$ = 42 [5]. Among 22 skulls that were reviewed, only two

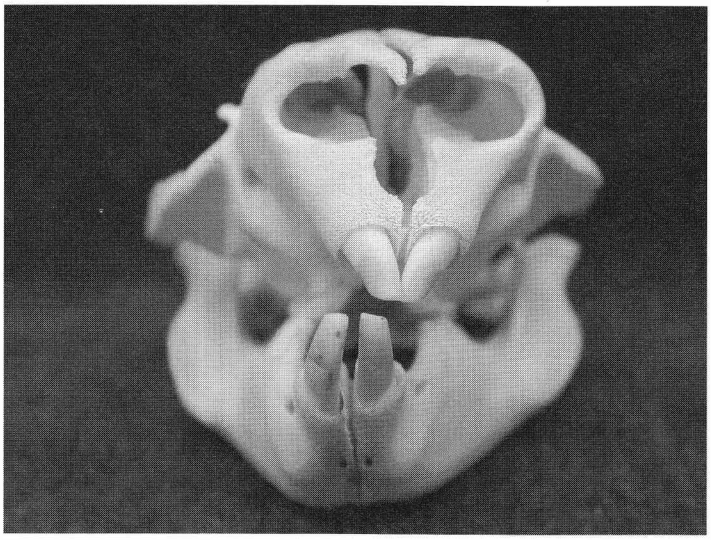

Fig. 31. Malocclusion showing a left sided displacement of the incisor teeth due to overgrowth of the left mandibular cheek teeth in a wombat (*Vombatus*).

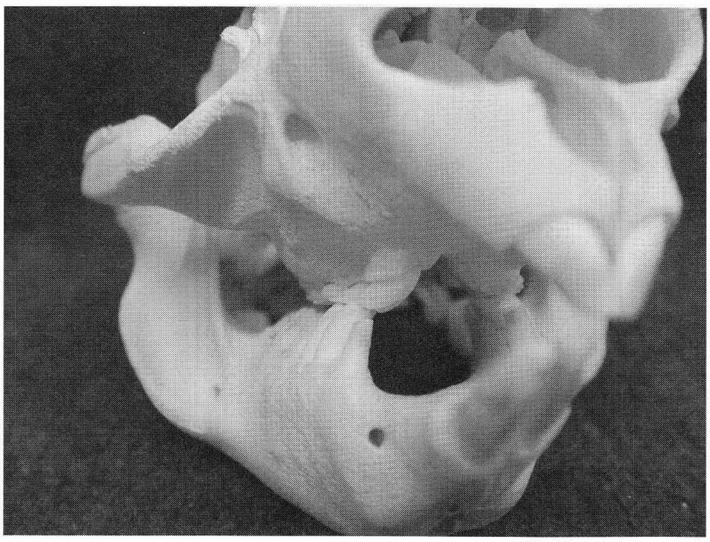

Fig. 32. Malocclusion showing excessive overgrowth of cheek teeth in a wombat (*Vombatus*) from Figure 31.

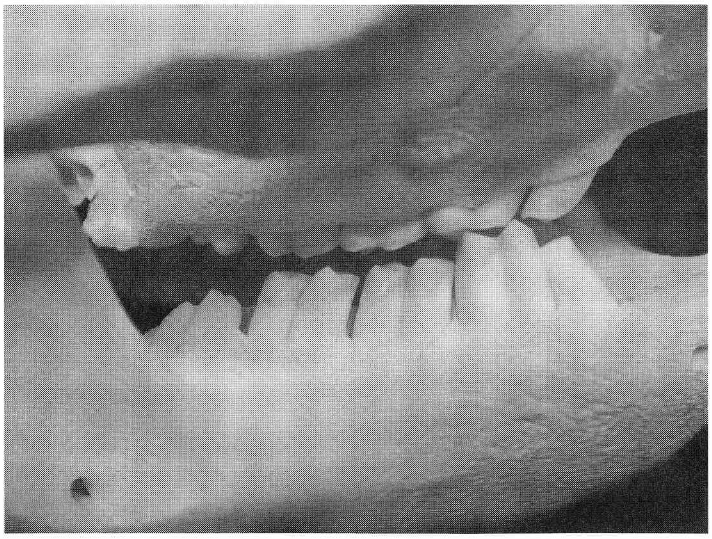

Fig. 33. Malocclusion showing excessive growth of the mandibular cheek teeth in a wombat (*Vombatus*) from Figure 31.

