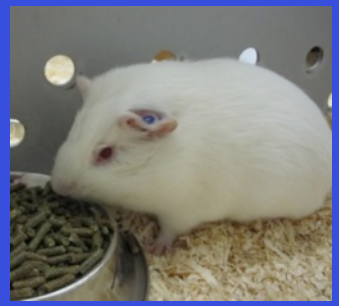
Influence of diets of different abrasiveness on tooth wear, growth and shape in rabbits (*Oryctolagus cuniculus*) and guinea pigs (*Cavia porcellus*)



Marcus Clauss[1], Jacqueline Müller[1], Daryl Codron[1], Ellen Schulz[2], Jürgen Hummel[3], Mikael Fortelius[4], Patrick Kircher[5], Jean-Michel Hatt[1]

[1]Clinic for Zoo Animals, Exotic Pets and Wildlife, University of Zurich,
[2]Biocenter Grindel and Zoological Museum, University of Hamburg,
[3]Department of Animal Sciences, University of Göttingen,
[4]Department of Geosciences and Geography, University of Helsinki,
[5]Division of Diagnostic Imaging, University of Zurich

University of Zurich[UZH]

Clinic of Zoo Animals, Exotic Pets and Wildlife

DFG FOR 771

Question

How does diet abrasivness affect tooth wear (in terms of tissue loss, mesowear, 3Dtexture)?

Initial plan

Experimental work with goats:

- 4 groups of 7 animals
- kept for 9 months each on a specific diet
- CT scans at start, middle, end (measure mesowear and tissue loss)
- finally, teeth available for regular scoring incl. 3D texture analysis
- measuring abrasives in diet, digestive tract segments, faeces

History

1. Research Grant of University Zurich

- experiment initiated in 2011
- candidate left after 5 months of experiment for permanent position
- experiment had to be terminated after 6 months
- lots of leftover food

2. Marie-Curie Fellowship

- candidate could not start because offered a permanent position during evaluation stage
- application handed in as first project of candidate's permanent assignment, decision mid-June 2014

3. No grant but dedicated student

- decision to add experiment with rabbits/guinea pigs

Experimental work with goats:

- 4 groups of 7 animals
- kept for 8 months each on a specific diet
- CT scans at start, middle, end (measure mesowear and tissue loss)
- finally, the [illegible] for [illegible] project 2D [illegible]
- [illegible] goats in dis[illegible] [illegible] [illegible]

Doctoral student Jacqueline Müller

RESEARCH ARTICLE

Growth and Wear of Incisor and Cheek Teeth in Domestic Rabbits (*Oryctolagus cuniculus*) Fed Diets of Different Abrasiveness

JOURNAL OF EXPERIMENTAL ZOOLOGY
PART A
ECOLOGICAL GENETICS AND PHYSIOLOGY
A Journal of Integrative Biology

JACQUELINE MÜLLER[1], MARCUS CLAUSS[1]*, DARYL CODRON[1,2], ELLEN SCHULZ[3], JÜRGEN HUMMEL[4], MIKAEL FORTELIUS[5], PATRICK KIRCHER[6], AND JEAN-MICHEL HATT[1]

[1]Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Zurich, Switzerland
[2]Florisbad Quaternary Research, National Museum, Bloemfontein, South Africa
[3]Biocenter Grindel and Zoological Museum, University of Hamburg, Hamburg, Germany
[4]Department of Animal Sciences, Ruminant Nutrition, Georg-August University, Göttingen, Germany
[5]Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland
[6]Division of Diagnostic Imaging, Vetsuisse Faculty, University of Zurich, Zurich, Switzerland

ABSTRACT

Although patterns of tooth wear are crucial in palaeo-reconstructions, and dental wear abnormalities are important in veterinary medicine, experimental investigations on the relationship between diet abrasiveness and tooth wear are rare. Here, we investigated the effect of four different pelleted diets of increasing abrasiveness (due to both internal [phytoliths] and external abrasives [sand]) or whole grass hay fed for 2 weeks each in random order to 16 rabbits (*Oryctolagus cuniculus*) on incisor and premolar growth and wear, and incisor and cheek tooth length. Wear and tooth length differed between diets, with significant effects of both internal and external abrasives. While diet abrasiveness was linked to tooth length for all tooth positions, whole forage had an additional effect on upper incisor length only. Tooth growth was strongly related to tooth wear and differed correspondingly between diets and tooth positions. At 1.4–3.2 mm/week, the growth of cheek teeth measured in this study was higher than previously reported for rabbits. Dental abnormalities were most distinct on the diet with sand. This study demonstrates that concepts of constant tooth growth in rabbits requiring consistent wear are inappropriate, and that diet form (whole vs. pelleted) does not necessarily affect cheek teeth. Irrespective of the strong effect of external abrasives, internal abrasives have the potential to induce wear and hence exert selective pressure in evolution. Detailed differences in wear effects between tooth positions allow inferences about the mastication process. Elucidating feedback mechanisms that link growth to tooth-specific wear represents a promising area of future research. *J. Exp. Zool. 321A:283–298, 2014.* © 2014 Wiley Periodicals, Inc.

J. Exp. Zool. 321A:283–298, 2014

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Diet design

Table 1. Composition of different complete pelleted diets (lucerne L, grass G, grass and rice hulls GR, grass and rice hulls and sands GRS) and grass hay (H).

	L	G	GR	GRS	H
Ingredients					
Lucerne meal (%)	60.0	–	–	–	–
Grass meal (%)	–	60.0	64.8	64.8	–
Rice hulls (%)	–	–	20.0	20.0	–
Sand[a] (%)	–	–	–	5.0	–
Pure lignocellulose (%)	33.8	27.4	5.0	–	–
Soybean meal (%)	–	7.0	5.0	5.0	–
Molasses (%)	3.0	3.0	3.0	3.0	–
Lignobond (%)	2.0	2.0	2.0	2.0	–
Soy oil (%)	1.0	0.4	–	–	–
Mineral/vitamin premix (%)	0.2	0.2	0.2	0.2	–
Dry matter (% as fed)	91.4	91.9	91.8	92.2	90.8
Nutrient composition (g/kg DM)					
Total ash	79	64	75	130	104
Crude protein	102	90	97	85	109
aNDFom[b]	578	600	487	459	579
ADFom[c]	434	403	322	299	354
ADL[d]	131	110	74	65	52
Dry matter digestibility (%)	39.7 ± 9.3	34.3 ± 8.1	41.2 ± 5.7	40.7 ± 11.1	45.1 ± 4.1

[a]Sand for playgrounds, grain size 0–1 mm, REDSUN garden products B.V., Heijen, Denmark; mean particle size measured by sieve analysis as dMEAN (Fritz et al., 2012) of 0.233 mm.
[b]aNDFom neutral detergent fiber, determined using amylase and ash corrected.
[c]ADFom acid detergent fiber, ash corrected.
[d]ADL acid detergent lignin ash corrected.
[e]ADIA acid detergent insoluble ash (a measure for abrasives).

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Pure lignocellulose (%)	33.8	27.4	5.0	–	–
Soybean meal (%)	–	7.0	5.0	5.0	–
Molasses (%)	3.0	3.0	3.0	3.0	–
Lignobond (%)	2.0	2.0	2.0	2.0	–
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ADL[d]	131	110	74	65	52
ADIA[e]	**05**	**16**	**24**	**77**	**38**
Dry matter digestibility (%)	39.7 ± 9.3	34.3 ± 8.1	41.2 ± 5.7	40.7 ± 11.1	45.1 ± 4.1

Clear difference in abrasives

[a]Sand for playgrounds, grain size 0–1 mm, REDSUN garden products B.V., Heijen, Denmark; mean particle size measured by sieve analysis as dMEAN (Fritz et al., 2012) of 0.233 mm.
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Grass meal (%)	—	60.0	64.8	64.8	—
Rice hulls (%)	—	—	20.0	20.0	—
Sand* (%)	—	—	—	5.0	—
Grass hay (%)	28.8	32.4	—	—	—
Soybean meal (%)	—	7.0	5.0	5.0	—
Molasses (%)	3.0	3.0	3.0	3.0	—
Lignobond (%)	2.0	2.0	2.0	2.0	—
Soy oil (%)	1.0	—	—	—	—
Mineral/vitamin premix (%)	0.2	—	—	0.2	—
Dry matter (% as fed)	91.4	92.2	92.2	92.2	90.8
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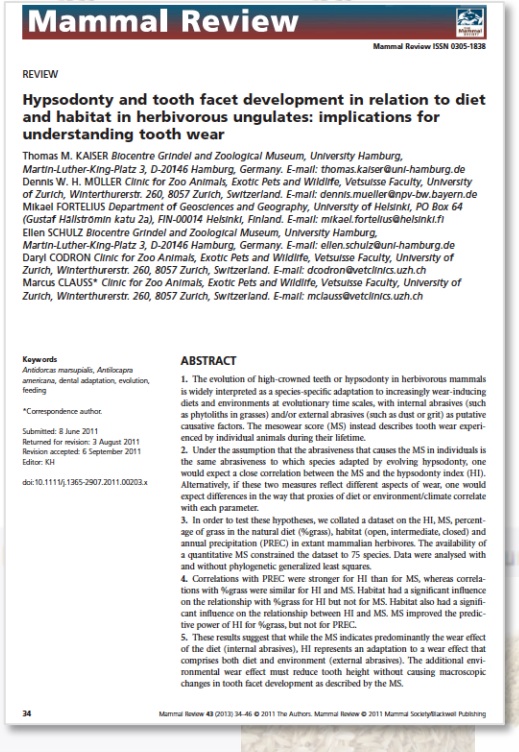
Clear difference in abrasives
- but no defined quantification of abrasive size
- abrasives size not a factor in the experiments



Mammal Review

Mammal Review ISSN 0305-1838

REVIEW

Hypsodonty and tooth facet development in relation to diet and habitat in herbivorous ungulates: implications for understanding tooth wear

Thomas M. KAISER *Biocentre Grindel and Zoological Museum, University Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany. E-mail: thomas.kaiser@uni-hamburg.de*
Dennis W. H. MÜLLER *Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Winterthurerstr. 260, 8057 Zurich, Switzerland. E-mail: dennis.mueller@npv-bw.bayern.de*
Mikael FORTELIUS *Department of Geosciences and Geography, University of Helsinki, PO Box 64 (Gustaf Hällströmin katu 2a), FIN-00014 Helsinki, Finland. E-mail: mikael.fortelius@helsinki.fi*
Ellen SCHULZ *Biocentre Grindel and Zoological Museum, University Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany. E-mail: ellen.schulz@uni-hamburg.de*
Daryl CODRON *Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Winterthurerstr. 260, 8057 Zurich, Switzerland. E-mail: dcodron@vetclinics.uzh.ch*
Marcus CLAUSS* *Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Winterthurerstr. 260, 8057 Zurich, Switzerland. E-mail: mclauss@vetclinics.uzh.ch*

Keywords
Antidorcas marsupialis, Antilocapra americana, dental adaptation, evolution, feeding

*Correspondence author.

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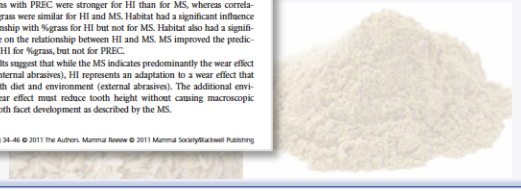
ABSTRACT

1. The evolution of high-crowned teeth or hypsodonty in herbivorous mammals is widely interpreted as a species-specific adaptation to increasingly wear-inducing diets and environments at evolutionary time scales, with internal abrasives (such as phytoliths in grasses) and/or external abrasives (such as dust or grit) as putative causative factors. The mesowear score (MS) instead describes tooth wear experienced by individual animals during their lifetime.
2. Under the assumption that the abrasiveness that causes the MS in individuals is the same abrasiveness to which species adapted by evolving hypsodonty, one would expect a close correlation between the MS and the hypsodonty index (HI). Alternatively, if these two measures reflect different aspects of wear, one would expect differences in the way that proxies of diet or environment/climate correlate with each parameter.
3. In order to test these hypotheses, we collated a dataset on the HI, MS, percentage of grass in the natural diet (%grass), habitat (open, intermediate, closed) and annual precipitation (PREC) in extant mammalian herbivores. The availability of a quantitative MS constrained the dataset to 75 species. Data were analysed with and without phylogenetic generalized least squares.
4. Correlations with PREC were stronger for HI than for MS, whereas correlations with %grass were similar for HI and MS. Habitat had a significant influence on the relationship with %grass for HI but not for MS. Habitat also had a significant influence on the relationship between HI and MS. MS improved the predictive power of HI for %grass, but not for PREC.
5. These results suggest that while the MS indicates predominantly the wear effect of the diet (internal abrasives), HI represents an adaptation to a wear effect that comprises both diet and environment (external abrasives). The additional environmental wear effect must reduce tooth height without causing macroscopic changes in tooth facet development as described by the MS.

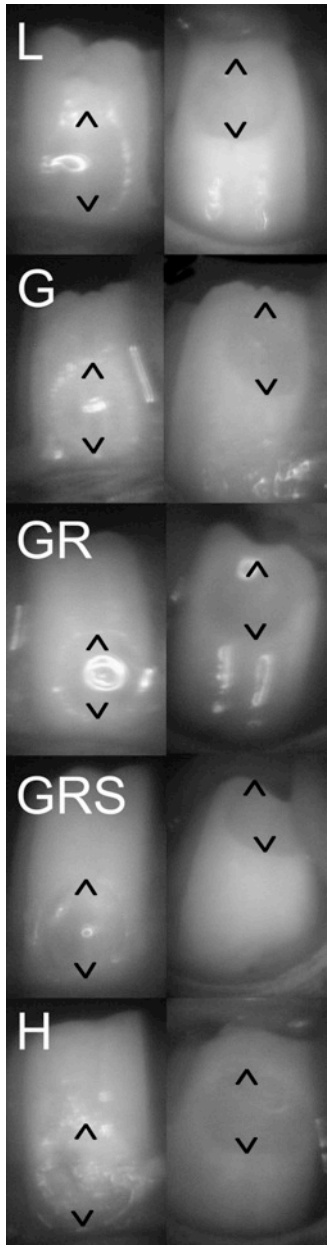


Method

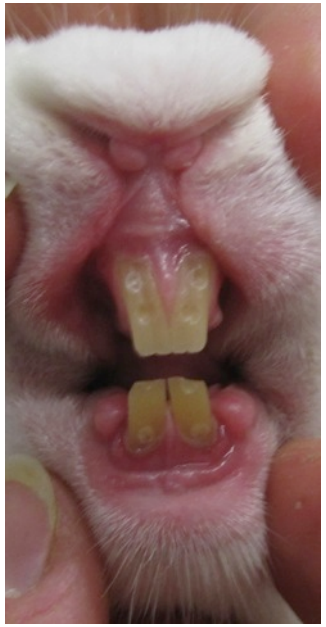
16 animals, 5 diets, each diet fed for 2 weeks

burr marks on incisors and p3 (rabbits) – manual reading

measuring of food intake, faecal excretion, time required to eat 10 g (rabbits)



Experiment rabbits



Experiment guinea pigs

Method

CT scans after each diet period

Method

CT scans after each diet period

mean yearly total precipitation of 910 mm and experiences a mean monthly temperature of 11.6°C (data from NOAA, 1974). When these climatic data are used to calculate the Holdridge potential evapotranspiration to precipitation (E/P) ratio (Holdridge, 1967) for each collection site, the New Mexico area exhibits a ratio of 1.55, and the Indiana area exhibits a ratio of 0.75. Both locations show an equivalent potential to evapotranspire water from the soil to the atmosphere; however, the amount of water (precipitation) available for the process of evapotranspiration in New Mexico is only half that available in Indiana. Based on this criterion, the New Mexico habitat presents a more severe water stress to *M. l. occultus* than does the Indiana habitat to *M. l. lucifugus*.

The greater urine concentrating ability of *M. l. occultus* enables it to withstand better the water stress resulting from the low relative humidity in its day roosts. Studier and Ewing (1971) reported a relative humidity of less than 5% for the greater portion of the daylight hours in a New Mexico roost of this bat. The day roosts of *M. l. lucifugus* would not present such a severe water stress because the relative humidity of the habitat in general is considerably higher.

The ability of *M. l. occultus* to increase urine concentration when denied water postprandially further adapts this animal to its dry, montane habitat. By increasing urine concentration when denied water after feeding, these bats conserve water by reducing urinary water loss and thus partially offset the lack of water intake. In habitats occupied by *occultus*, animals often must fly considerable distances to a permanent water source (as far as 16 km, D. Howell, pers. comm.). Reducing urinary water loss after feeding would help offset the increased pulmocutaneous water loss incurred by bats flying long distances during foraging. *M. l. lucifugus*, on the other hand, occurs in a habitat where water is more readily available, and this bat prefers to live near and to forage over water. A mechanism of water conservation such as that shown by *M. l. occultus* would not appreciably increase the adaptedness of *M. l. lucifugus* to its environment.

