A Computed Tomographic Study of the Premolar Teeth of Babyrousa spp.

Citation for published version:
Macdonald, A, Ziehmer, B, Kitchener, AC, Gelang, M, Åblad, B, Lintonsson, R, von Pückler, K, Schaub, S, Kiefer, I & Schwarz, T 2023, 'A Computed Tomographic Study of the Premolar Teeth of Babyrousa spp.', *Journal of Veterinary Dentistry*, pp. 1-12. https://doi.org/10.1177/08987564231166551

Digital Object Identifier (DOI):
10.1177/08987564231166551

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Journal of Veterinary Dentistry

A Computed Tomography Study of the Premolar Teeth of *Babyrousa* spp.

Alastair A Macdonald, BSc, PhD, Dr Utrecht, MBA, FHEA[1], Bianca Ziehmer, BSc, MSc[2], Andrew C. Kitchener, BSc, PhD[3], Magnus Gelang, PhD[4], Björn Åblad, DVM[5], Ruth Lintonsson, DSV, MI&F[5], Kerstin von Pückler, Dr. med. vet., DECVDI[6], Sebastian Schaub, Dr. med. vet., DECVD[6], Ingmar Kiefer, Dr. vet. med.[7] and Tobias Schwarz, MA, Dr. med. vet., FRSB, PgCAP, FHEA, DECVDI, DACVR, DVR, FRCVS[1]

Abstract

A photographic and computed tomography (CT) scanning study was carried out on the premolar teeth of eighteen adult male *Babyrousa babyrussa* skulls, ten skulls of *Babyrousa celebensis*, including six adult males, one adult female, one subadult male, one subadult female and one juvenile male. The occlusal morphology of the adult maxillary premolar teeth of *B. babyrussa* was very similar to that of *B. celebensis*. Almost all the maxillary third premolar teeth (107/207) had two roots, whereas maxillary fourth premolar teeth (108/208) had three or four roots. All of the mesial tooth roots of 107/207 and 108/208 were tapering rod-like structures; each contained a single pulp canal. Almost all distal roots of 107/207 were ‘C’ shaped and contained two pulp canals. The 108/208 palatal roots were ‘C’ shaped and contained two pulp canals. The mesial and distal roots of the mandibular third premolar teeth (307/407) teeth were uniformly rod-like, as were the mesial roots of the mandibular fourth premolar teeth (308/408) teeth. The distal roots of the 308/408 teeth were ‘C’ shaped. All *B. babyrussa* 307/407 teeth have a single pulp canal located in each of the mesial and distal roots. The 308/408 mesial tooth root contained one pulp canal. In all but three of the 36 distal 308/408 roots of *B. babyrussa* teeth and in seven of the 14 distal roots of *B. celebensis* teeth there was a single pulp canal; in the other seven teeth there were two pulp canals. Each of the three medial roots contained one pulp canal.

Keywords

anatomy, wild pig, babirusa, *Babyrousa spp.*, tooth root, root canal

Introduction

The babirusa (genus *Babyrousa*)[1] is a suid endemic to eastern Indonesia, inhabiting the islands of Buru; the Sula Islands of Sehu, Taliabu, and Mangole; the island of Sulawesi; and the Togian Islands.[2-4] Early anatomical investigations of the appearance of the teeth in the adult male babirusa, based on the skulls of animals from Buru, have been reported in the literature.[5-9] The adult male maxillary dentition comprises four incisor teeth, two canine teeth, four premolar and six molar teeth. The corresponding mandibular dentition contains six incisor teeth, two canine teeth, four premolar and six molar teeth. The female may, or may not, have canine teeth.[6-9] Illustrations of the teeth[9,10] raised the hypothesis that the roots underlying the premolar teeth were not simple in form.

In the course of recent studies of babirusa skulls,[11-14] a number of maxillary and mandibular specimens were found to have missing teeth. These observations added to the suggestion that among the babirusa there were variations in the number, sizes and shapes of the premolar tooth roots. Approximately round and oval-shaped tunnels were observed running into the spongy (cancellous) bone of the maxilla and mandible (Figure 1); the cross-sectional shape of some of these alveoli[15] were similar to the letter 'C' with a bony core to the 'C' (Figures 1A, 1C). This shape and a review of its development have been described.[15]

A search of the literature failed to reveal the results of any systematic study of the anatomy of the premolar teeth of babirusa. And yet, clinical veterinary dentistry has begun to be undertaken on the babirusa.[16-17] As a consequence, we undertook a computed tomography (CT) examination of babirusa skulls from four museum collections[a-d]. The skulls selected represented the babirusa species from Buru and the Sula Islands (*B. babyrussa*) and from the island of Sulawesi (*B. celebensis*).