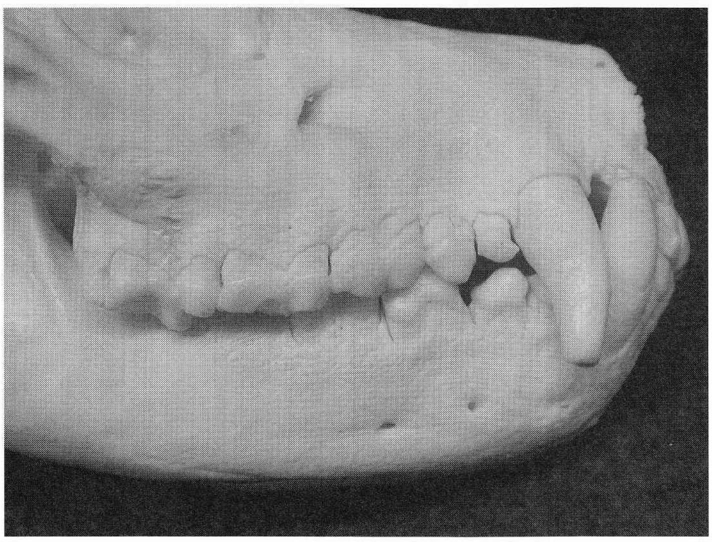

Fig. 34. Lateral view of a Tasmanian devil (*Sarcophilus harrisii*).

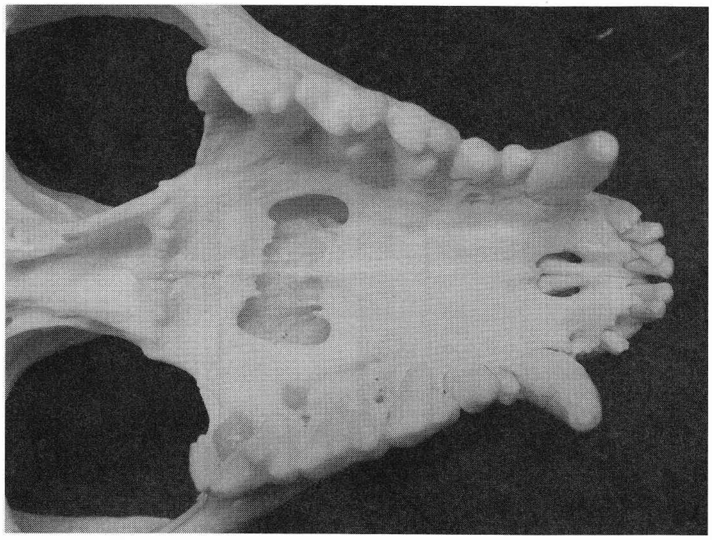

Fig. 35. The upper jaw of a Tasmanian devil (*Sarcophilus harrisii*).

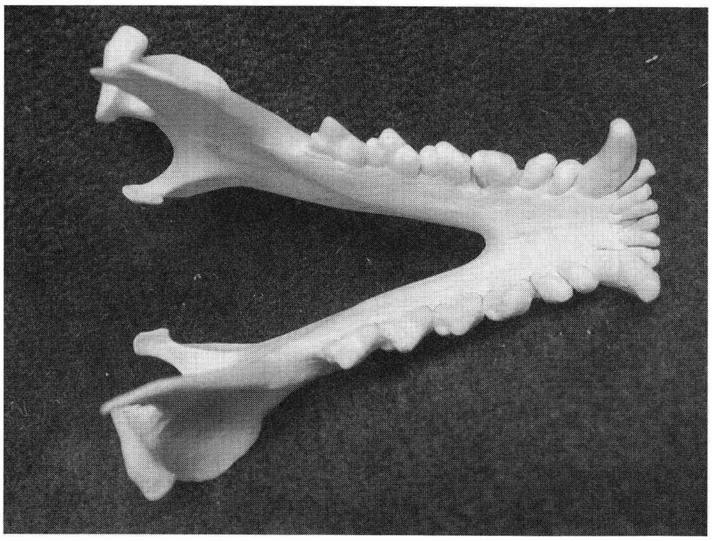

Fig. 36. The lower jaw of a Tasmanian devil (*Sarcophilus harrisii*).

showed positional anomalies. In the first, the left maxilla had a normal P1, an abnormally-shaped P2, and no molars; in the second, there was crowding of the incisors and rotation of P3 [57]. No significant oral infectious diseases have been recorded in this species.

The banded anteater (*Myrmecobius fasciatus*) has more teeth than any other land mammal. The dental formula is: $I^{4}_{3}:C^{1}_{1}:P^{3}_{3}:M^{5-6}_{5-6} = 50–54$ [5]. The deciduous molar usually stays in place between P3 and M1. All of the teeth are small and delicate; the molars are tritubular.

Superfamily Didelphoidea (opossums)

In the American opossum, there are no diastemas, adjacent teeth are in contact, and the buccal surfaces of the cheek teeth form a straight line. When there is insufficient room in the arch, P3 tends to be rotated or misplaced mesially or lingually. The lower incisors are more or less equal in size and are not procumbent; the canines are large and the molars are tritubular. The American opossum's dental formula is: $I^{5}_{4}:C^{0-1}_{1}:P^{3}_{3}:M^{4}_{4} = 48–50$ [5].

Summary

Oral disease occurs in all species, from the tiny marsupial mouse to the large red kangaroo, and from the smallest mole to the largest bat. Although there has been little research done in most of the species in this article, the whole range of dental and oral diseases has been recorded, including periodontal disease, caries, and many variations in position and number of teeth. Hopefully, the interest in these species will continue and further study will enable us to understand these diseases more thoroughly.

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