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John E. Bassett and Jacob E. Wiebers, *Department of Biological Sciences, Purdue University, Lafayette, IN 47907 (present address of Bassett: Department of Physiology and Biophysics, SJ-40, University of Washington, Seattle, WA 98195).* *Submitted 10 March 1978. Accepted 19 August 1978.*

A METHOD FOR DETERMINING GROWTH RATES IN CONTINUOUSLY GROWING MOLARS

Numerous herbivorous mammals have rootless, continuously growing teeth, of which the best-known examples are the incisors of rodents. Similarly constructed incisors have evolved in several mammalian orders (Moeller, 1974). The development of continuous growth in molars is

Method

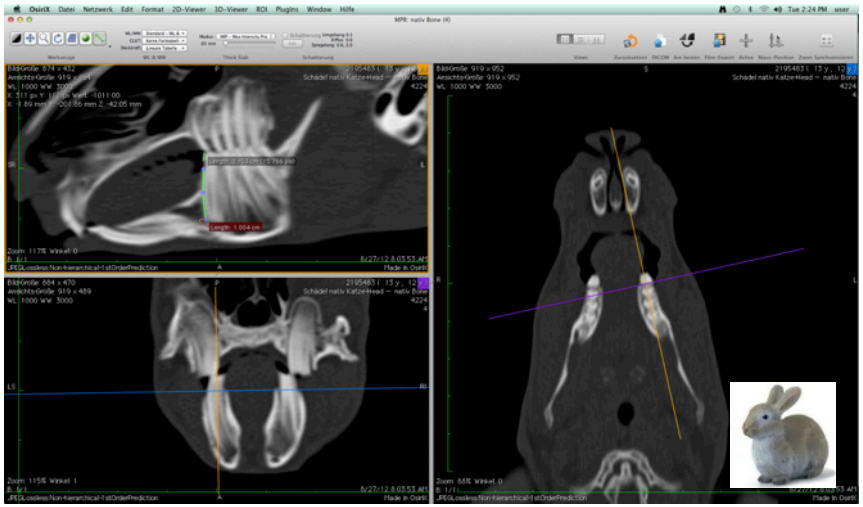
CT scans after each diet period

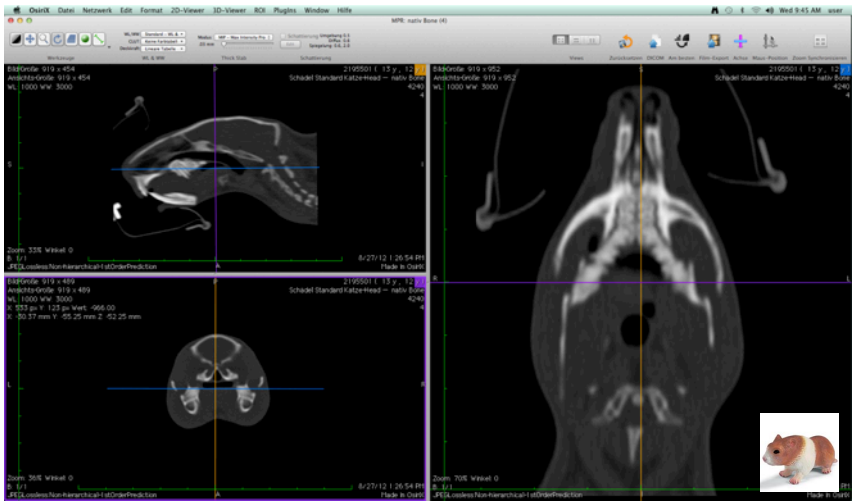
(during final period, application of two fluorescence markers)

Preservation of teeth at the end of experiment for 3Dtexture

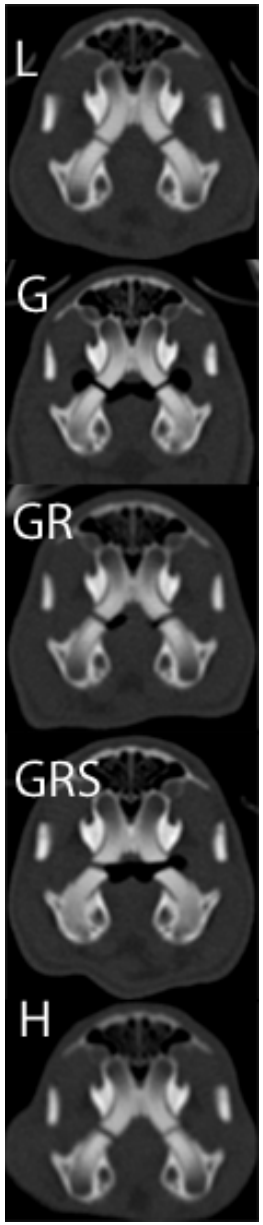
(additional experiment in rabbits: switchover from diet L to G and vice versa)

CT scans

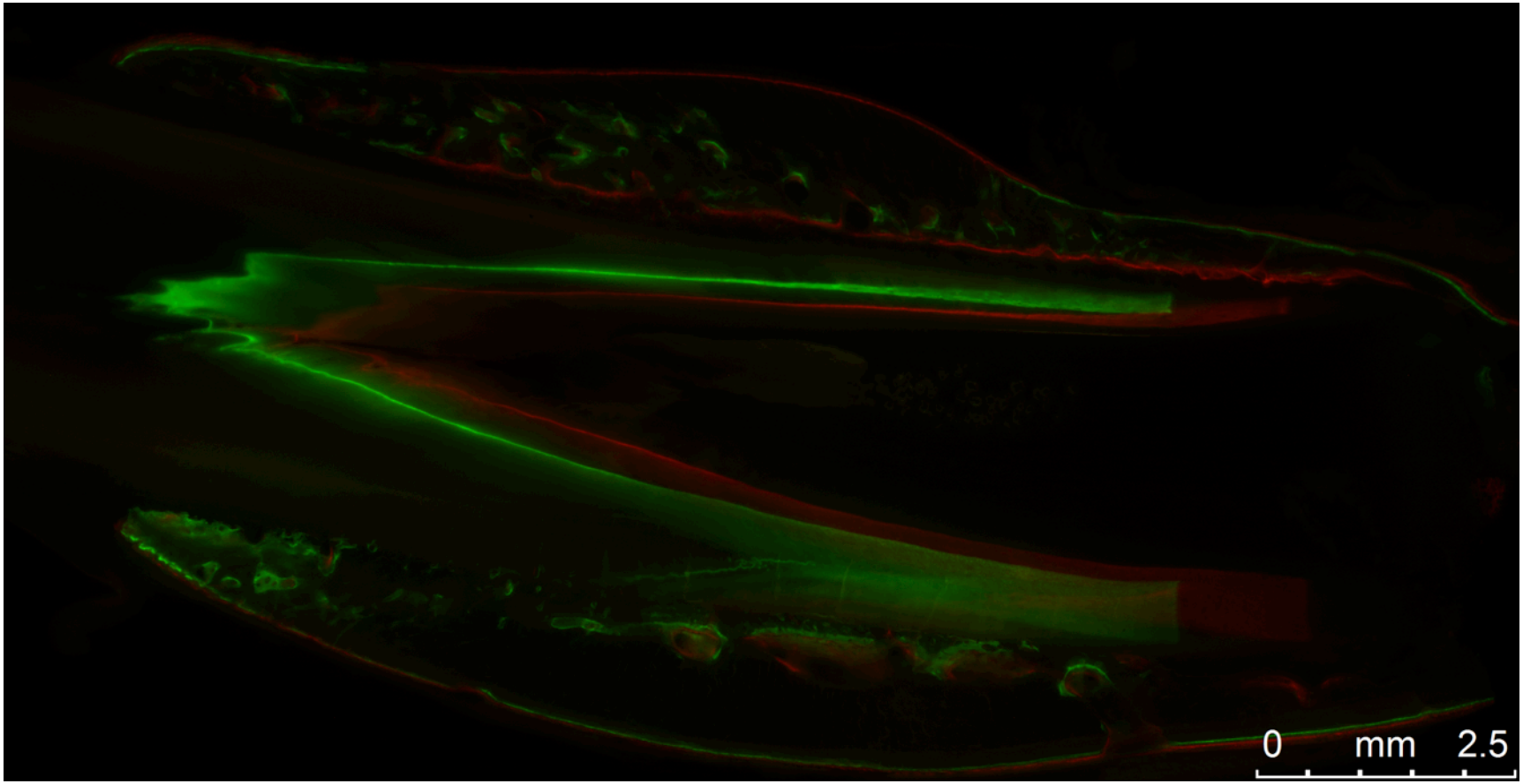




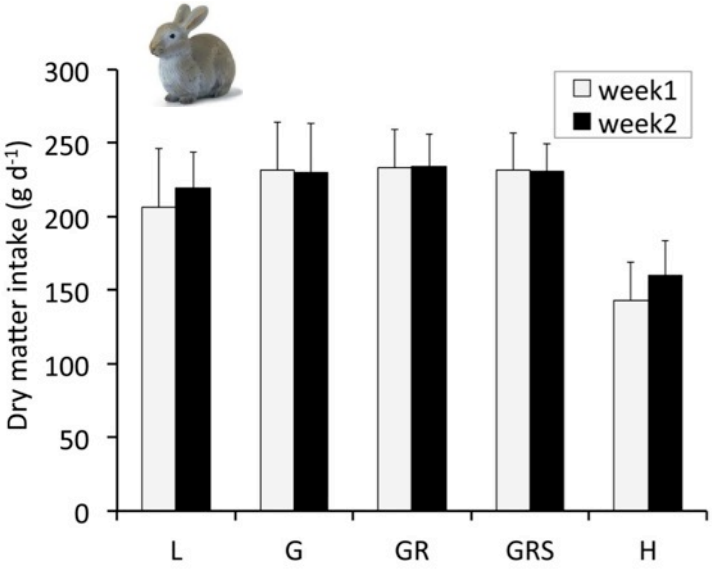
CT scans

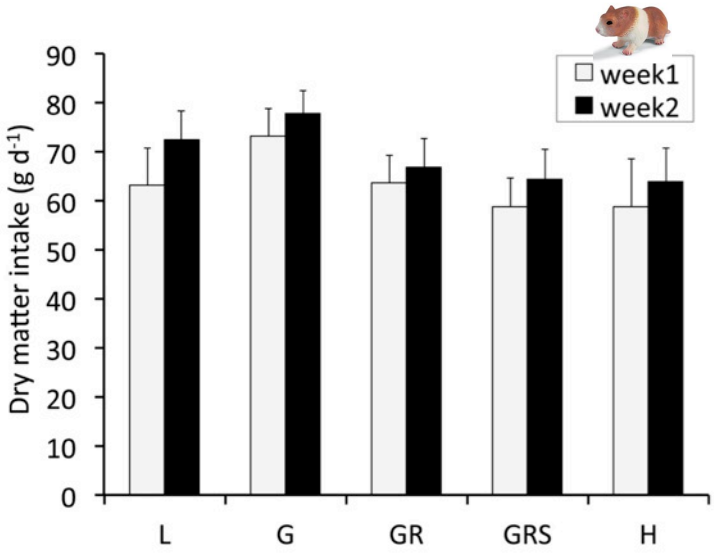


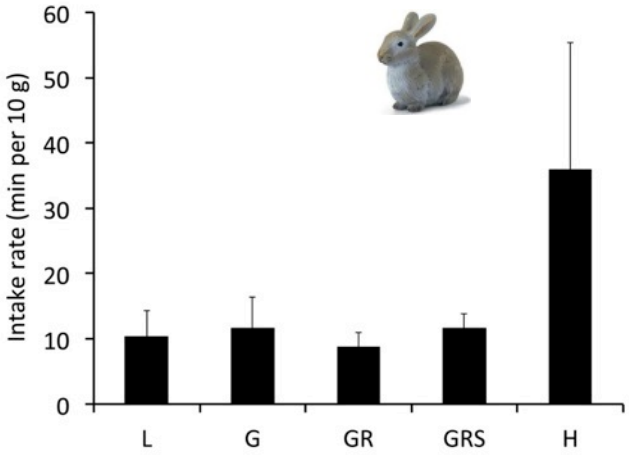
Histology (ongoing)



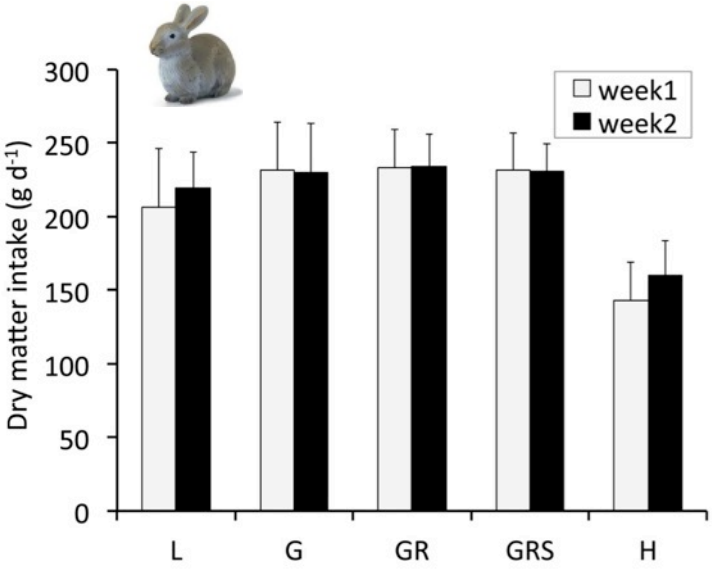
Food intake / Intake rate

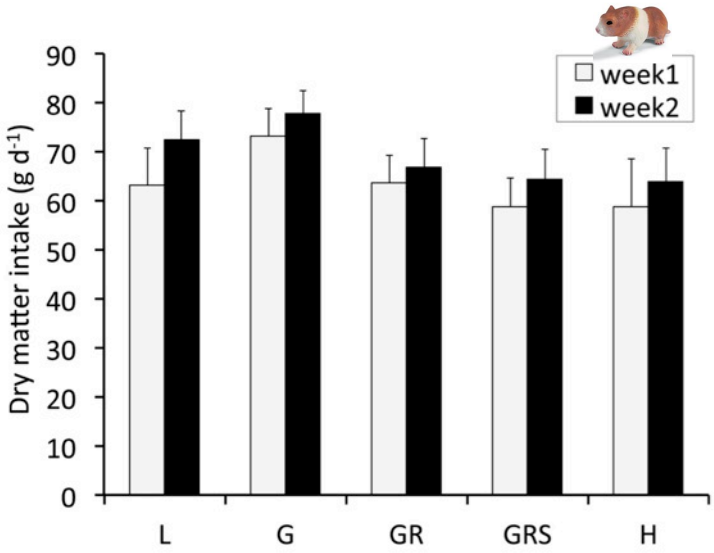


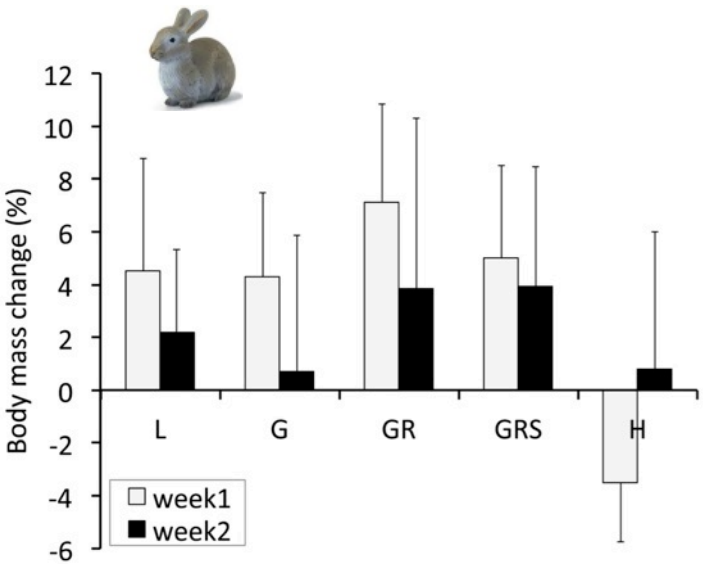


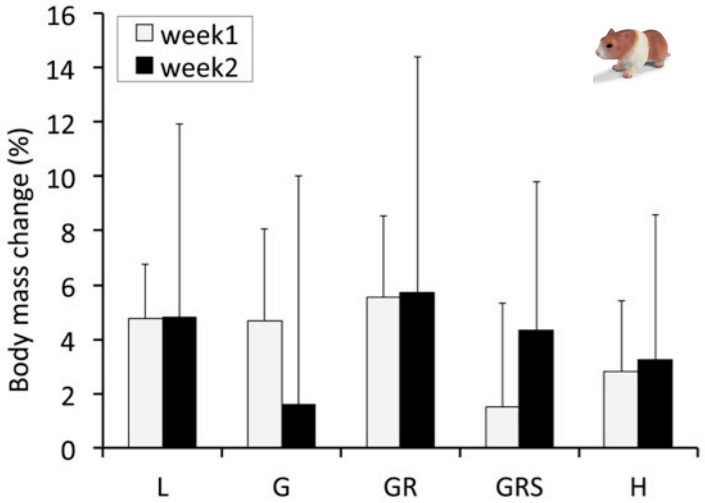


Food intake / Body mass change

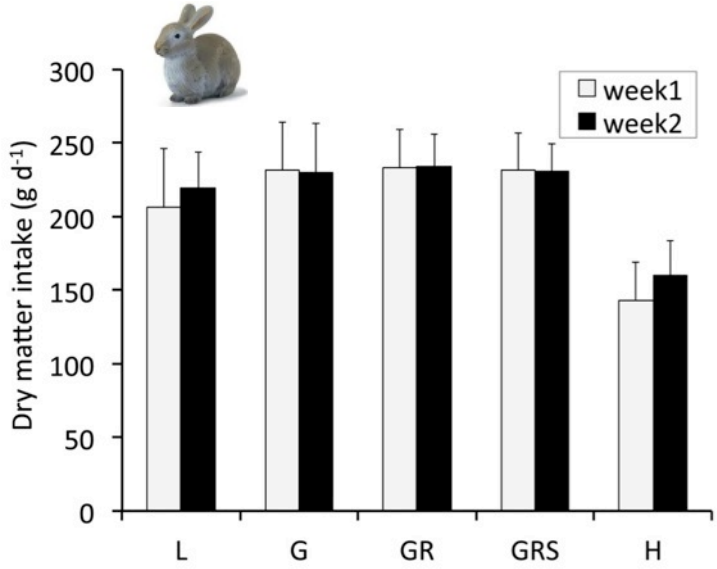


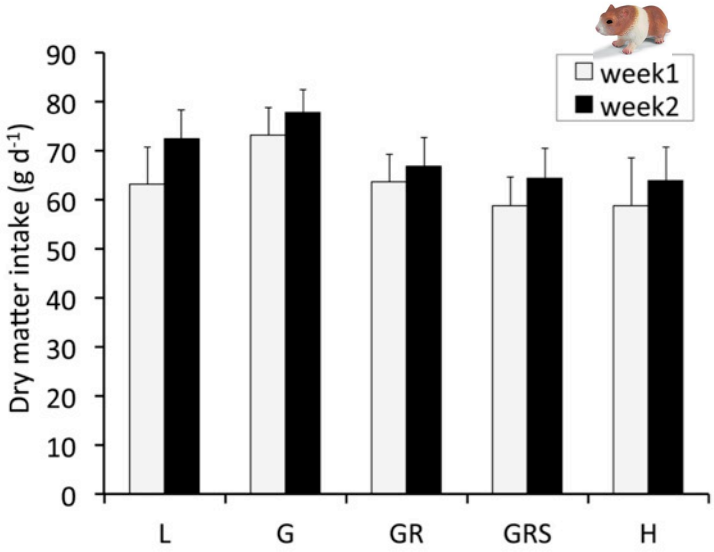


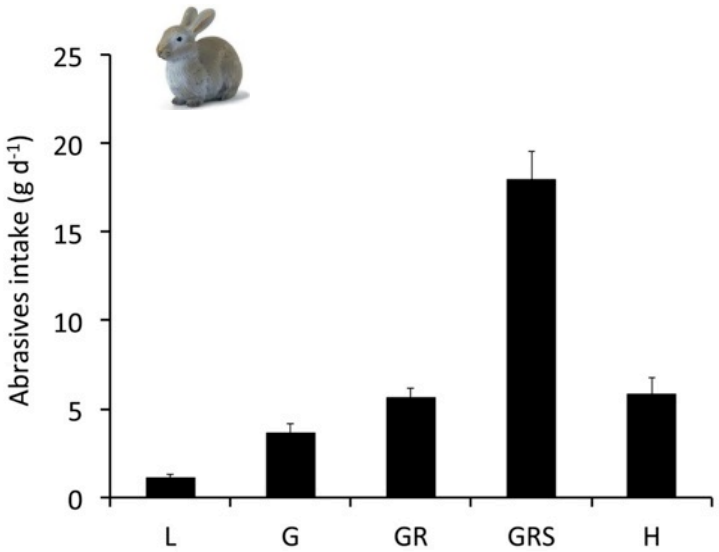


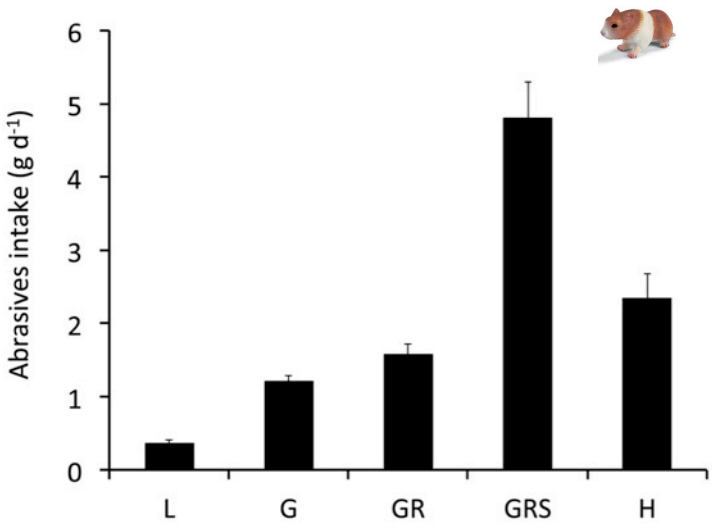


Food intake / Abrasives intake









Hypotheses I

Tooth growth compensates for wear; therefore we expect tooth length to be relatively constant across diets and growth tightly correlated with wear.