The modified Triadan system of veterinary tooth nomenclature was adopted for this study[18] and is illustrated in Figure 2. The veterinary dental nomenclature[19] was used to provide the description of dental location and orientation. The positions of persistent deciduous teeth, when present, were allocated the corresponding identification numbers 306 and 406 on the mandible, and 106 and 206 on the maxilla.

Materials and Methods

The research material comprised thirteen adult male *B. babyrussa* skulls from Buru, five adult male *B. babyrussa* skulls from Buru or the Sula Islands and six adult male and one adult female *B. celebensis* skulls from Sulawesi (Table 1). An additional three *B. celebensis* skulls from Sulawesi were studied; one juvenile male, one subadult male, and one subadult female.

All specimens were photographed, including close-up views of the occlusal surfaces of the teeth. To enable anatomical clarity in the description of observations, the dental anatomical nomenclature of the babirusa teeth was derived from that published for Suidae.[20] The main cusps on the maxillary premolars are called paracone, protocone, metacone and tetracone (Figure 3). The main cusps on the mandibular premolars are called protoconid, metaconid and hypoconid (Figure 4).

For geographical proximity reasons the skulls were CT-scanned at four different institutions using four different CT scanner models[e-h].

Tooth length was measured from the highest point of the crown (the coronal end) to the apex (the extremity) of the tooth root (Figure 5). Tooth root length was measured from either the buccal or the lingual/ palatal cementoenamel junction (depending on root orientation) to the apex of the root (Figure 5). The occlusal edges of the premolar tooth were formed from the enamel cusps. The occlusal surface ‘mesial to distal’ length and ‘buccal to lingual or palatal’ width of each premolar tooth was measured. Tooth root diameter was measured across the mid length of the tooth root (Figure 5).

Statistical analyses[i] were undertaken on the teeth from the adult babirusa.

Results

Occlusal morphology

The occlusal morphology of the adult maxillary premolar teeth of *B. babyrussa* (Figures 6A, 6B) was very similar to that of *B. celebensis* (Figure 6C). The enamelled crowns of *B. babyrussa* maxillary third premolar teeth (107/207) (n=34) were longer (9.6 ± 0.7 mm) than they were wide (6.5 ± 0.8 mm) (P<0.001). Comparable results were found in *B. celebensis* 107/207 (n=11) (length = 11.1 ± 0.7 mm; width = 7.8 ± 0.7 mm; n=11; P<0.001). The enamelled crowns of the maxillary fourth premolar teeth (108/208) were rounded (Figure 6); *B. babyrussa* measured 9.9 ± 0.7 mm in length and 9.7 ± 0.7 mm in width (n=34) (NS). In *B. celebensis* these teeth measured 10.0 ± 1.3 mm in length and 10.1 ± 1.1 mm in width (n=12) (NS).

The paracone of 107/207 is in the form of a centrally situated, somewhat laterally compressed cone (Figures 3, 6). On its distobuccal surface lies the slightly smaller metacone (Figure 3). The protocone is smaller still and is situated on the palatal side of the crown (Figures 3, 6). The paracone 108/208 is bordered distally on the buccal side by a slightly smaller metacone (Figures 3, 6). The palatal side of the crown is largely occupied by the protocone. Distal to these three cusps lies the smaller tetracone. The valleys, or fossids, running distally between the buccal and palatal cusps of 107/207 and 108/208 appear to be a significant feature of these tooth crowns (Figure 3).

The occlusal morphology of the adult mandibular premolar teeth of *B. babyrousa* (Figures 7A, 7B) is very similar to that of *B. celebensis* (Figure 7C). The enamelled crowns of *B. babyrussa* mandibular third premolar teeth (307/407) were longer (10.5 ± 1.0 mm) than they were wide (5.7 ± 0.9 mm) (n=35; $P<0.001$). Comparable results were found in *B. celebensis* 307/407 which were also longer (11.7 $\pm$ 1.0 mm) than they were wide (6.1 $\pm$ 1.5 mm) (n=14; $P<0.001$). The enamelled crowns of the mandibular fourth premolar teeth (308/408) were somewhat elongated; *B. babyrussa* measured 11.9 $\pm$ 0.8 mm in length and 7.9 $\pm$ 0.8 mm in width (n=35) ($P<0.001$). The enamelled crowns of 308/408 in *B. celebensis* measured 12.1 $\pm$ 1.1 mm in length and 8.1 $\pm$ 1.6 mm in width (n=14; ($P<0.001$).

The protoconid of 307/407 is the predominant, conical cusp with the small metaconid on its distal slope and the slightly larger hypoconid on the distal edge of the tooth (Figure 4). Together they form a serrated edge to the distal half of the tooth. The protoconid of 308/408 is also the predominant cusp on that tooth, mesially located and occupying about half the occlusal surface area. The metaconid occupies the distal slope of the 308/408 protoconid. The distal edge of the crown supports the small protocone lingually and the tetracone distally.

Tooth root structure

The structures of the maxillary premolar tooth roots were either conical, with a variable amount of tapering from the crown to the apex, or alternatively, they were to some degree ‘C’ shaped for a variable proportion of their course from the crown to the apex (Figures 1, 8). All of the mesial tooth roots of 107/207 and 108/208 were conical, as were all 13 centrobuccal and all distobuccal tooth roots of 108/208 (Figures 8, 9); each contained a single pulp canal. Often a shallow longitudinal channel ran down the opposing surfaces of the roots (Figure 8A, 8C). In all but two of the 56 distal roots of 107/207 this furrow was sufficiently large to make the root ‘C’ shaped and contain two pulp canals. Of the latter, 32 roots tapered obliquely to a single apex, 20 divided into two conical structures which tapered to separate apices; the remaining two teeth were absent from the skull. The 50 108/208 palatal roots were ‘C’ shaped and contained two pulp canals (Figure 9B, 9E); in 48 of these the roots tapered obliquely to a single apex, while in the other two the roots tapered to separate apices (Figure 9).

The structure of the mesial and distal roots of 307/407 was uniformly conical (Figures 4, 10). The mesial roots of 308/408 teeth were also conical (Figure 9). However, the distal roots of 308/408 teeth were to some degree longitudinally furrowed or ‘C’ shaped for a variable proportion of their course from the crown to the apex. Two *B. babyrussa* and four *B. celebensis* showed two pulp canals in the distal root of 308/408.

Maxillary tooth roots, B. babyrussa

Of the 18 crania, 17 of the 107/207 (94%) had two roots (Figure 8); whilst one (6%) had three roots. Of the 18 crania, 12 of the 207 and 14 of the 107 (72%) had three roots; six of the 207 and three of the 107 (25%) had four roots (Figure 9); there was no evidence for one 107 in one specimen from Buru (SMF 430). Measurements of the lengths of the teeth, the crown heights, the root lengths, the thickness of the roots and the diameters of the root apices are summarised in Table 2. The length of 107/207 through the mesial root was longer than through the distal root ($P<0.001$), which corresponded to the relative lengths of these two roots ($P<0.05$). The crown length above the mesial root of the 107/207, represented in part by the paraconal cusp, was longer ($P<0.05$) than the crown length above the distal root, represented in part by the metacone. The distal root was thicker than the mesial root ($P<0.001$) but narrowed to a smaller apex ($P<0.05$). The length of 108/208 through the mesiobuccal root was also longer than through the distobuccal and palatal roots ($P<0.001$). The crown height of the mesiobuccal root, represented in part by the paraconal cusp, was longer ($P<0.001$) than the crown length above the palatal root, represented in part by the protocone. There was no difference in either length or root thickness between the three roots of 108/208. The palatal root apices were larger than those of the mesiobuccal ($P<0.001$) and distobuccal ($P<0.05$) roots.

Maxillary tooth roots, B. celebensis

All 14, 107 and 207 had two roots. Ten of the 108 and 208 (71%) had three roots. One bilateral pair of 108/208 (7%) had four roots. One bilateral pair of teeth (7%) was unclear. Measurements of the lengths of the teeth, the crown heights, the root lengths, the thickness of the roots and the diameters of the root apices are summarized in Table 2. No differences between roots in either tooth length or tooth root length were detected in 107/207. There was also no difference in crown heights. However, the distal root was thicker than the mesial root ($p<0.05$) but narrowed to a smaller apex ($P<0.001$). The lengths of 108/208 through the mesiobuccal ($P<0.001$) and the distobuccal ($P<0.01$) were longer than through the palatal root. The crown height of the meso-buccal root, represented in part by the paraconal cusp, was longer ($P<0.01$) than the crown height above the palatal root, represented in part by the protocone (Table 2). The distal roots of 107/207 were thicker than the mesial roots ($P<0.05$) but narrowed to a smaller apex ($P<0.01$). The mesial roots of 108/208 were thicker than those of the distobuccal ($P<0.001$) and palatal ($P<0.001$) roots. No difference in the sizes of their tooth root apices was detected. The subadult babirusa 107 and 207 had two roots, whilst the 108 and 208 all had three roots.