Nevertheless, differences in tooth length between diets, due to an incomplete compensation between growth and wear, can be detected.

Hypotheses II

Functional differences between incisors and cheek teeth lead to different wear and growth on different diets, i.e.

a) incisors are worn more heavily when feeding whole hay that needs more gnawing as compared to pellets;

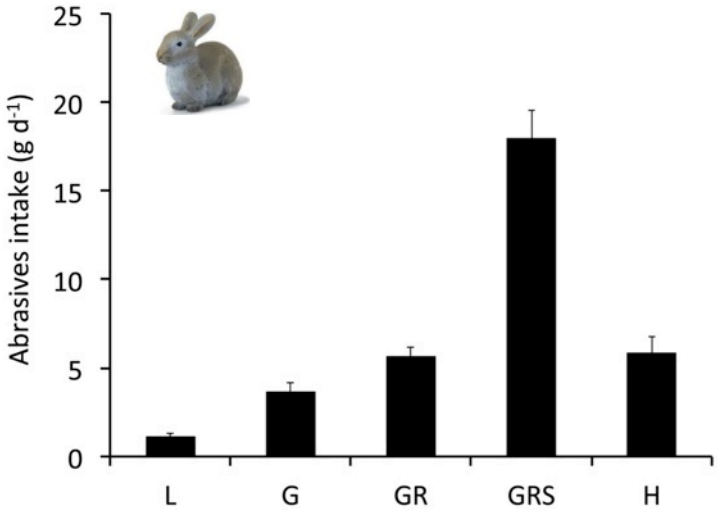
b) cheek teeth, with a chewing action more independent from whether the diet is offered whole or pelleted, are worn more heavily with increasing dietary abrasiveness;

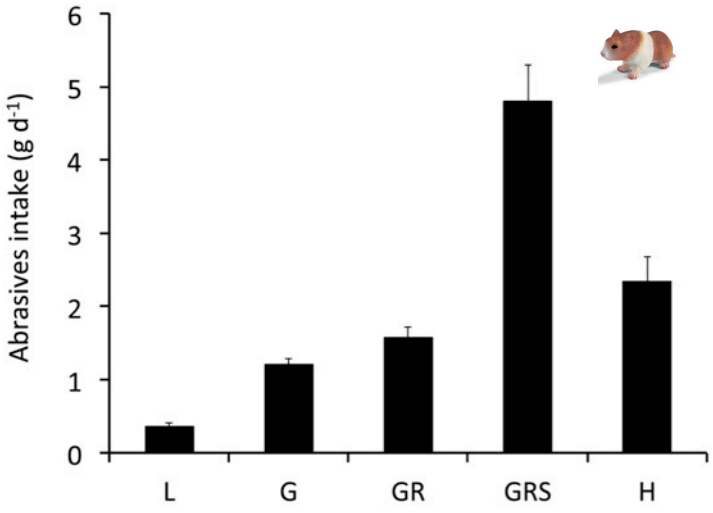
c) external abrasives (sand) lead to a gradient in wear along the maxillary cheek tooth row whereas increased internal abrasives (phytoliths in rice hulls) do not lead to such a gradient

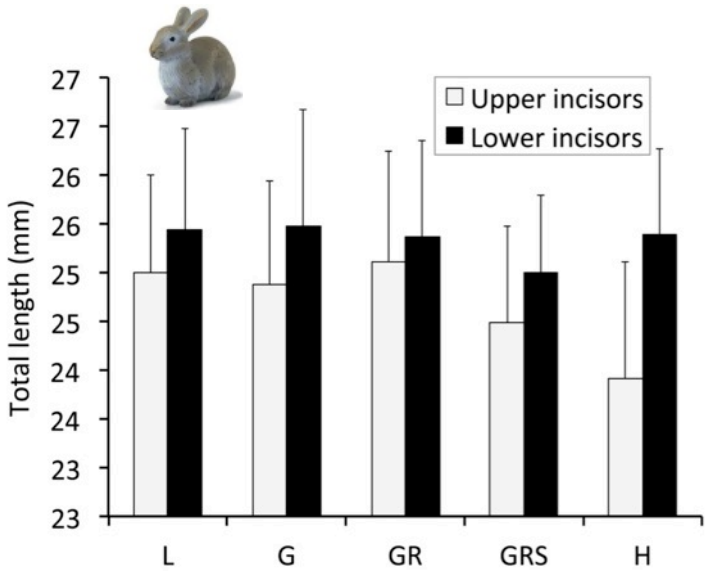
Hypotheses III

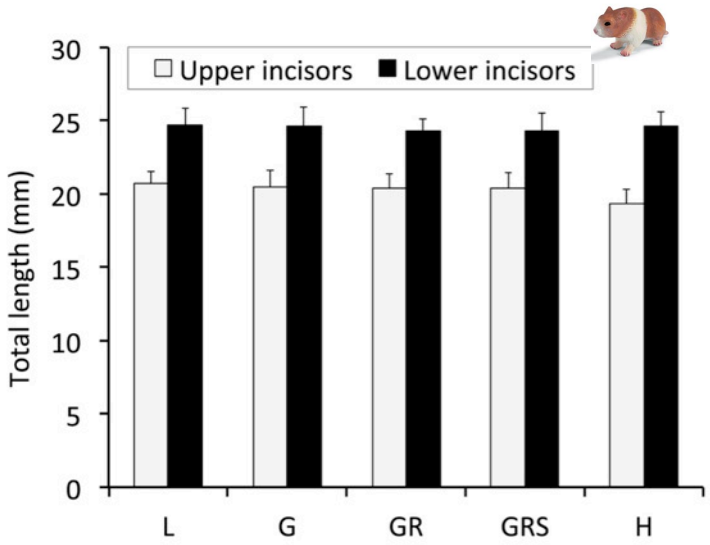
No hypothesis regarding differences between maxillary and mandibulary teeth!