Mandibular tooth roots, B. babyrussa

Of the 18 mandibles, 17 of the 307 had two roots, one had three roots, and all 407 had two roots. All 18 308 and 408 had two roots (Figure 10). Measurements of the lengths of the teeth, the crown heights, the root lengths, the thickness of the roots and the diameters of the root apices are summarised in Table 3. The lengths of 307/407 through the distal roots were longer ($P<0.001$) than through the mesial roots. The crown height above the distal root, represented in part by the metacone, was longer ($P<0.01$) than the crown height over the mesial root of 307/407, represented in part by the paraconal cusp. However, the lengths of 308/408 through the mesial roots were longer ($P<0.001$) than through the distal roots and the crown height over the mesial root was also longer than over the distal root ($P<0.01$). There were no differences in length between the roots of 307/407 and 308/408 (Table 3). The thicknesses of the distal roots and root apices of both teeth were greater ($P<0.001$) than for the corresponding mesial roots.

Mandibular tooth roots, B. celebensis

In all 14 skulls, 307 and 407 had two roots. Likewise, in all of the 14 skulls 308 and 408 had two roots. Measurements of the lengths of the teeth, the crown heights, the root lengths, the thickness of the roots and the diameters of the root apices are summarised in Table 3. The lengths of 307/407 through the distal roots were longer (*P*<0.001) than through the mesial roots, and the crown heights above the distal roots were also longer than those over the mesial roots (*P*<0.001). The lengths of 308/408 through the mesial roots were longer (*P*<0.05) than through the distal roots. The mesial roots of 307/407 and 308/408 were longer (*P*< 0.01 and *P*<0.001 respectively) than the distal roots. The thicknesses of the distal roots and root apices of both teeth were greater (*P*<0.001 and *P*<0.01 respectively) than for the corresponding mesial roots. The juvenile and subadult babirusa had two roots for the 307/407 and 308/408.

Pulp chambers

The pulp chambers of 107/207 were arched and elongated regions positioned under the paracone and metacone (Figure 3). The ridged roof of the chambers lay above the junction of the crown and the root of the tooth (Figures 8B, 8D, 11A). The floors of the pulp chambers were served by the rod-shaped mesial roots via the funnel end of a single, approximately axially located pulp canal (Figure 8). From the 'C-shaped' distal roots the pulp chambers were supplied (in all but one skull) by two pulp canals.

The pulp chambers of 108/208 teeth coalesced under the three main cusps of the tooth, the paracone, protocone and metacone (Figure 3). The roof of the chamber was irregular in shape and was situated at or above the junction of the crown and the root of the tooth (Figures 8F, 11B). The pulp chamber formed a wide and deep space into which fed the funnel-ended pulp canals from the three or more tooth roots (Figure 9). Each of the ‘C-shaped’ palatal roots contained two pulp canals. Each of the thirteen medial/accessory roots contained one pulp canal.

The elongated pulp chamber of 307/407 tooth was largely situated under the protoconid (Figure 4). The ridged roof of the chamber extended up under the cusp and its floor lay below the junction of the crown and the root of the tooth (Figures 10, 11C). In all *B. babyrussa* teeth there was a single centrally located pulp canal in each of the mesial and distal roots. In two *B. celebensis* skulls the distal tooth roots bilaterally contained two pulp canals.

The pulp chamber of 308/408 tooth broadened mesially and distally under the protoconid and metaconid (Figure 4). In all teeth most of the volume of the chamber was situated below the junction of the crown and the root of the tooth (Figure 10A), but its roof could extend up into the dentine under the cusps (Figure 11D). The chamber was uniformly supplied from the mesial tooth root by one centrally located pulp canal; in all but three of the 36 of the distal roots of *B. babyrussa* teeth and in seven of the 14 distal roots of *B. celebensis* teeth there was a single pulp canal; in the other seven teeth there were two pulp canals. Each of the three medial roots contained one pulp canal.

Discussion

This study is the first since those from 1900[8-9] to have closely examined the structure of the maxillary and mandibular premolar teeth in the adult babirusa (*Babyrousa* spp.). It has extended, by illustration and measurement, Stehlin's observed descriptions of these teeth and has provided additional detail regarding the anatomical variation of their roots. It has confirmed that for both *Babyrousa spp.* the roots of these teeth were more complex than simple conical structures (Figures 8, 9). Whereas the mesial root of the mesiodistally elongated 107/207 did have a conical type of structure, the distal root was most often 'C' shaped. The rooting of the 108/208 tooth also included a 'C' shaped component, on its palatal side. By way of contrast, the mesial and distal roots of the mandibular premolar teeth were all tapering, conical structures, deeply anchored in the bone (Table 3; Figure 10). This corresponded to the measurements reported for domestic pig *Sus domesticus*[21-22] and to the results of the radiographic study on the Large White breed of pig.[23]