Incisor length

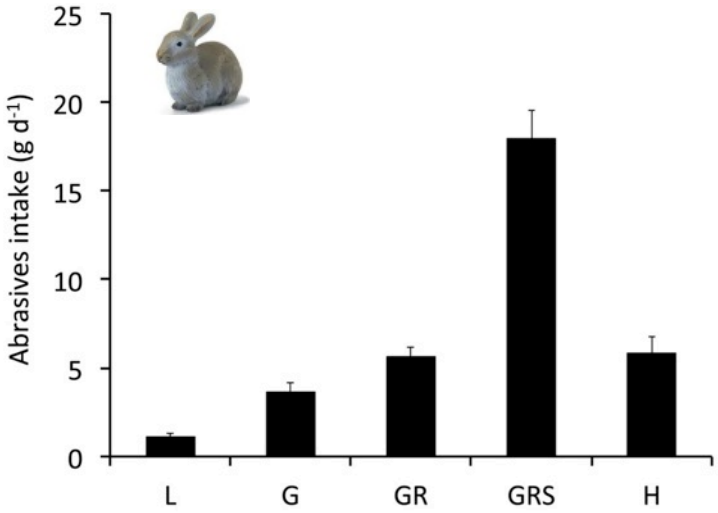


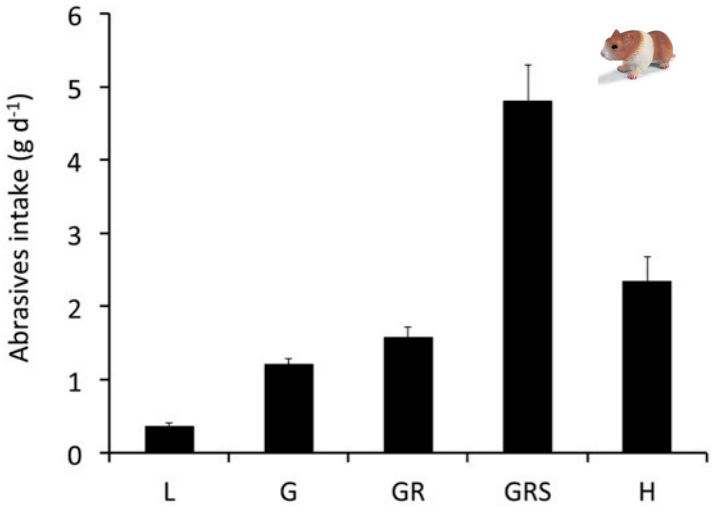


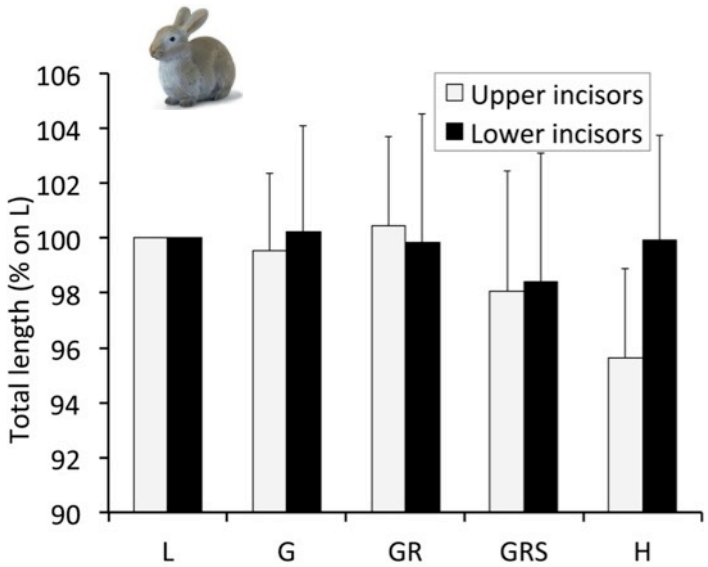


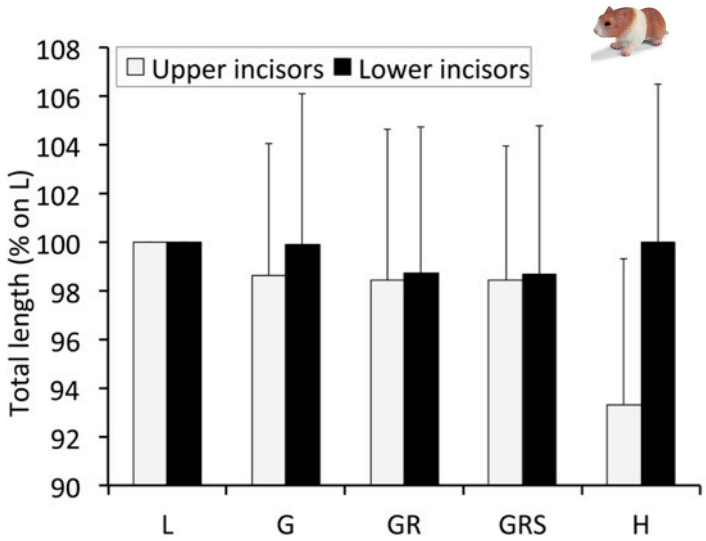


Incisor length

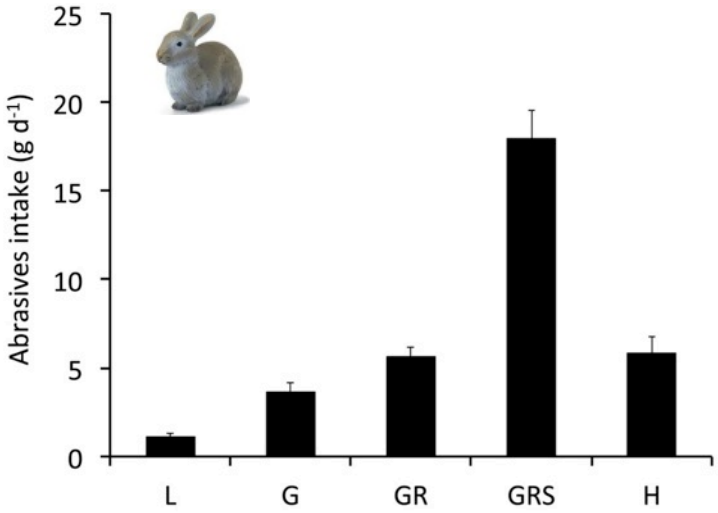


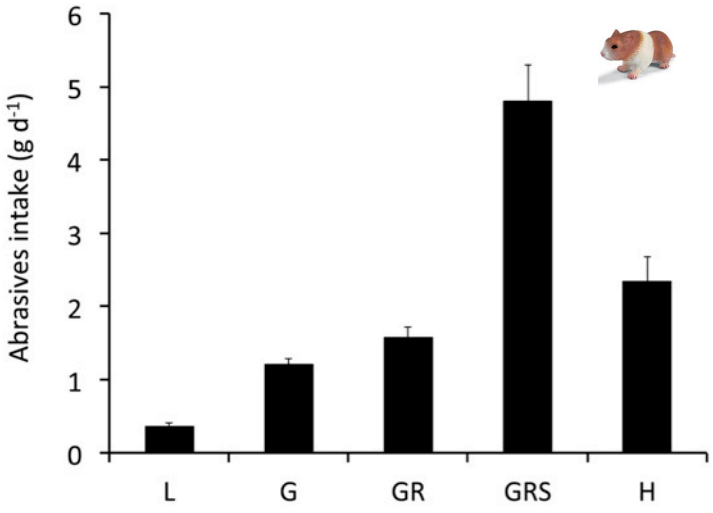


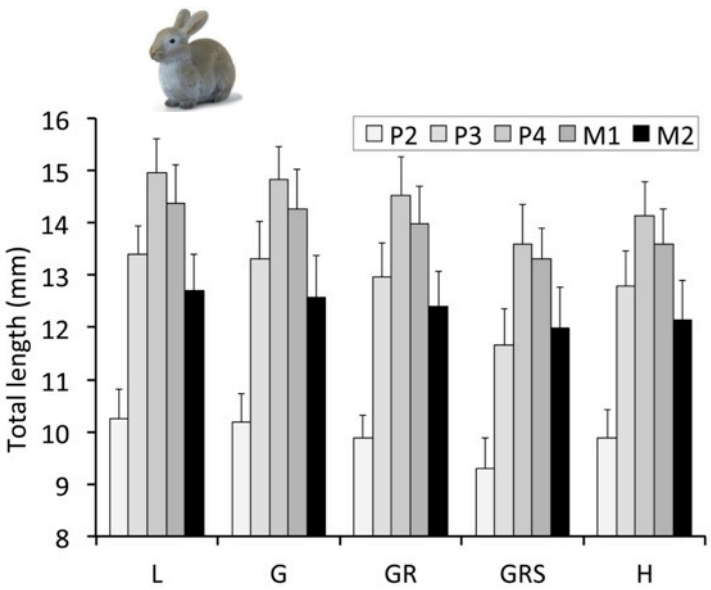


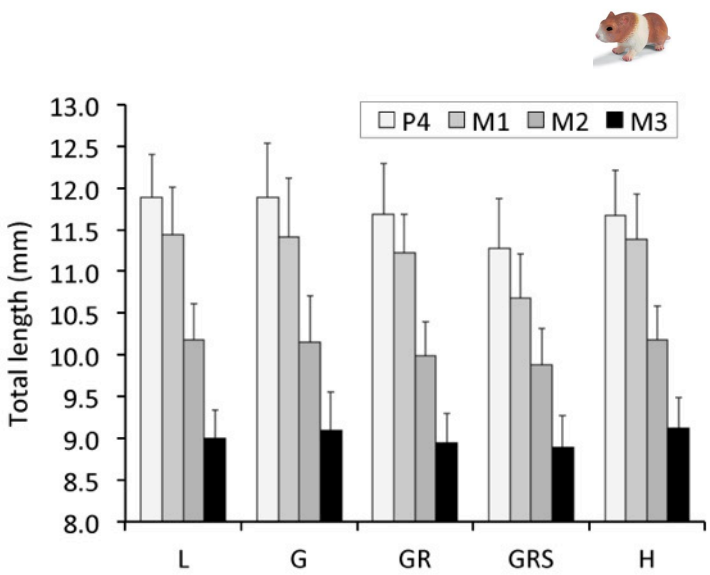


Upper molar length

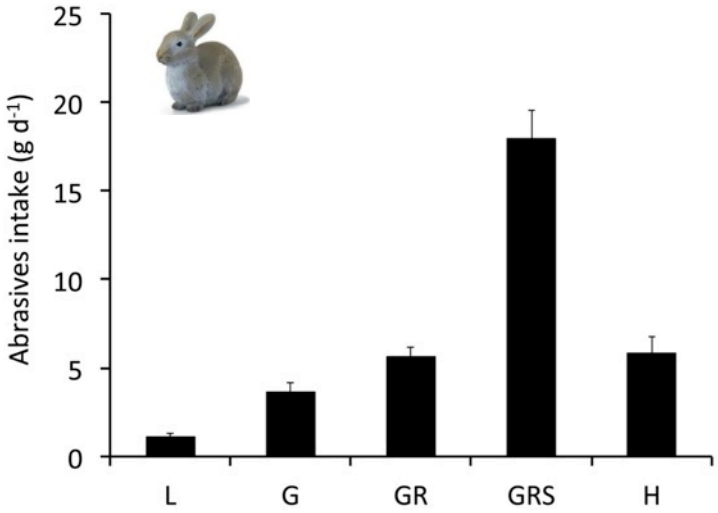


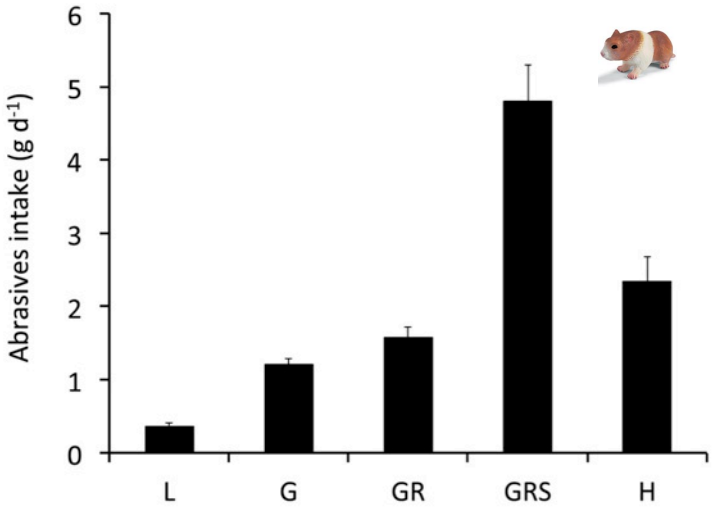


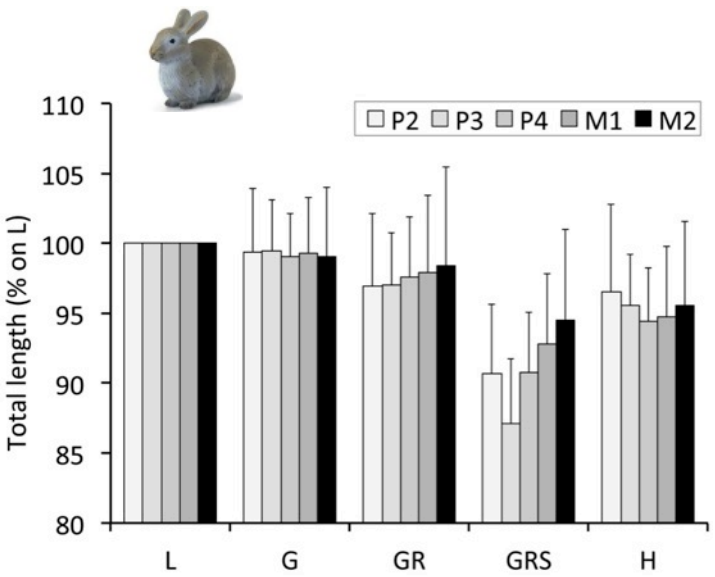


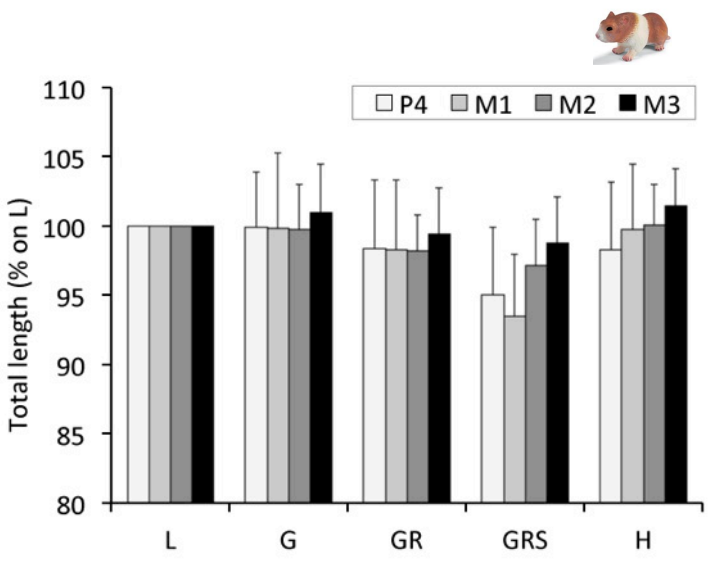


Upper molar length

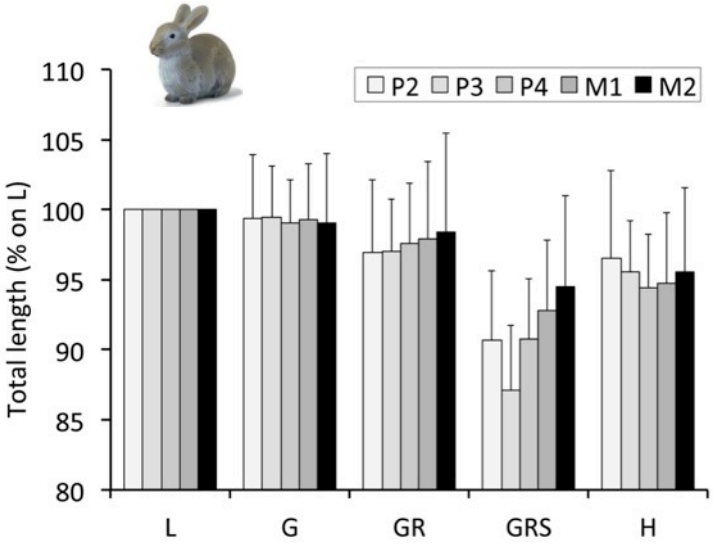


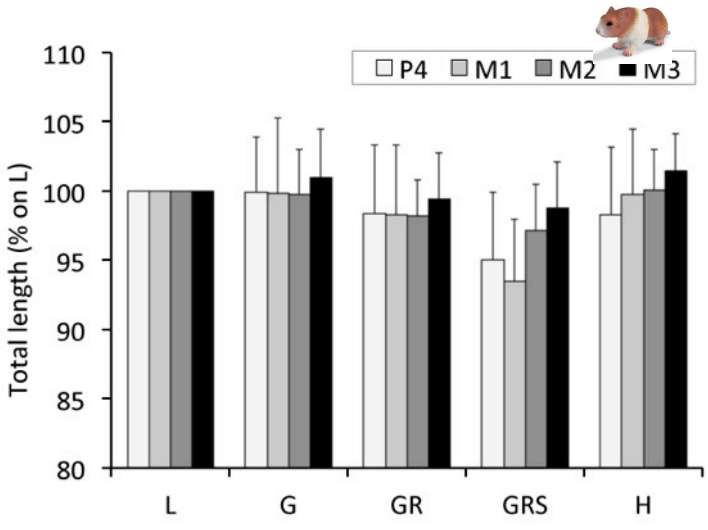


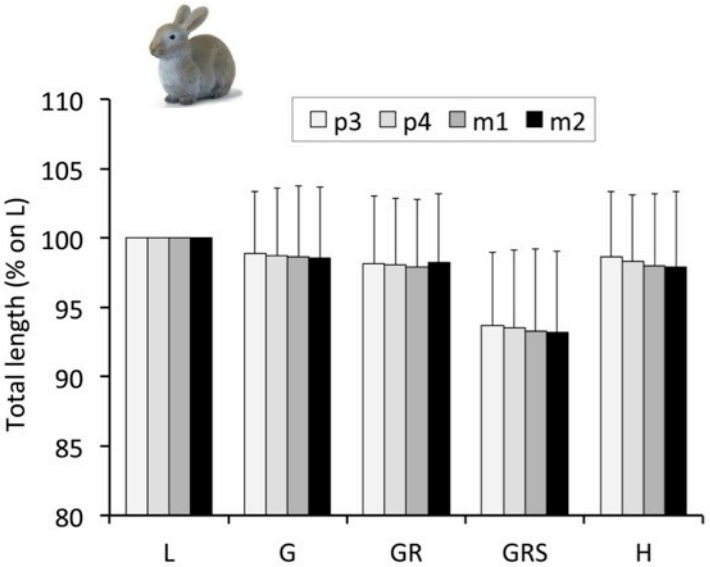


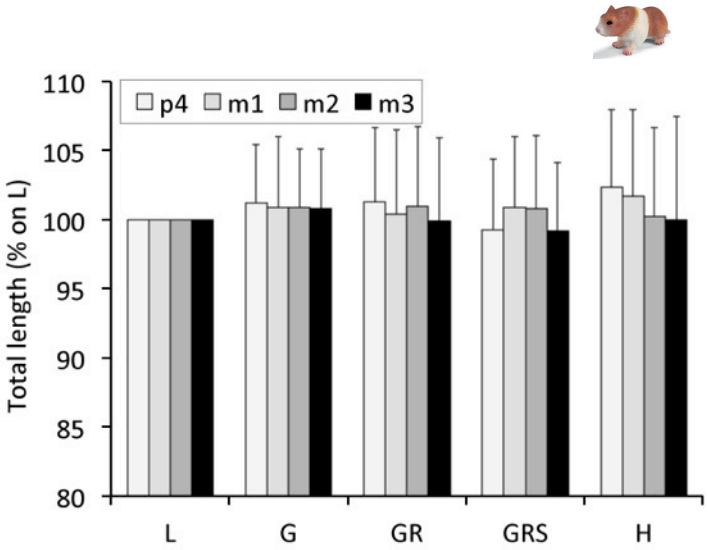


Upper/Lower molar length

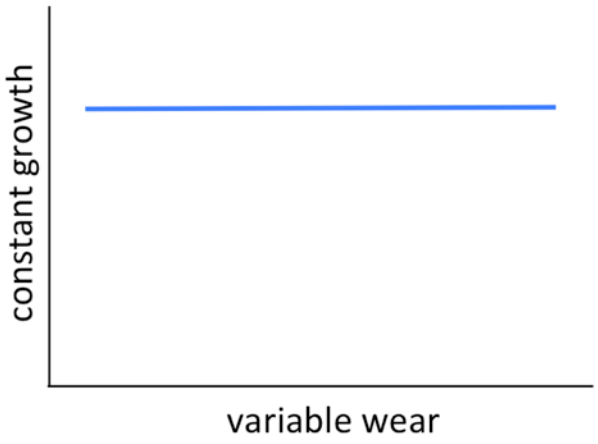


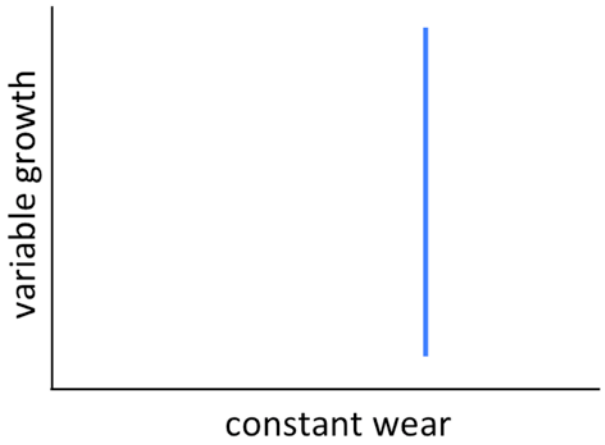


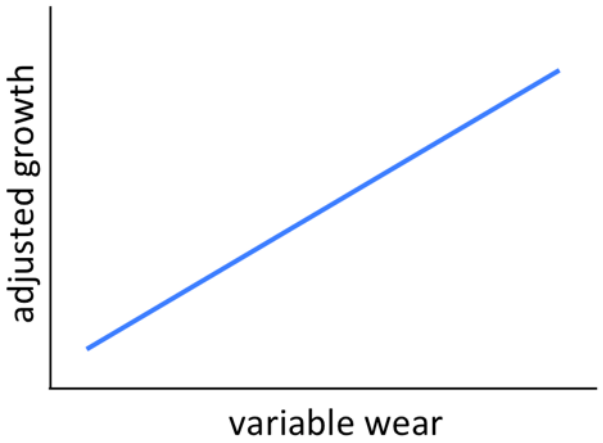




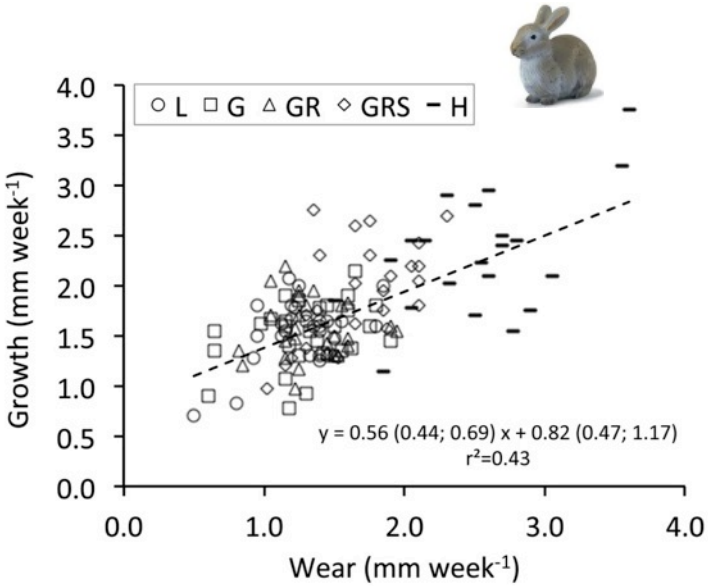
Growth

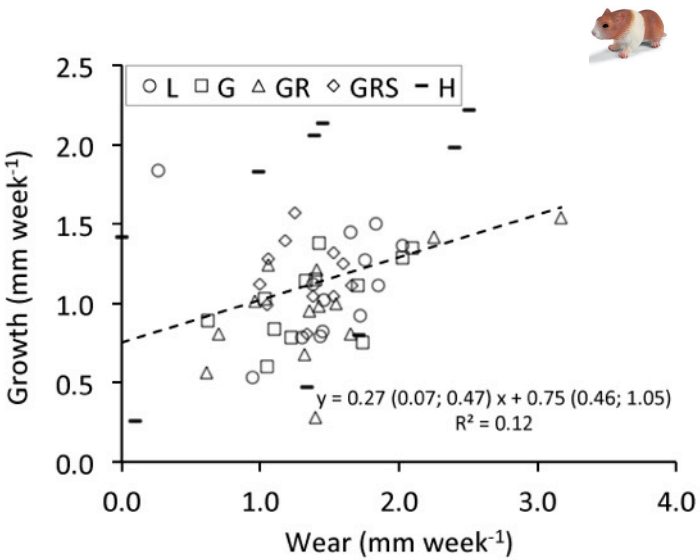

constant growth
variable wear

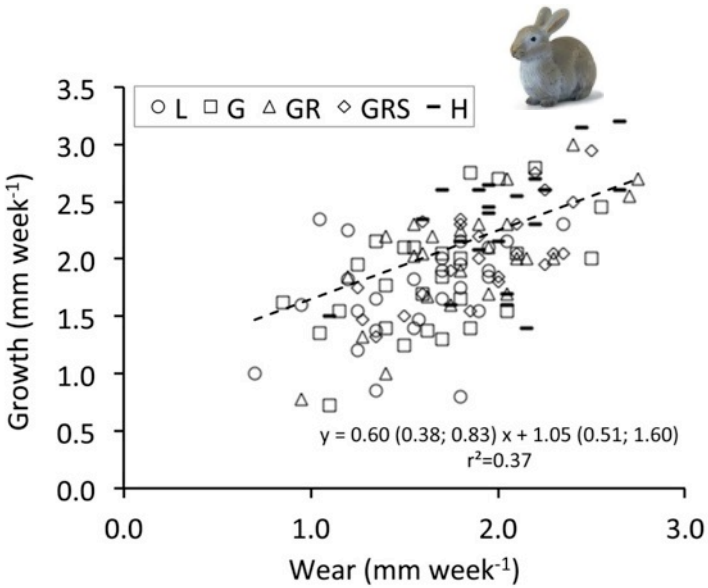

variable growth
constant wear

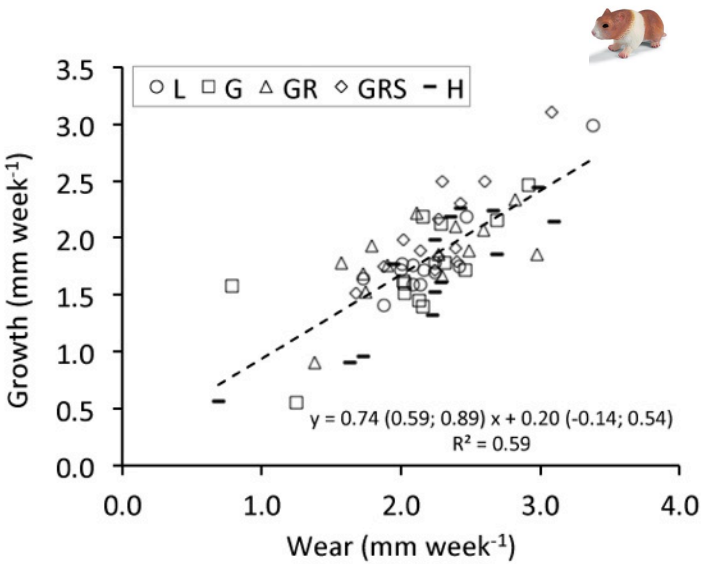

adjusted growth
variable wear

Upper/lower incisor growth

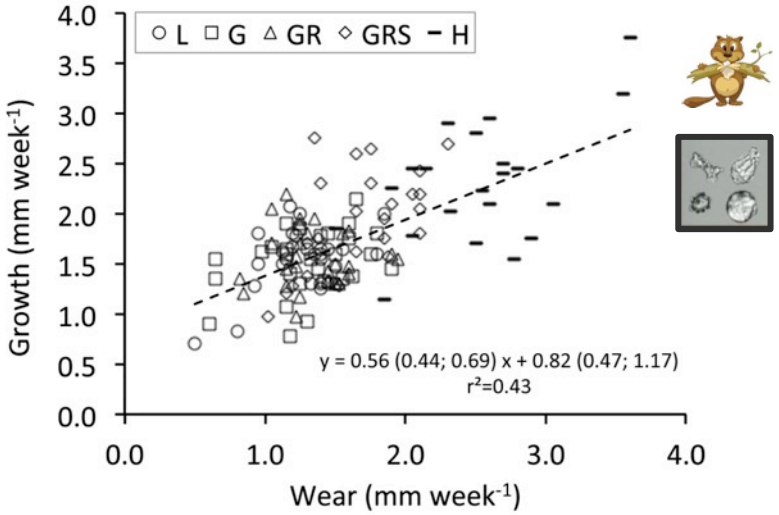


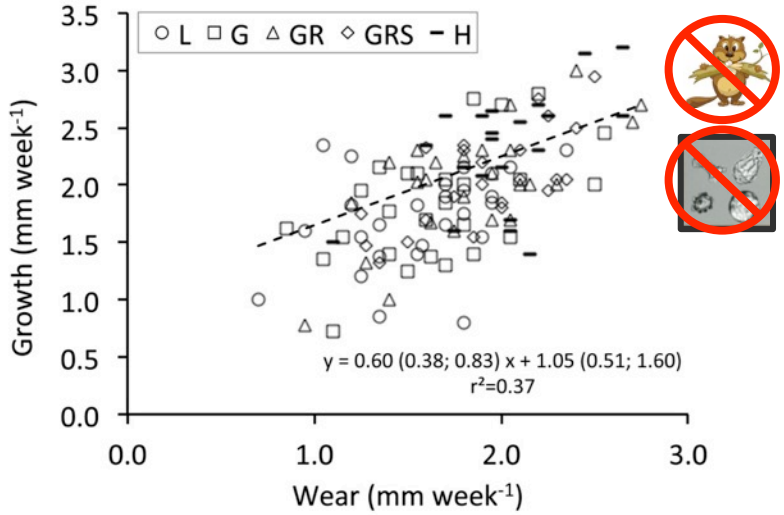


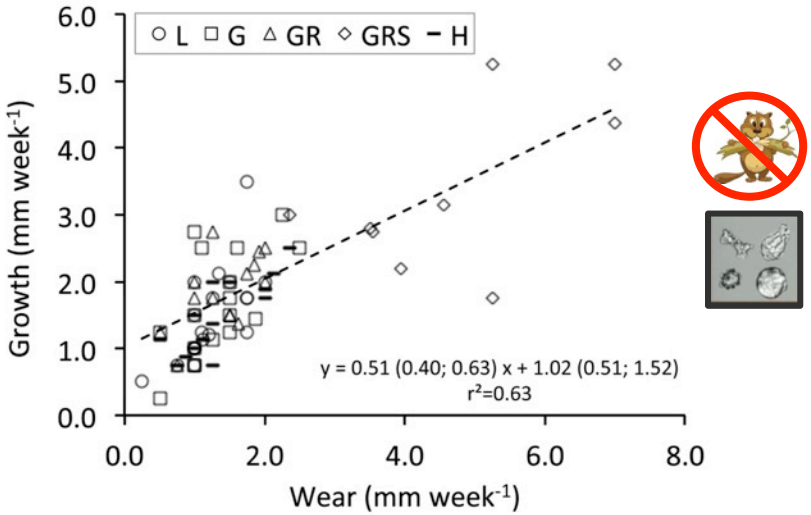




Lower premolar growth







Absolute growth

Study	Method	Diet	Upper incisor		Lower incisor		Lower cheek teeth	
			Growth	Wear	Growth	Wear	Growth	Wear
(Shadle, '36)	Tooth mark	nm		2.0		2.4		
(Spannbrucker et al., '77)	nm	nm	2.1-2.3		2.1-2.3			
(von Koenigswald and Golenishev, '79)	Enamel staining	nm	2.5		2.7		1.1-1.3	
(Lobprise and Wiggs, '91)	nm	nm	2		2.4			
(Wolf and Kamphues, '95)	Tooth mark	Carrots	1.68	1.61	1.64	1.45		
		Grass hay	1.74	1.65	1.82	1.61		
		Grain mix	1.39	1.21	1.25	1.14		
		Pellets	1.33	1.18	1.11	1.02		
(Meredith, '07)	nm	nm	3	3	3	3	0.7	0.7
(Harcourt-Brown, '09)	nm	nm	2.0-2.4		2.0-2.4			
(Lord, '11)	nm	nm	2.0-2.5	2.0-2.5	2.0-2.5	2.0-2.5	0.6-0.7	
(Schumacher, '11)	nm	nm					0.5-0.7	
(Jekl and Redrobe, '13)	nm	nm	2-4	2-4	2-4	2-4	0.7-0.93	0.7-0.93
this study	Tooth mark[1]	L	1.54	1.27	1.72	1.57	1.47	1.23
		G	1.53	1.31	1.80	1.66	1.66	1.33
		GR	1.57	1.34	2.00	1.84	1.78	1.33
		GRS	1.98	1.68	2.09	1.90	3.23	4.47
		H	2.39	2.52	2.42	2.02	1.37	1.27

Hypotheses I - confirmed

Tooth growth compensates for wear *on the basis of individual teeth*; therefore we expect tooth length to be relatively constant across diets and growth tightly correlated with wear.