It has long been recognised that the babirusa has fewer premolar teeth (two in the maxilla and two in the mandible on each side; premolars one and two are missing) than *Potamochoerus spp.*,[24] which have three or four in the maxilla and two or three in the mandible, and *Sus scrofa* which has four upper and four lower premolars on each side.[7-8] Therefore, it was of interest to know how these were rooted. One study reported that the maxillary third and fourth premolars of the Chinese experimental miniature pig (*Sus domesticus*) have three to four roots.[25] An earlier and more detailed study, published that the domestic pig maxillary first premolar tooth had two roots, the second and third premolars had three each, and that the fourth premolar teeth had four roots.[22] The maxillary third premolar teeth of the Japanese wild pig (*Sus scrofa leucomystax)*[26] had three roots, one mesial, one distobuccal and one distopalatal, and the fourth premolar teeth had four roots, two on the buccal side and two on the palatal side.[27] The maxillary third premolar teeth of *Sus* corresponds to teeth 107 and 207 of *Babyrousa* (Figure 1). Thus, with 33 observations of three roots in the maxillary third premolar teeth of *Sus,*[22] there was consistently one root more in this tooth of *Sus domesticus*[21] than the two roots found in all but one of the equivalent *Babyrousa* teeth. The maxillary fourth premolar teeth of *Sus* correspond to teeth 108 and 208 of *Babyrousa* (Figure 2). These maxillary fourth premolar teeth have been reported to have three roots (5 times = 15%), four roots (21 times = 64%), five roots (5 times = 15%) and six roots (twice = 6%) (Table 1)[22]. Our equivalent observations for *B. babyrussa* were that 26 108/208 (74%) had three roots and nine (25%) had four roots, and for *B. celebensis*, ten teeth (83%) had three roots and two teeth (16%) had four roots.

In another study, it was reported that the maxilla of wild *Sus scrofa* had two roots in the first premolar, three roots in the second and third premolars, and three roots in the fourth premolars, of which two roots were usually forked so that a total of five root tips occurred.[28] In unpublished studies on maxillae of two adult male *Sus celebensis* the authors found that the maxillary third premolars had two roots and the fourth maxillary premolars had three or four roots.

A previous study reported that in the mandible of domestic pigs the first premolar had one or two roots, the second premolar had two roots, and the third premolar was found to have two roots (20 times =69%) and three roots (9 times =31%), the fourth premolar always had three roots (29 times).[22] In contrast, a separate study indicated that in mandible of the 'Clawn' strain of miniature Japanese domestic pig, the second, third and fourth premolar teeth had two roots.[29] The same observations were also made for the second and third premolar teeth in the Japanese wild pig, but three roots were found in the fourth premolar teeth.[27] For the mandible of the European wild pig, *Sus scrofa*, two roots for the first and second premolar teeth, and three roots for the third and fourth premolar teeth have been reported.[30] The third mandibular premolar teeth of *Sus* corresponded to 307 and 407, and the fourth premolar teeth corresponded to 308 and 408 in *Babyrousa*. This study found that 35 of the 307 and 407 teeth in *B. babyrussa* had two roots and one had three roots, whereas in *B. celebensis* all of the mandibular premolar teeth had two roots. In unpublished studies on the mandibles of two adult male *Sus celebensis* the authors found that both the third and fourth premolar teeth had two roots.

The pulp canals described in the current study lay within the scale of resolution of the CT scans used. A single well-defined canal was seen running largely axially from the root apex to the pulp chamber in all mesial roots of the first premolar teeth (Figure 8). A similar finding was made in a micro-CT study of the mandibular teeth of miniature *Sus domesticus*.[29] They also reported that the distal root of the fourth mandibular premolar teeth had two root canals. Thin and indistinctly 'ghosted' opacities were seen to be associated with a number of the palatal roots of 108/208 in the present study. These raised the hypothesis of further intra-root pulp-canal complexity. The higher resolution offered by micro-CT studies has revealed that individual human premolar maxillary tooth roots do show considerable variability in the number, size, shape, pattern and interconnectivity of pulp canals contained within them; the root canal system is not a single canal running uniformly from pulp chamber to apex.[31-33] Methods have subsequently been devised to describe this complex variation within human premolar teeth.[34-36] These methods offer alternative frameworks for comparable descriptions and further veterinary analyses of the maxillary teeth of babirusa and other wild pig species in the future.

The cutting function of the premolar teeth of *Sus scrofa* has been long commented upon.[8,22] Although the equivalent teeth of the babirusa were morphologically more rounded, the relatively narrow longitudinal shape of the maxillary third premolar tooth and both opposing mandibular premolar teeth supports this view (Figures 3, 4). The fossids (Figure 3), running distally between the buccal and palatal cusps of 107/207 and 108/208, and the somewhat serrated arrangement of distal cusps of maxillary and mandibular premolar teeth (Figures 3, 4) also contribute to this conclusion. Studies of the feeding behaviour of babirusa in zoological collections[37-38] and in the wild[3,39] have placed emphasis on leaf and fruit browsing behaviour. *B. celebensis* in zoological collections have been observed cropping the leaves off bramble bushes (*Rubus* sp. L.) and low-hanging cherry trees (*Prunus* sp. L.),[38] and have been seen standing on their hind limbs to browse on the leaves of taller trees[40] and swimming in water courses to access freshwater lettuce (*Pistia stratiotes* L.).[41] *B. babyrussa* on Buru have been observed biting soft leaves off low-lying (unidentified) plants and creepers as they walked past them.[12] Other food substances reported from Buru and the Sula Islands included the leaves of Cyanthea [*Alsophyla*] *glauca* Bory and *Homalomena pendula* (Blume) Bakh.f., the low-hanging fruits of various fig trees (*Ficus* spp. L.), the sweet olot (*Hornstedtia rumphii* Sm.) and the fruit of *Rubus fraxinifolius* (Poiret).[3] The biting of various types of vegetation for nest-building has also been reported.[42] The occlusal shapes of the premolar teeth contribute to an ease-of-carrying function, and the depths of the roots indicate inherent strength and stability. The relative lack of wear with age of the occlusal surfaces of the premolar teeth when compared to the molar teeth suggests that the premolar teeth are mainly involved in cutting relatively soft plant material.[12] In contrast, the elongated chisel-like mandibular incisors are used to cut through tougher plant material, such as sweet potato (*Ipomoea batatas* (L.) Lam.) and coconut (*Cocos nucifera* L.) kernel and haustorium.[41,43] Tooth wear profiles indicate that the cracking of seeds and nuts as well as the mastication of foods are largely undertaken by the molar teeth.[12-13] However, the rounded enamel crowns and additional roots of the maxillary third premolar teeth suggest that these teeth may contribute towards the food crushing functions of babirusa molar teeth.

Conclusions

The relative structure of the mandibular third premolar teeth in babirusa suggest that although a cutting function appears to be present, it may play a sufficient but subsidiary role to that of food grinding and crushing by the maxillary fourth premolar teeth. The occlusal surfaces, tooth root number and the physical structures of the roots of the fourth premolar teeth would appear to support such a hypothesis.

Materials

a. Senckenberg Naturhistorische Sammlungen Dresden, Germany (SNSD)
b. National Museums Scotland, Edinburgh, Scotland (NMS)
c. Naturmuseum Senckenberg, Frankfurt am Main, Germany (SMF)
d. Göteborgs naturhistoriska museum, Göteborg, Sweden (GNM)
e. The Universities of Edinburgh, 64 slice CT, Somatom® Definition AS Siemens, Erlangen, Germany
f. The University of Giessen, 16-slice CT, Brilliance® 16, Philips Medical Systems, Eindhoven, Netherlands
g. The University of Leipzig, 6 slice CT, Brilliance® 6, Philips Medical Systems, Eindhoven, Netherlands
h. Blåstjärnans Djursjukhus Göteborg, 16-slice CT, GE Revolution® EVO CT, GE Healthcare Japan Corporation, Tokyo, Japan.
i. JASP Team (2020) JASP (Version 0.14.1)

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

References

1 Perry G. Arcana; or the museum of natural history London: Printed by George Smeeton for James Stratford;1811:457-458.

2. Sheherazade, Hesdianti E, Indrawan M. Moluccan babirusa Babyrousa babyrussa (Linnaeus, 1758). In: Melletti, M, Meijaard, E, eds. *Ecology, Evolution and Management of Wild Pigs and Peccaries. Implications for Conservation*. Cambridge: Cambridge University Press; 2018:70-75.

3. Macdonald AA, Kailuhu V, Pattikawa MJ. 2018. Babirusa (*Babyrousa* spp.) on Buru and the Sula Islands, Maluku, Indonesia. *Suiform Sound*. 2018;17(1):22-36.

4. Macdonald, AA. Sulawesi Babirusa *Babyrousa celebensis* (Deninger, 1909). In: Melletti, M, Meijaard, E, eds. *Ecology, Evolution and*

Management of Wild Pigs and Peccaries. Implications for Conservation. Cambridge: Cambridge University Press; 2018:59-69.