Nevertheless, differences in tooth length between diets, due to an incomplete compensation between growth and wear, can be detected.

Hypotheses I - confirmed

Tooth growth compensates for wear *on the basis of individual teeth*; therefore we expect tooth length to be relatively constant across diets and growth tightly correlated with wear.

Nevertheless, differences in tooth length between diets, due to an incomplete compensation between growth and wear, can be detected.

There must be a tooth-specific feedback mechanism probably using occlusion pressure as a feedback signal. This sensor remains to be identified.

Hypotheses II – mostly confirmed

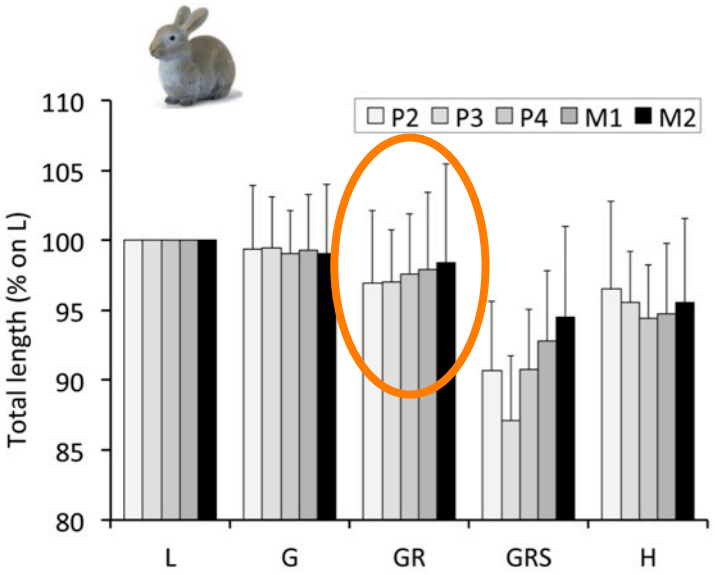
Functional differences between incisors and cheek teeth lead to different wear and growth on different diets, i.e.

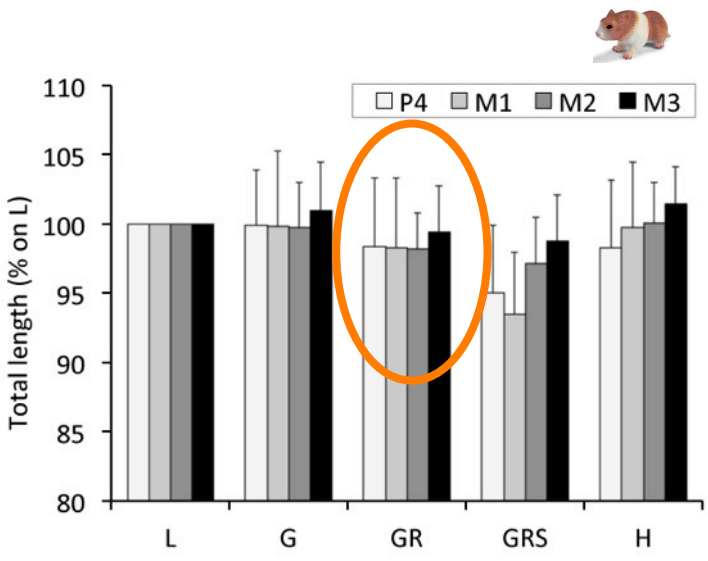
a) upper incisors are worn more heavily when feeding whole hay that needs more gnawing as compared to pellets;

b) cheek teeth, with a chewing action more independent from whether the diet is offered whole or pelleted, are worn more heavily with increasing dietary abrasiveness;

c) ~~external abrasives (sand) lead to a gradient in wear along the maxillary cheek tooth row whereas increased internal abrasives (phytoliths in rice hulls) do not lead to such a gradient~~

Phytoliths abrade!





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Research

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Author for correspondence:
Peter W. Lucas
e-mail: peter.lg@fc.edu.kw

Mechanisms and causes of wear in tooth enamel: implications for hominin diets

Peter W. Lucas[1], Ridwaan Omar[2], Khaled Al-Fadhalah[3], Abdulwahab S. Almusallam[4], Amanda G. Henry[5], Shaji Michael[6], Lidia Anokia Thai[7], Jörg Watzke[8], David S. Strait[7] and Anthony G. Atkins[9]

[1]Department of Biodental Sciences, and [2]Department of Restorative Sciences, Kuwait University, PO Box 24923, Safat 13110, Kuwait
[3]Department of Mechanical Engineering, [4]Department of Chemical Engineering, and [6]Biotechnology Research Facility, College of Engineering and Petroleum, Kuwait University, PO Box 5969, Safat 13060, Kuwait
[5]Plant Foods in Hominin Dietary Ecology Group, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, Leipzig 04103, Germany
[7]Department of Anthropology, University at Albany, Albany, NY 12222, USA
[8]School of Construction Management and Engineering, University of Reading, Whiteknights, PO Box 219, Reading RG6 6AW, UK

The wear of teeth is a major factor limiting mammalian lifespans in the wild. One method of describing worn surfaces, dental microwear texture analysis, has proved powerful for reconstructing the diets of extinct vertebrates, but has yielded unexpected results in early hominins. In particular, although australopiths exhibit derived craniodental features interpreted as adaptations for eating hard foods, most do not exhibit microwear signals indicative of this diet. However, no experiments have yet demonstrated the fundamental mechanisms and causes of this wear. Here, we report nanowear experiments where individual dust particles, phytoliths and enamel chips were slid across a flat enamel surface. Microwear features produced were influenced strongly by intersecting mechanical properties and particle geometry. Quartz dust was a rigid abrasive, capable of fracturing and removing enamel pieces. By contrast, phytoliths and enamel chips deformed during sliding, forming U-shaped grooves or flat troughs in enamel, without tissue loss. Other plant tissues seem too soft to mark enamel, acting as particle transporters. We conclude that dust has overwhelming importance as a wear agent and that dietary signals preserved in dental microwear are indirect. Nanowear studies should resolve controversies over adaptive trends in mammals like enamel thickening or hypodontly that delay functional dental loss.

1. Introduction

Dental wear, the loss of tooth tissue, threatens the survival of individual mammals in the wild by jeopardizing their rate of food acquisition and processing [1–3]. Studied intensively for 60 years [4], wear patterns reflect the diet of living mammals and are capable of predicting diet in extinct forms [5–8]. This has been studied at various scales of measurement [9]. Macroscopic wear is ultimately what affects masticatory ability to reduce food particle sizes. The visible facets that form on molar teeth can be used to track changes in dental function and jaw movement [10], and are stable enough in position across species to trace the relationships between groups of early mammals [11]. However, the actual marks produced by wear mechanisms are microscopic. One analytical technique, dental microwear analysis, concentrates on describing the microscopic surface damage sustained by teeth when they collide with each other or with extraneous particles during feeding [12]. Species that consume leaves and other non-reproductive parts of plants seem to accumulate finely scratched tooth enamel surfaces with aligned features, while 'hard object' feeders tend to exhibit irregular or pitted wear patterns

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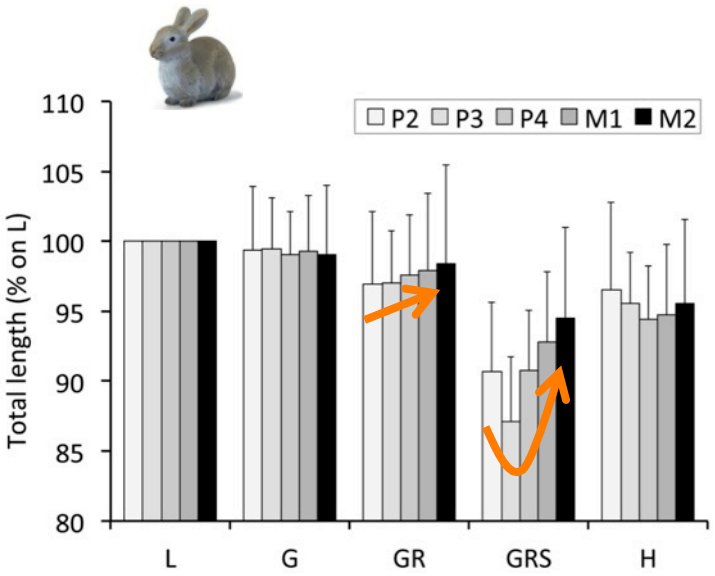
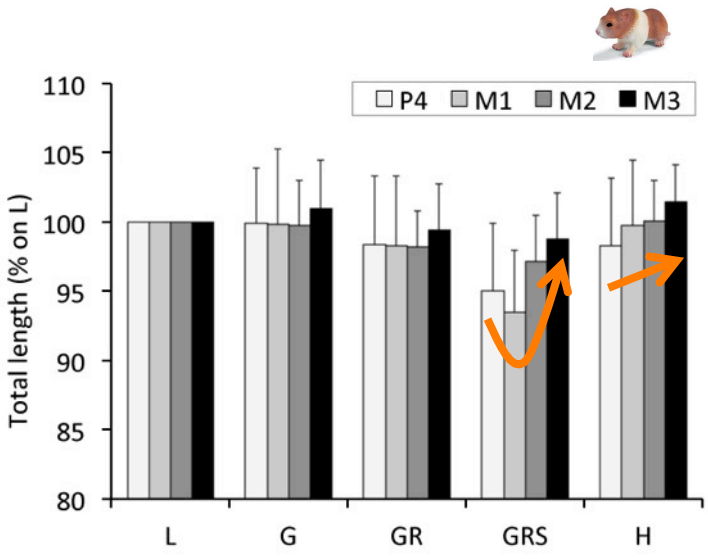
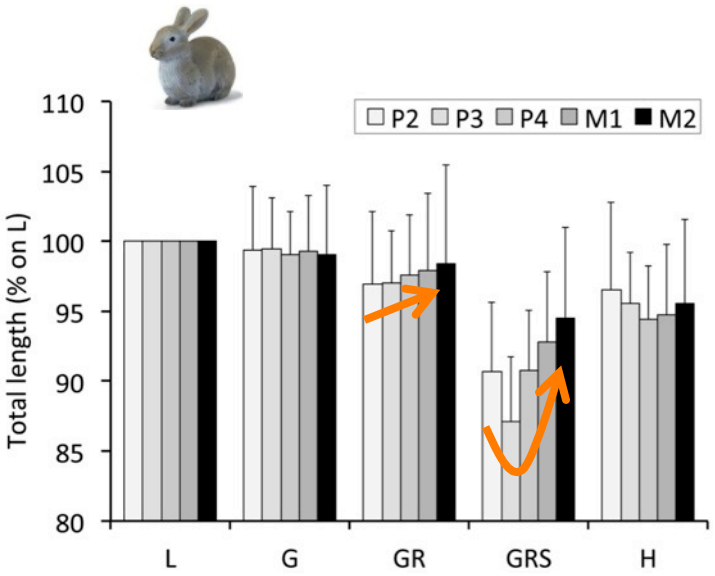
The cheek teeth gradient

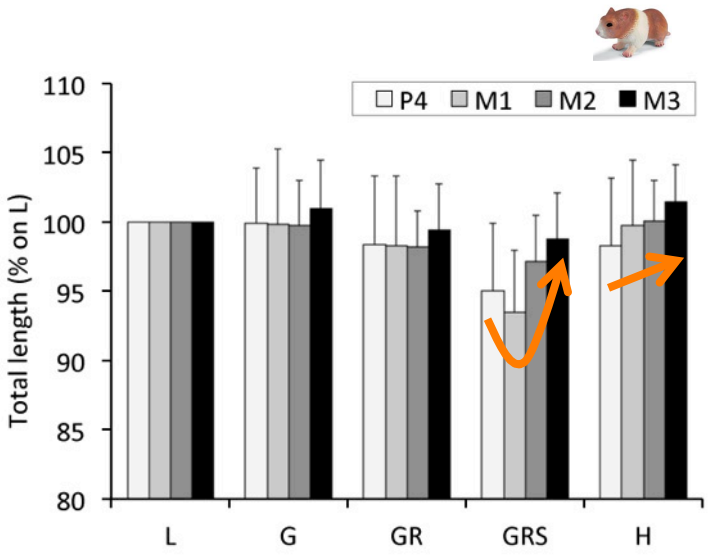




Wear gradients on both intrinsic and extrinsic abrasives.

The cheek teeth gradient



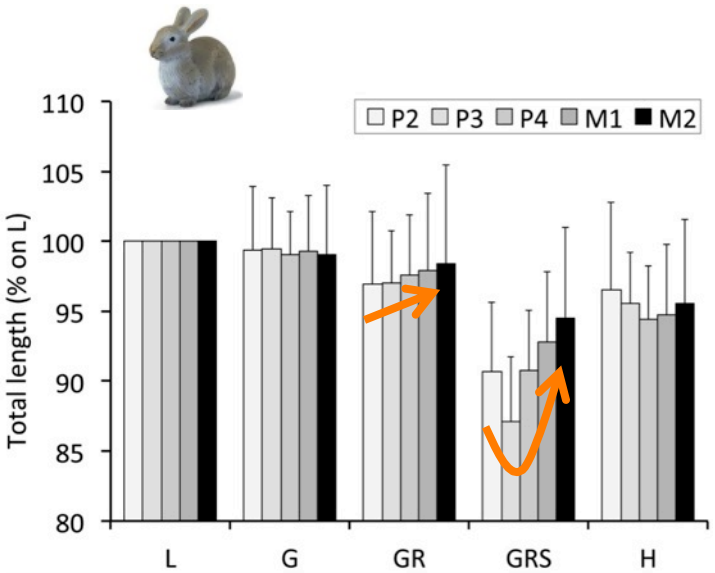


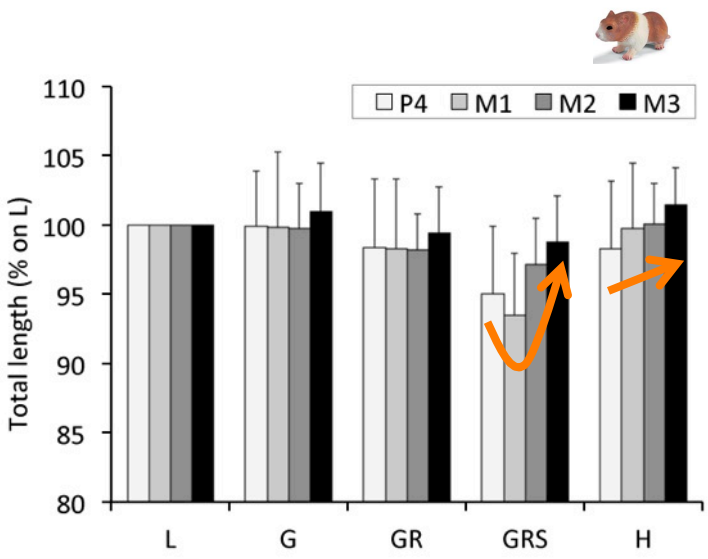
Different wear gradients (depending on diet) IN THE SAME INDIVIDUALS OF THE SAME SPECIES.

Wear gradients and functional grades in the diversification of the postcanine tooth row in mammalian dentitions

Wighart v. Koenigswald

The cheek teeth gradient

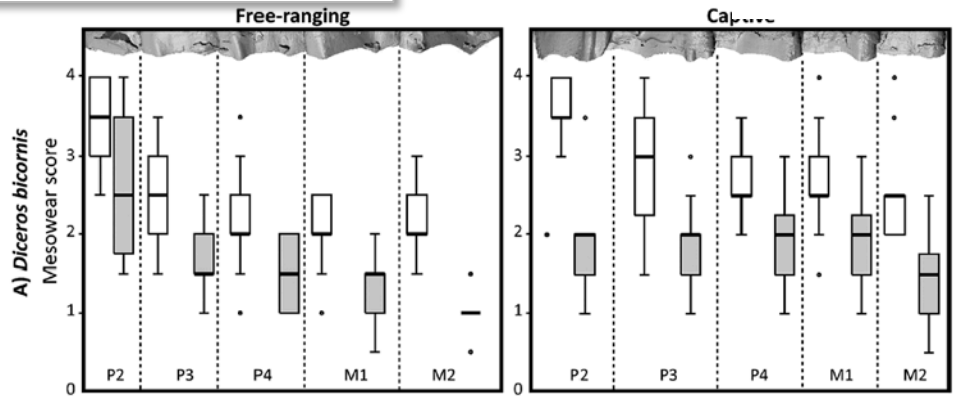




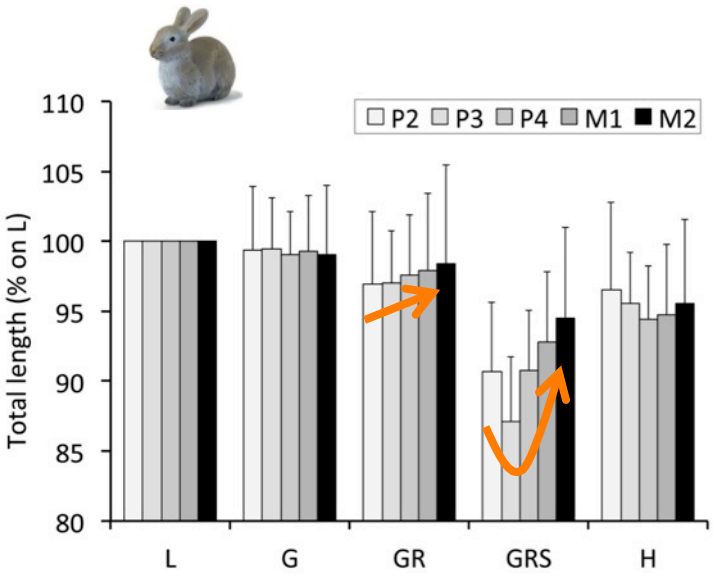
Contributions to Zoology, 83 (2) 107-117 (2014)