5. Nieuhof JJ. *Nieuhof's Gedenkwaerdige Zee-en Lant-Reize door de voormaemste Landschappen van West en Oost Indien*. Amsterdam: Bij de weduwe van Jacob van Meurs. 1682.

6 Ducrotay de Blainville HM. *Osteographie*. Paris: J.B. Bailliere et fils; 1839–1864:136-138,159-160,186-246.

7 Owen R. *Odontography*, London: H. Bailliere. 1840-1845.

8 Stehlin HG. Ueber die Geschichte des Suidae Gebisses Erster Teil *Abh Schweizer palaontolog Gesell.* 1899;26:1-336. Available from https://archive.org/details/StehlinH.g.1899-UeberDieGeschichteDesSuiden-gebisses/StehlinH.g.1899-UeberDieGeschichteDesSuiden-gebissesPart1/mode/2up [accessed 24 February 2021].

9 Stehlin HG. Ueber die Geschichte des Suidae Gebisses. Zweiter Teil *Abh Schweizer palaontolog Gesell.* 1900;27:337-527. Available from https://archive.org/ stream/StehlinH.g.1899-UeberDieGeschichteDesSuiden-gebisses/StehlinH.g.1900-

UeberDieGeschichteDesSuiden-gebissesPart2#page/n183/mode/2up [accessed 24 February 2021].

10. Cuvier F. *Des Dents des mammifères considérées comme caractères zoologiques*. Strasbourg: F.G. Levrault. 1825:212-213.

11. Macdonald AA. Erosion of canine teeth in babirusa (genus *Babyrousa*). *C R Biol.* 2017;340(5):271-278. doi:10.1016/j.crvi.2017.03.006. PMID:28478930.

12. Macdonald AA. Cheek tooth erosion in male babirusa (genus *Babyrousa*). *C R Biol.* 2019;342(5-6):199-208. doi:10.1016/j.crvi.2019.07.005. PMID:31474523.

13. Macdonald AA. Anomalous erosion patterns on the cheek teeth of babirusa (*Babyrousa* Perry 1811.). *Can J Zool.* 2021;99(1):1-8.

14. Macdonald AA, Shaw D. Maxillary tooth growth in the adult male babirusa (genus *Babyrousa*). *C R Biol.* 2018;341(4):235-244. doi:10.1016/j.crvi.2018.04.002. PMID:29752201.

15 Kato A. Ziegler A. Higuchi N. Nakata K. Nakamura H. Ohno N. Aetiology, incidence and morphology of the C-shaped root canal system and its impact on clinical endodontics. *Int Endo J.* 2014;47(11):1012-1033.

16 James SB. Cook RA. Raphael BL. et al. Immobilization of babirusa

(*Babyrousa babyrussa*) with xylazine and tiletamine/zolazepam and reversal with yohimbine and flumazenil. *J Zoo Wildl Med.* 1999;30(4):521-525.

17 Steenkamp G. Oral biology and disorders of tusked mammals. *Vet Clin Exot Anim.* 2003;6(3):689-725.

18 Floyd MR. The modified Triadan system: nomenclature for veterinary dentistry. *J Vet Dent.* 1991;8(4):18-19.

19 AVDC. American Veterinary Dental College: Nomenclature and Numbering of Teeth. https://avdc.org/avdc-nomenclature/ Accessed 30 March, 2021.

20 van der Made J. Listriodontinae (Suidae, Mammalia), their evolution, systematics and distribution in time and space. *Contrib Tert Quatern Geol.* 1996;33(1-4):3-254. Available from http://natuurtijdschriften.nl/record/521620 [accessed 26 July 2020].

21 Erxleben ICP. Systema regni animalis per classes, ordines, genera, species, varietates, cum synonymia et histria animalium, Lipsiae [Lipzig]: Impensis Weygandianis; 1777.

22 Habermehl KH. Über das Gebiß des Hausschweines (*Sus scrofa* dom. L.) mit besonderer Berücksichtigung der Backenzahnwurzeln. *Z Veterinarmed.* 1957;4:794-810.

23 Tonge CH, McCance RA. Normal development of the jaws and teeth in pigs, and the delay and malocclusion produced by calorie deficiencies. *J Anat.* 1973;115(Pt 1):1-22.

24 Gray JE. On the painted pig of the Camaroons (*Potamochœrus pencilliatus*). *Proc Zool Soc Lond*. 1852(20):129-132. [Dated 1852, published 27 June 1854].