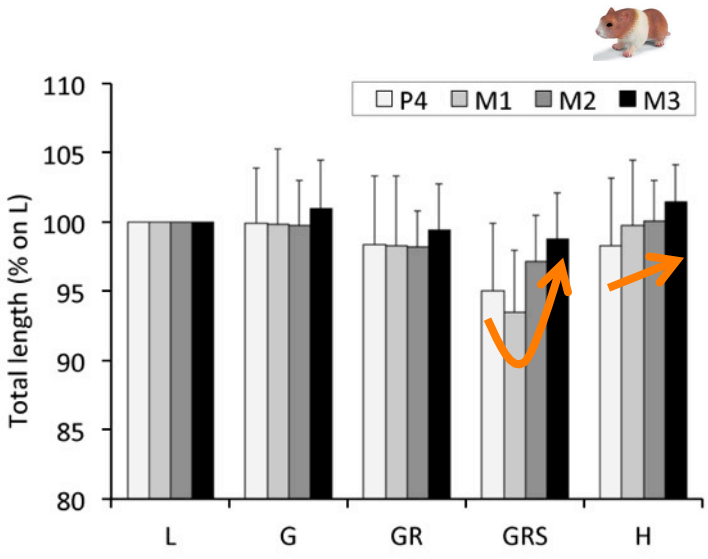
Tooth wear in captive rhinoceroses (*Diceros*, *Rhinoceros*, *Ceratotherium*: Perissodactyla) differs from that of free-ranging conspecifics

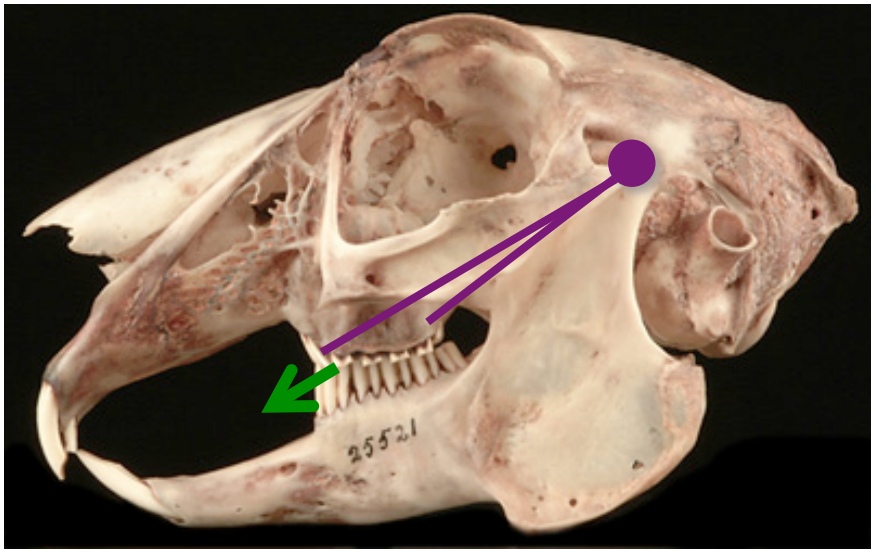
Lucy A. Taylor[1,2], Dennis W.H. Müller[3,4], Christoph Schwitzer[1], Thomas M. Kaiser[5], Daryl Codron[3,6], Ellen Schulz[5], Marcus Clauss[3,7]



The cheek teeth gradient



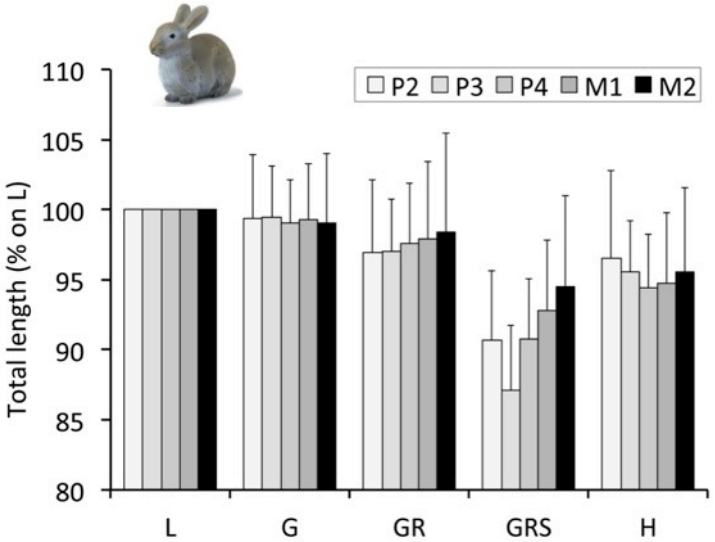


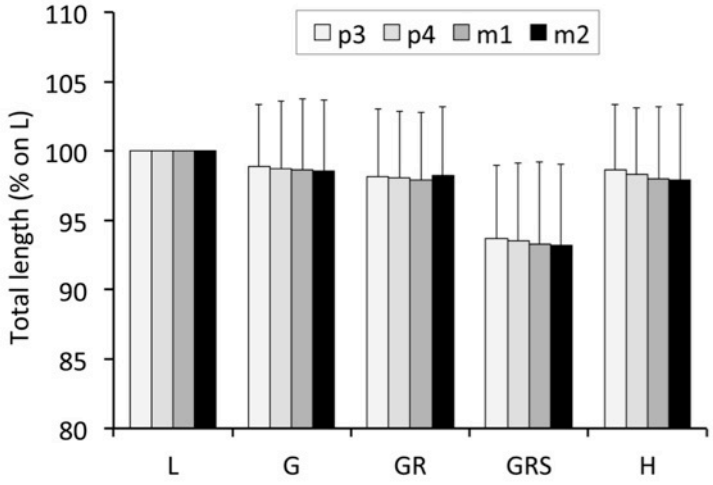


Hypotheses III – ad hoc explanation

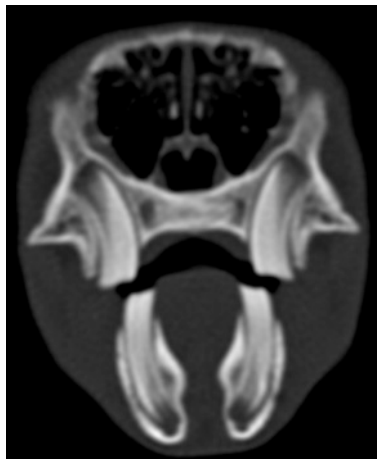
No hypothesis regarding differences between maxillary and mandibulary teeth!

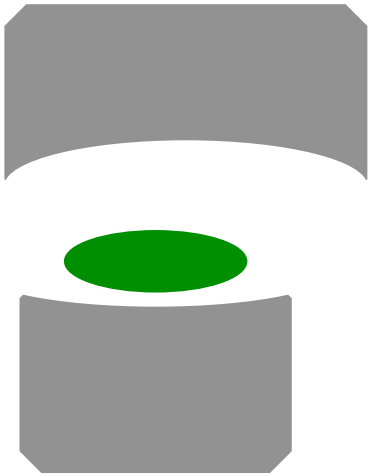
Maxilla-Mandible-Difference





Inverted pestle-and-mortar system:





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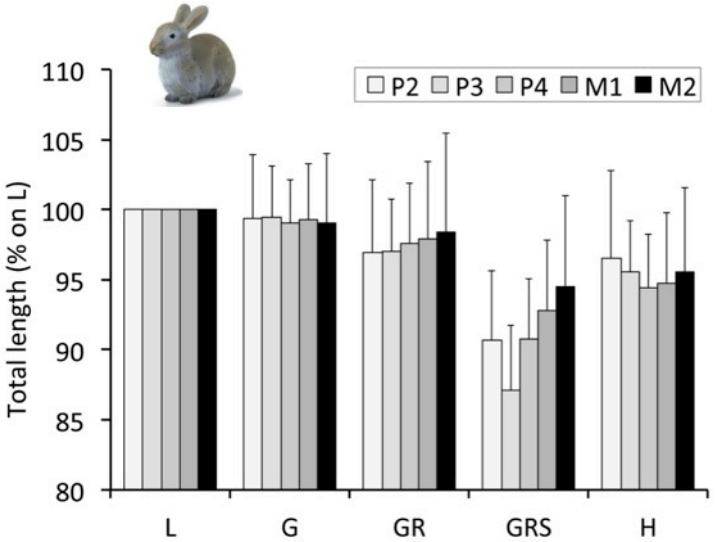

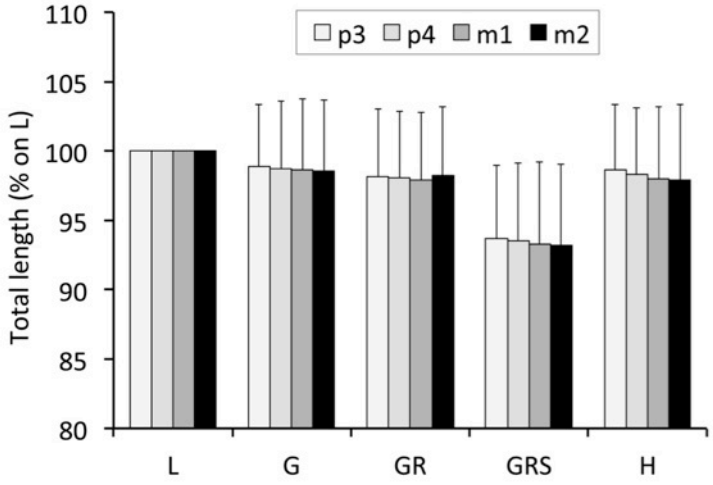

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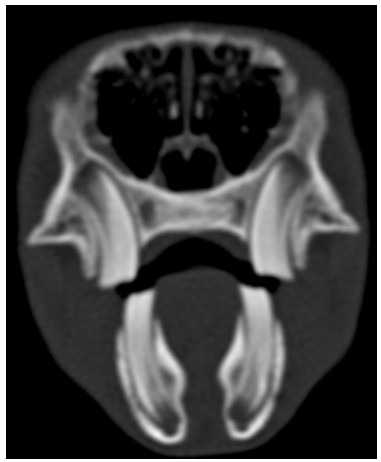

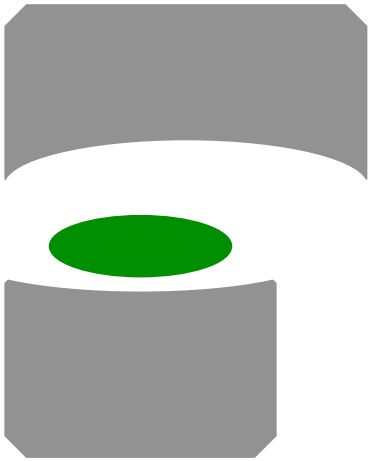

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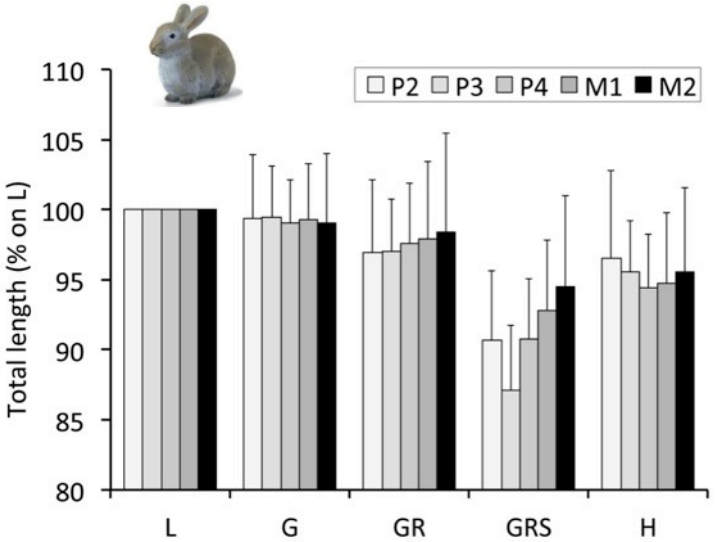

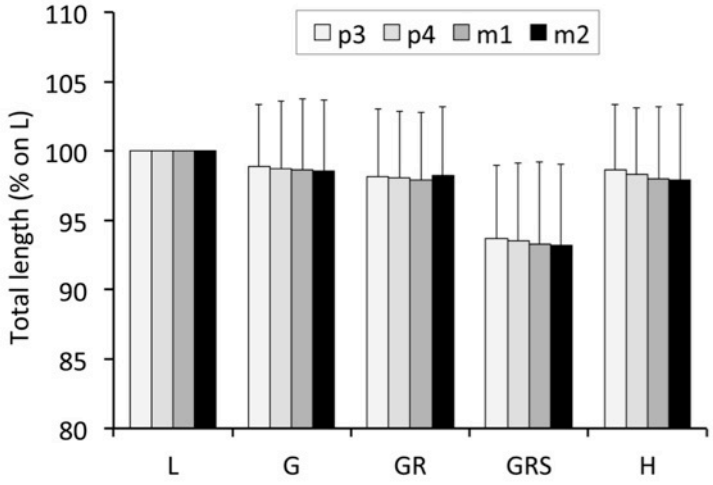

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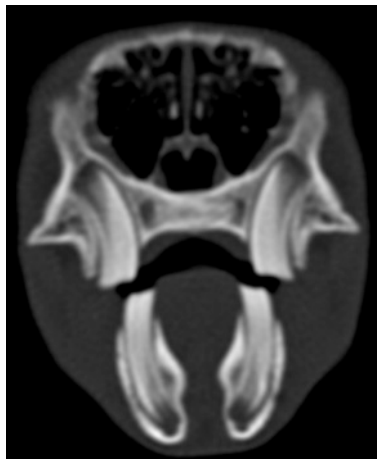

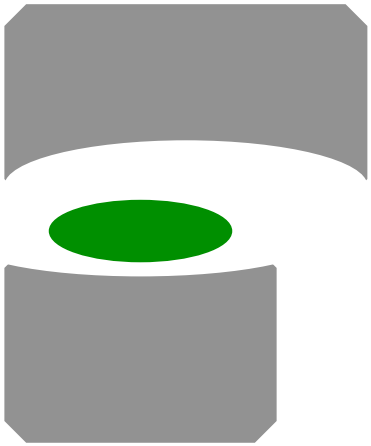

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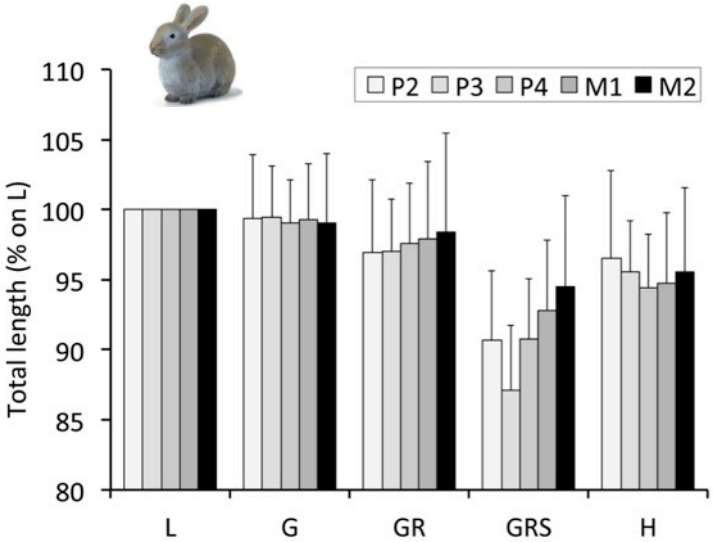

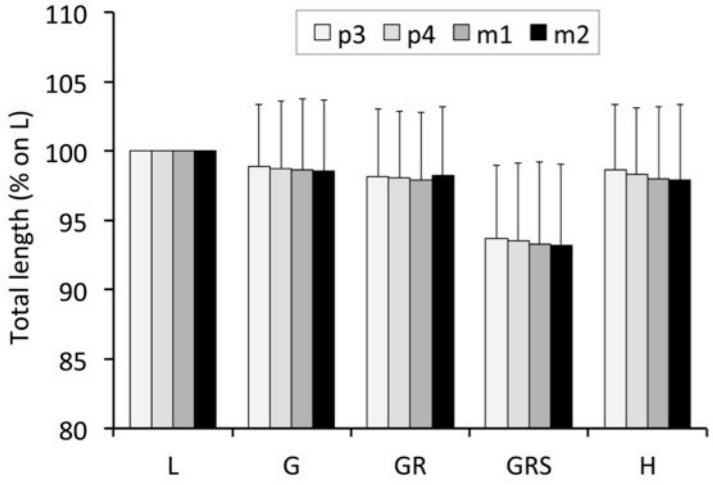

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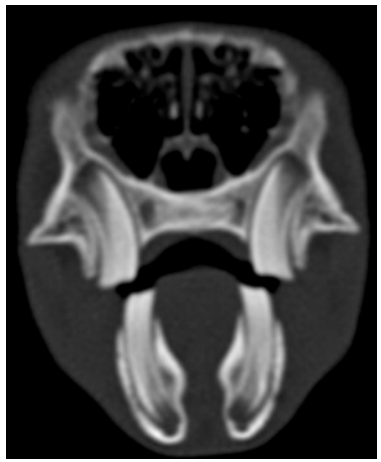

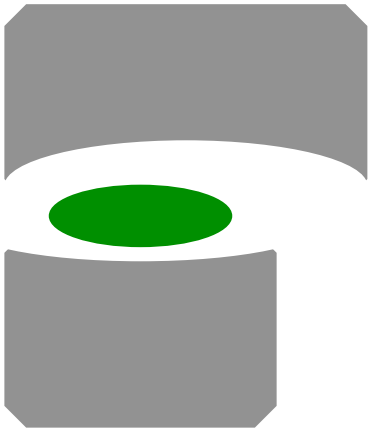

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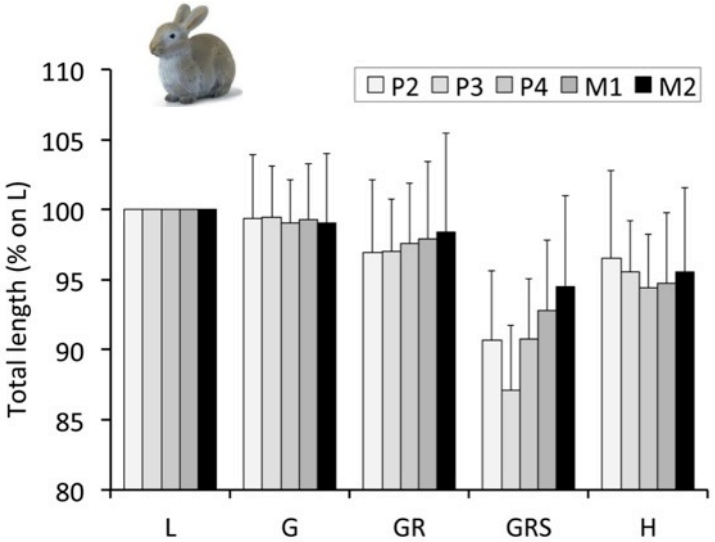

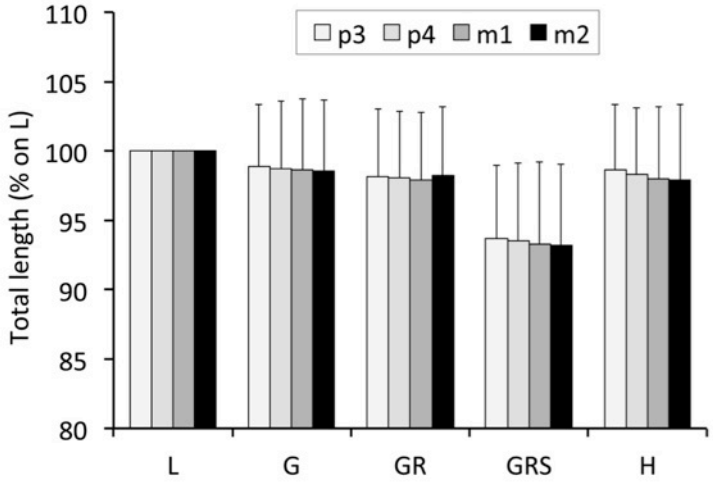

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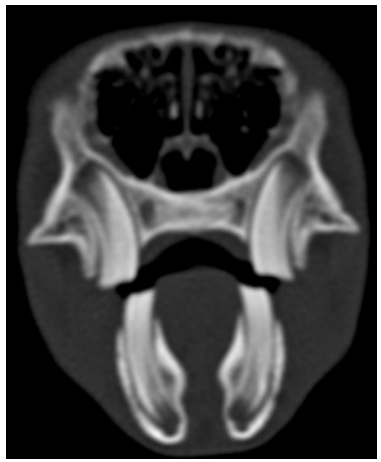

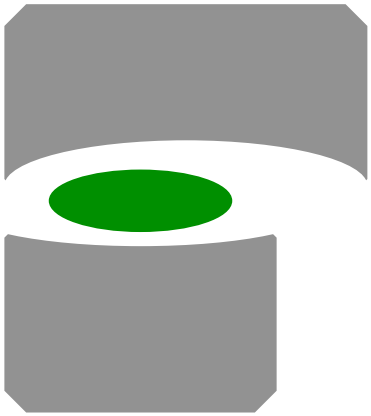

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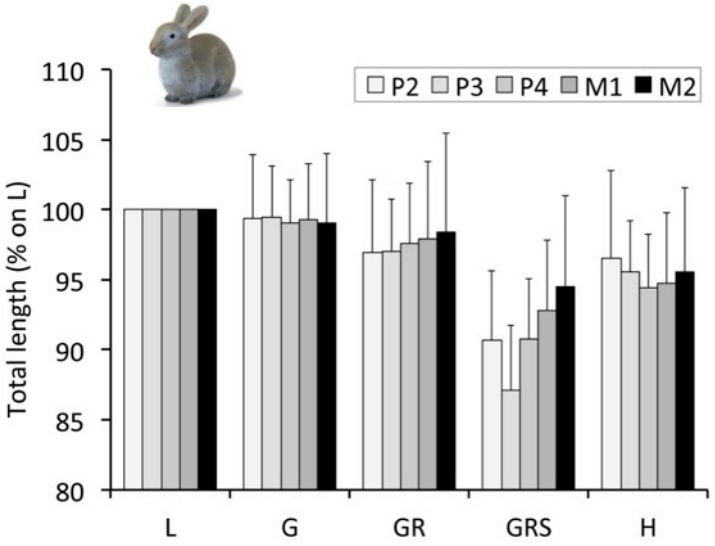

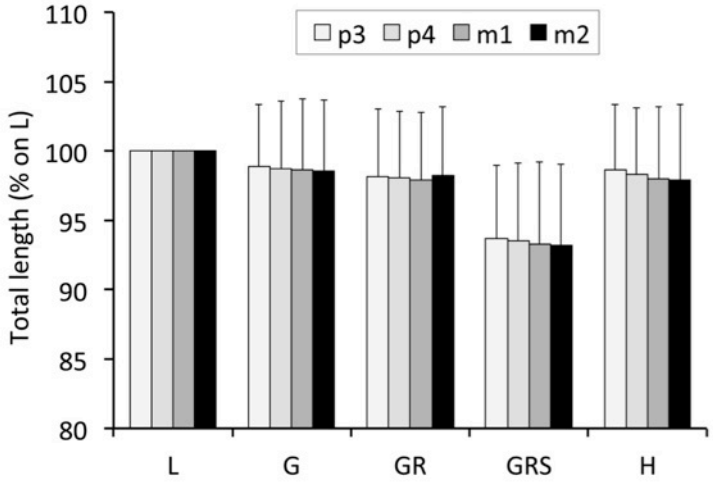

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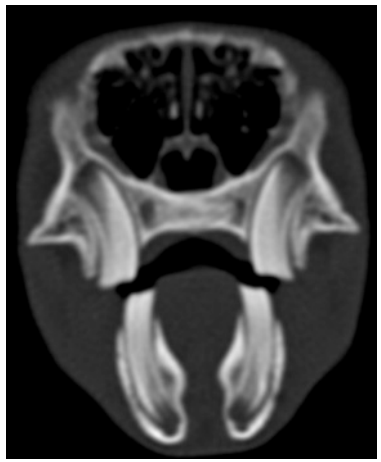

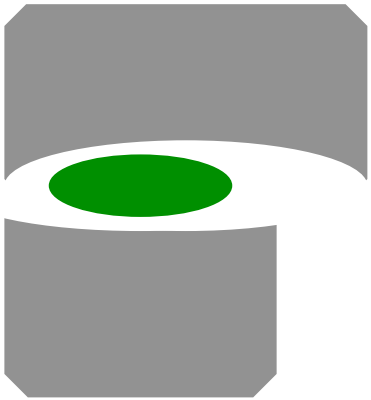

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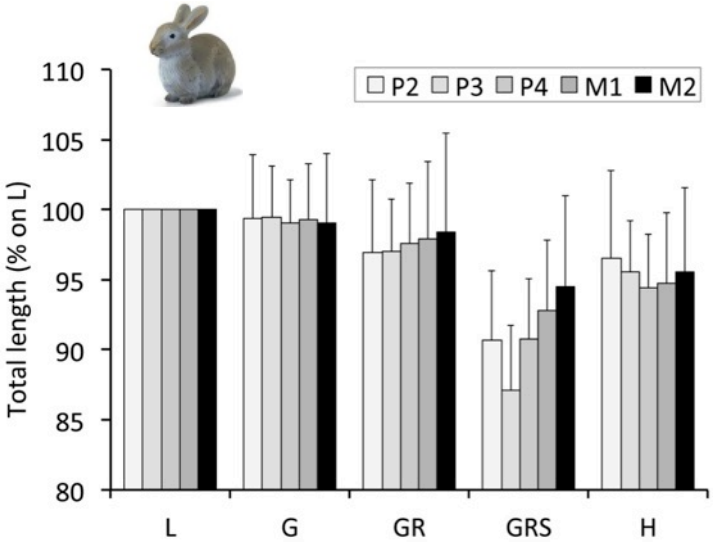

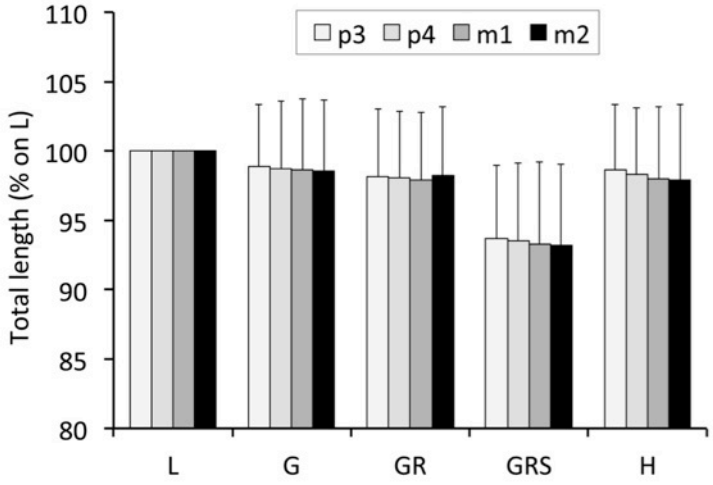

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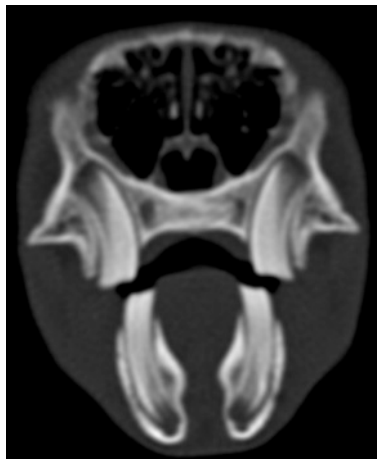

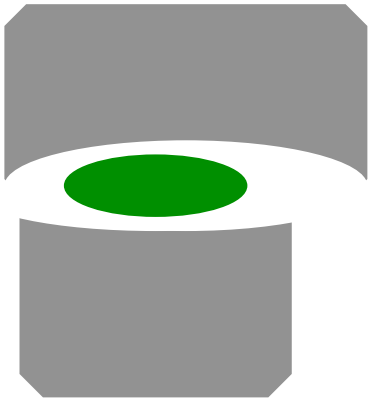

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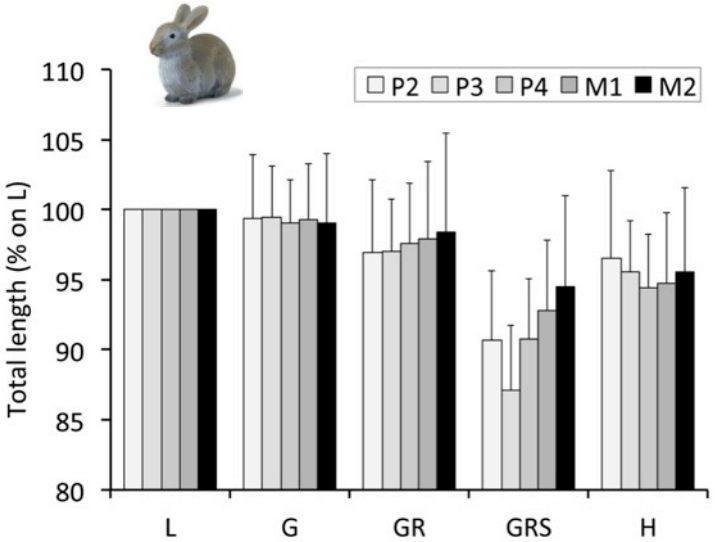

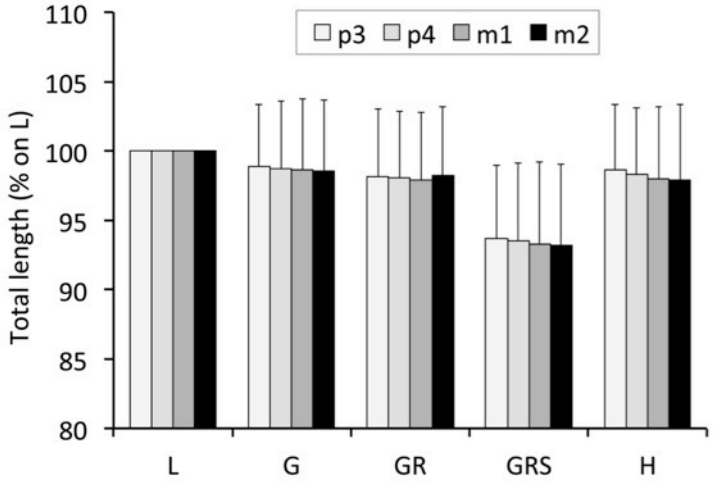

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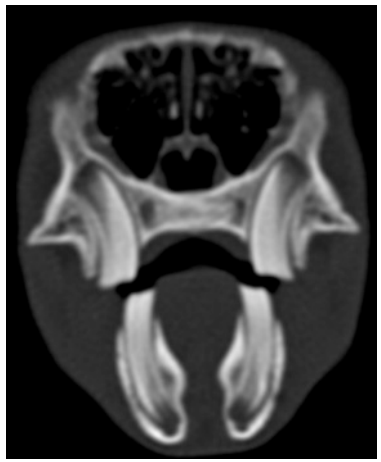

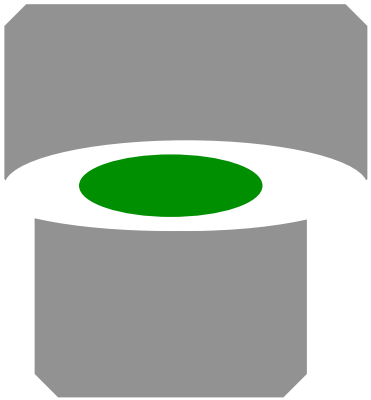

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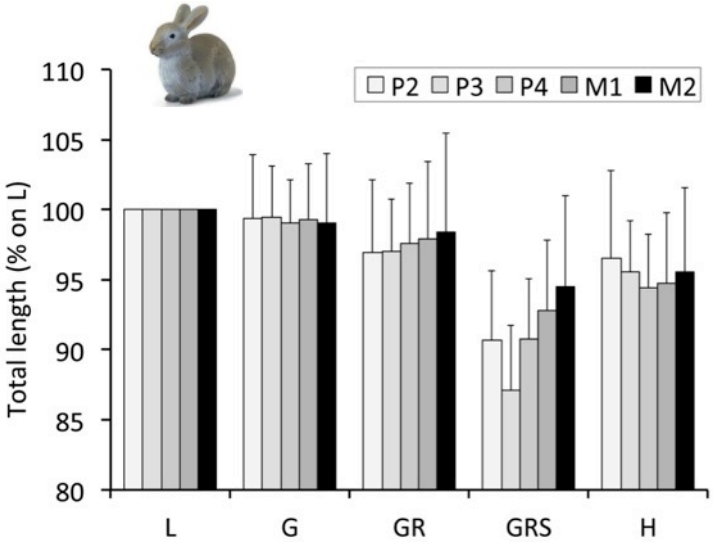

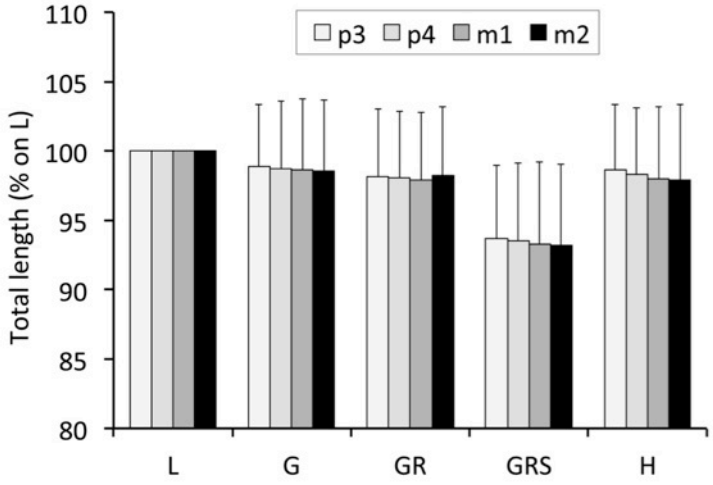

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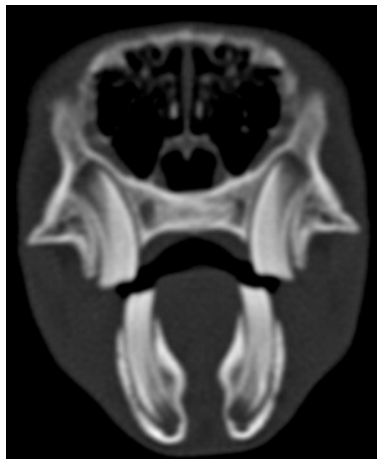

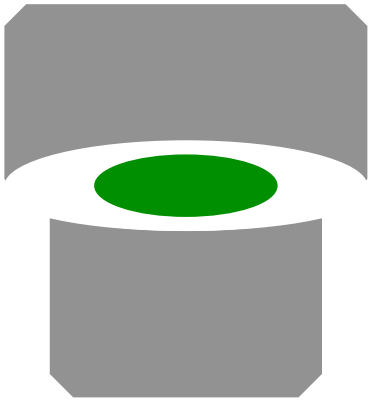

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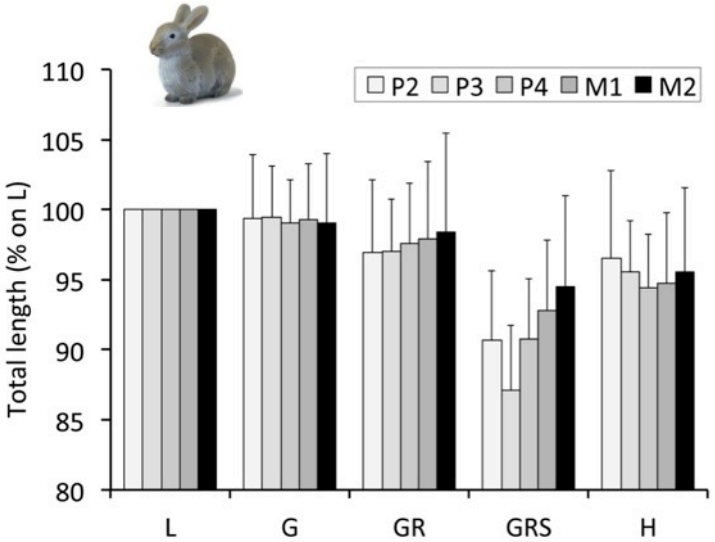

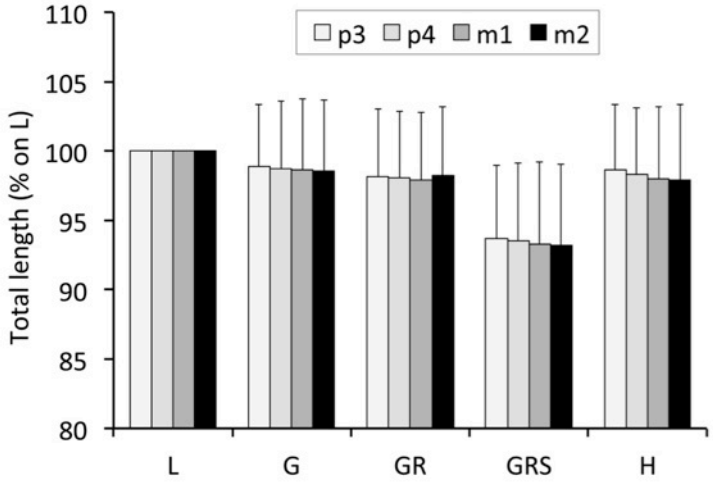

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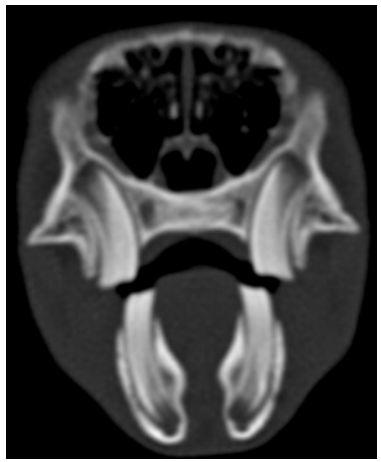

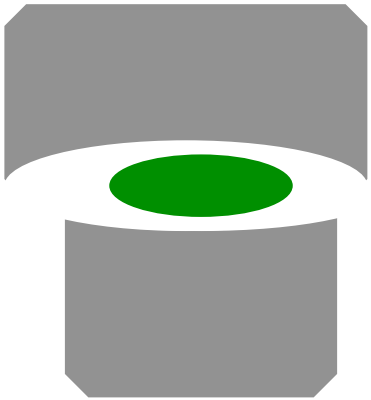

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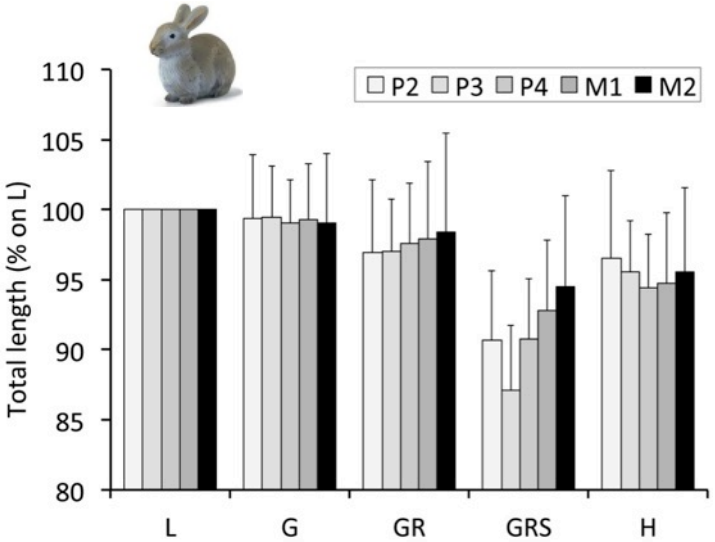