25 Wang S, Liu Y, Fang D, Shi S. The miniature pig: a useful large animal model for dental and orofacial research. *Oral Dis.* 2007;13(6):530-537.

26 Temminck CJ. Aperçu général et spécifique sur les mammifères qui habitent le Japon et les îles qui en dependent. In: von Siebold PF. Fauna japonica, sive, Descriptio animalium, quae, in itinere per japoniam jussu et auspiciis, superiorum, qui summum in India Batava imperium tenent, suscepto annis 1823-1830. Lugduni Batavorum: A. Arnz. 1842;5:6,57-58.

27 Imoto H. A morphological study on the cheek tooth of Japanese wild boar (*Sus scrofa leucomystax*). *J Kyushu Dent Soc.* 1977;30:754-796.

28 Gabriel P. Kopfdarm und Schlund des Wildschweines (exkl. Mundboden).VIII. Beitrag zur Anatomie von *Sus scrofa* L. und zum Domestikationsproblem. *Z Anat Entwickl.* 1934;102:521-571.

29 Ide Y, Nakahara T, Nasu M, et al. Postnatal mandibular cheek tooth development in the miniature pig based on two-dimensional and three-dimensional X-ray analyses. *Anat Rec.* 2013;296(8):1247-1254.

30 Gubler R. Die Mundbodenorgane des Wildschweines. *Anat A*nz. 1933;77:129-168.

31 Vertucci FJ. Root canal anatomy of the human permanent teeth. *Oral Surg.* 1984;58(5):589-599.

32 Ahmed HMA, Cheung GSP. Accessory roots and root canals in maxillary premolar teeth: a review of a critical endodontic challenge. *ENDO – Endod Pract Today* 2012;6(1):7-18.

33 Versiani MA, Pereira MR, Pécora JD, Sousa-Neto MD. Root Canal Anatomy of Maxillary and Mandibular Teeth. In: Versiani, M, Basrani, B, Sousa-Neto, M. eds. *The Root Canal Anatomy in Permanent Dentition*. Cham: Springer. 2019. https://doi.org/10.1007/978-3-319-73444-6_7

34 Bansal R, Hegde S, Astekar MS. Classification of root canal configurations: A review and a new proposal of nomenclature system for root canal configuration. *J Clin Diag Res* 2018;12(5):ZE01-ZE05.

35 Razumova S, Brago A, Barakat H, Howijieh A. Morphology of root canal system of maxillary and mandibular molars. In: Akarslan, Z, Bourzgui, F, eds. *Human teeth - key skills and clinical illustrations*, *IntechOpen*, 2019; DOI: 10.5772/intechopen.84151. Available from: https://www.intechopen.com/books/human-teeth-key-skills-and-clinical-illustrations/morphology-of-root-canal-system-of-maxillary-and-mandibular-molars. Accessed 5 March 2021.

36 Saber SEDM, Ahmed MHM, Obeid M, Ahmed HMA. Root and canal morphology of maxillary premolar teeth in an Egyptian subpopulation using two classification systems: a cone beam computed tomography study. *Int Endod J.* 2019;52(3):267-278.

37 Macdonald AA, Leus K. Creating a public understanding of the biology of the babirusa (*Babyrousa babyrussa*) within a caring zoo environment. *Ibex J Mount Ecol.* 1995;3:37-40.

38 Leus K, Vercammen P. Behaviour of a male and female babirusa (*Babyrousa babyrussa*, Suidae, Mammalia) during the first five days after

their move to a semi-natural enclosure. *Zool Garten NF.* 1996;66(3):133-155.

39 Tjiu B, Macdonald AA. Babirusa (*Babyrousa babyrussa*) on Buru island. *Suiform Sound.* 2016;15 (1):20-26.

40 Leus K, Bowles D, Bell J, Macdonald AA. Behaviour of the babirusa (*Babyrousa babyrussa*) with suggestions for husbandry. *Acta Zool Pathol Antverp.* 1992;82:9-27.

41 Ito M, Macdonald AA, Leus K, Atmaja DGA, Balik W. Food preparation behaviour of babirusa (*Babyrousa celebensis*). *J Zoo Aqua Res.* 2017;5(2):97-103. doi:10.19227/jzar.v5i2.274.

42 Ito M, Macdonald AA, Leus K, Balik IW, Arimbawa IWGB, Atmaja IDGA. Nest building behaviour of Sulawesi babirusa (*Babyrousa celebensis*). *Jap J Zoo Wildl Med.* 2019;24(1):9-20.

43 Ito M, Macdonald AA, Leus K, et al. Coconut feeding of the babirusa (*Babyrousa* spp.). *Jap J Zoo Wildl Med.* 2020;25(3):91-100.