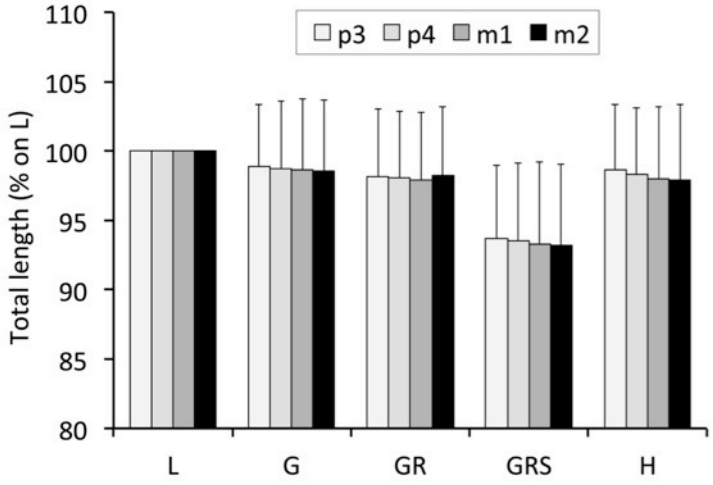

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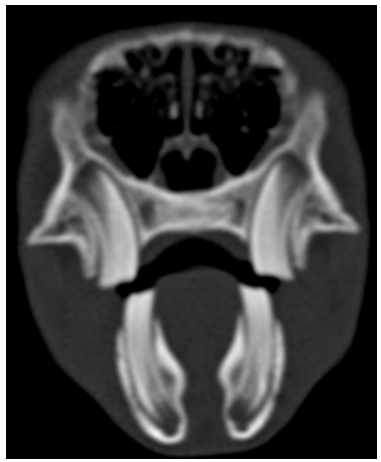

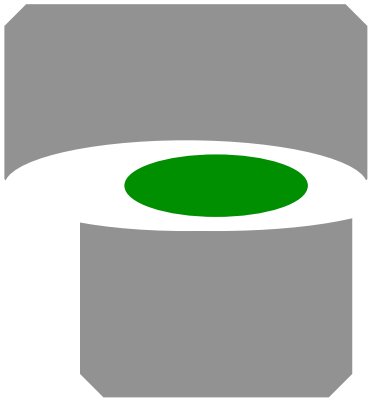

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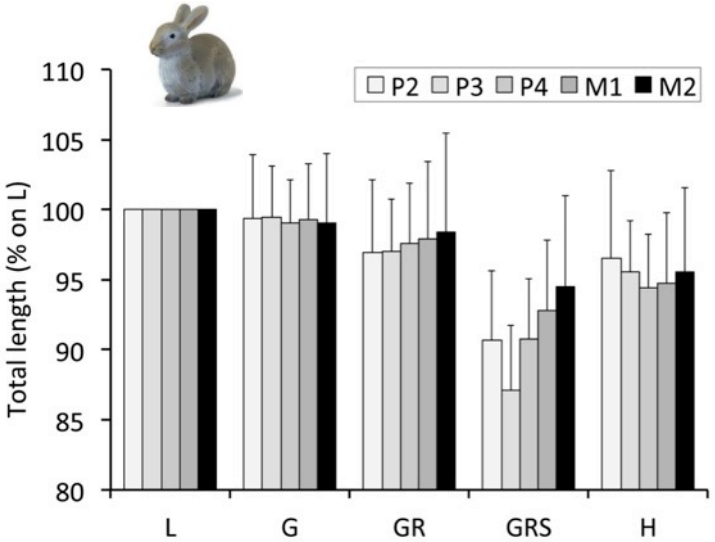

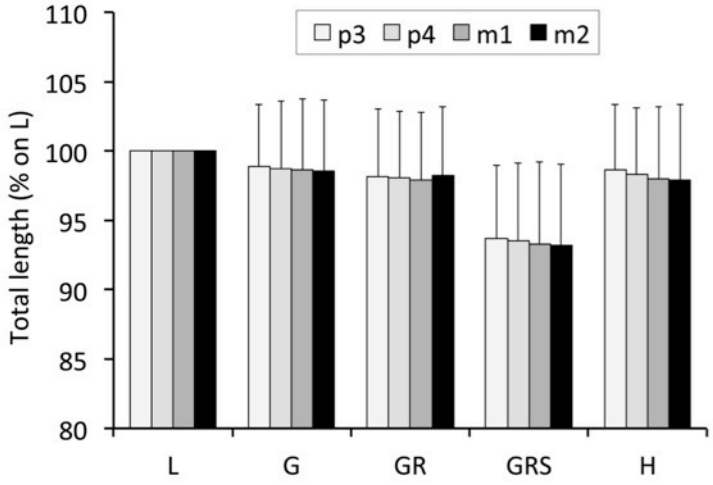

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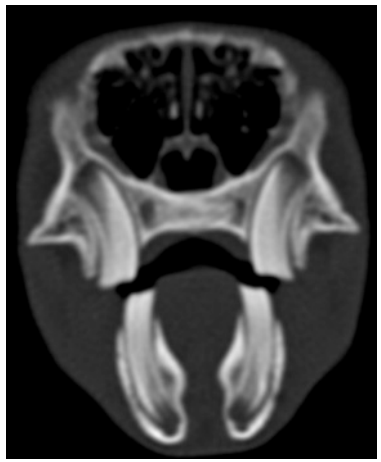

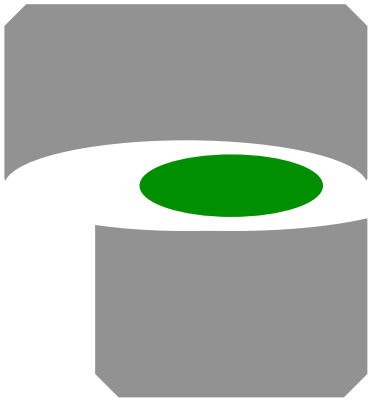

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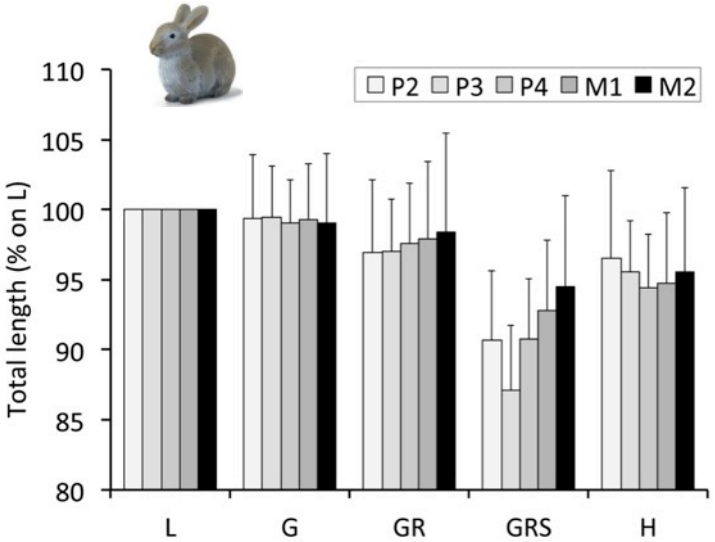

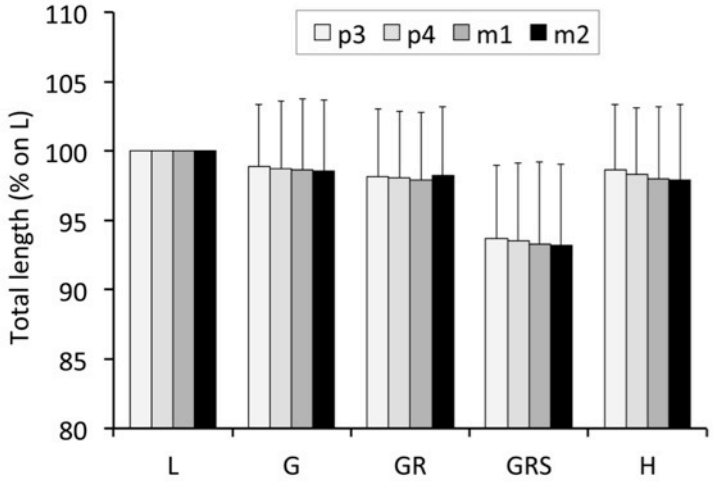

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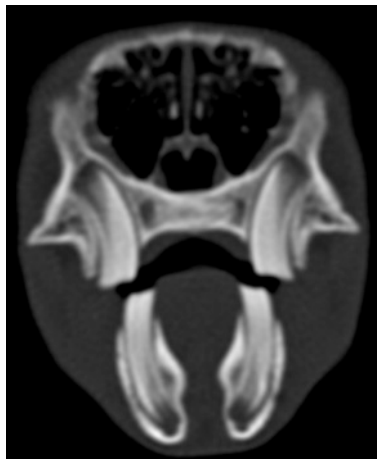

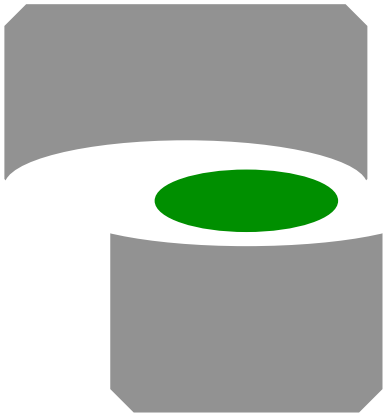

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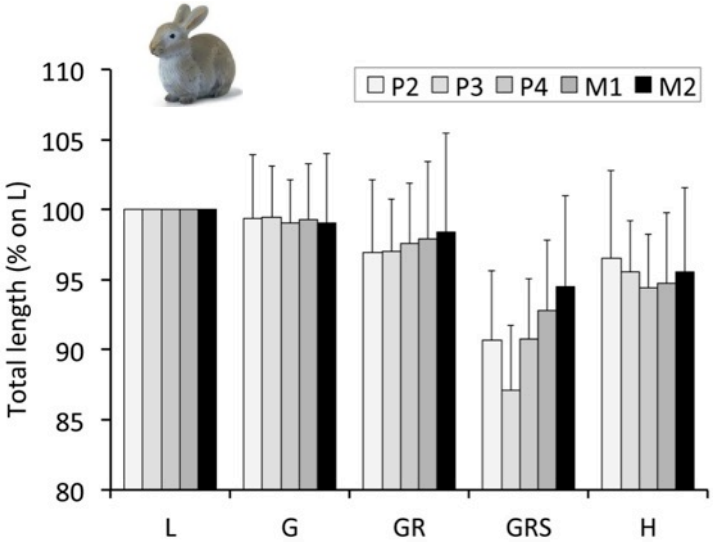

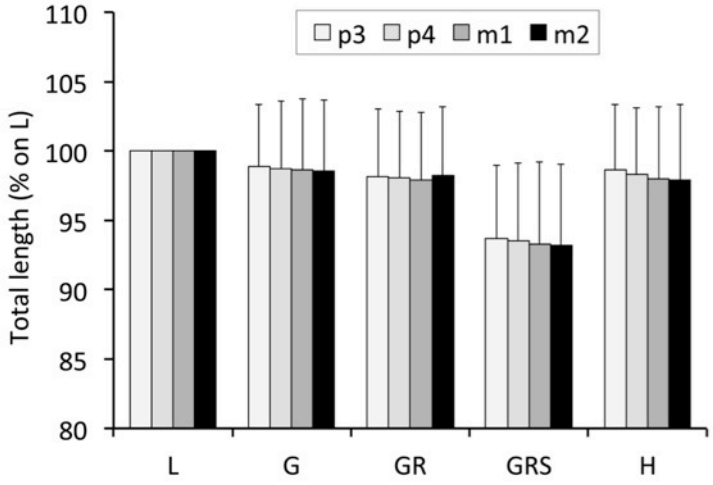

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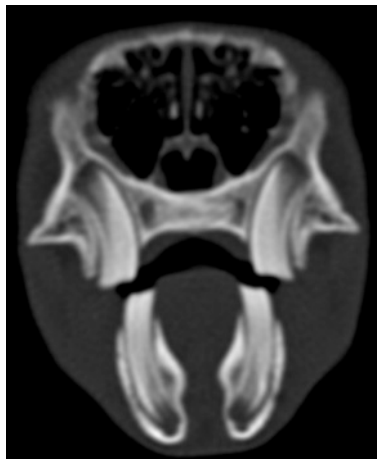

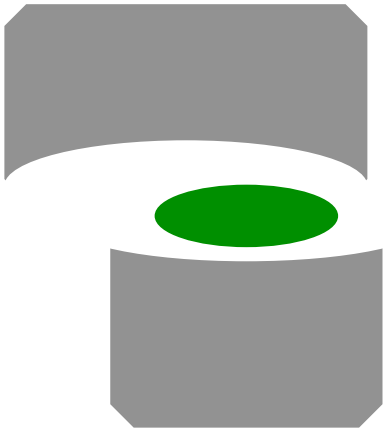

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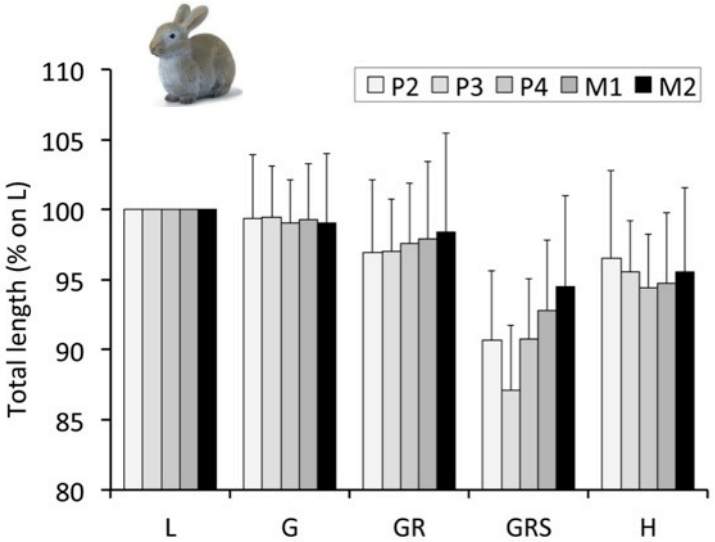

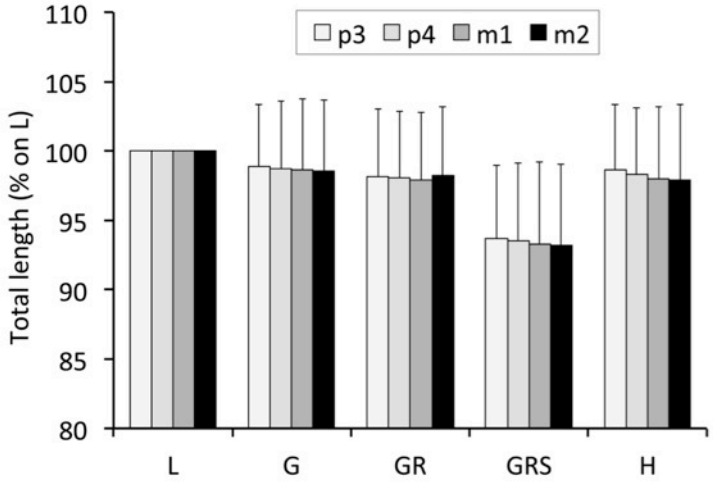

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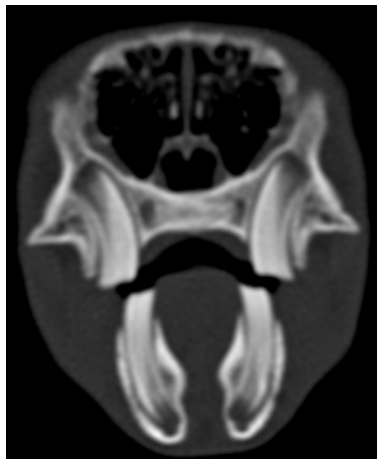

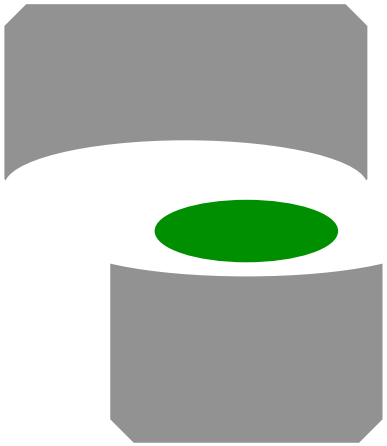

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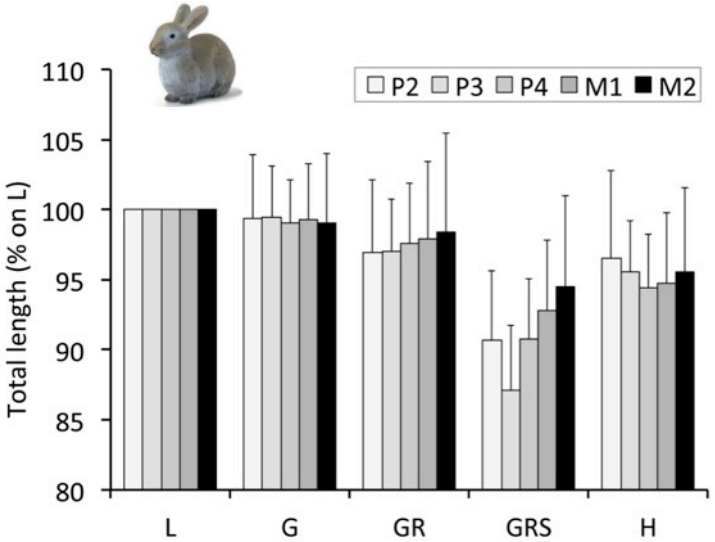

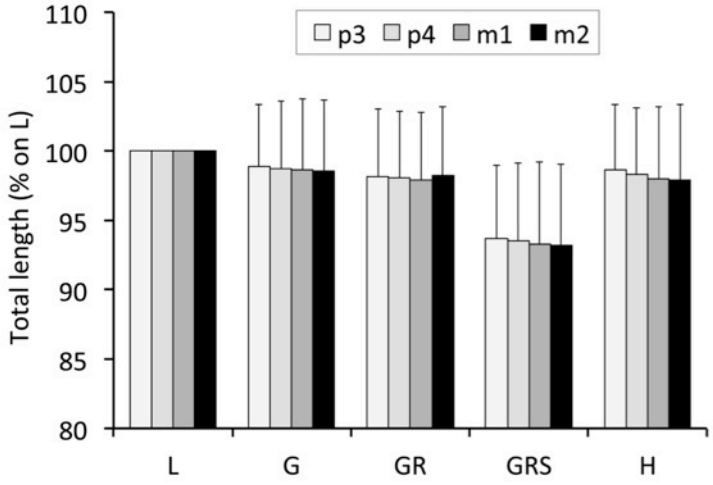

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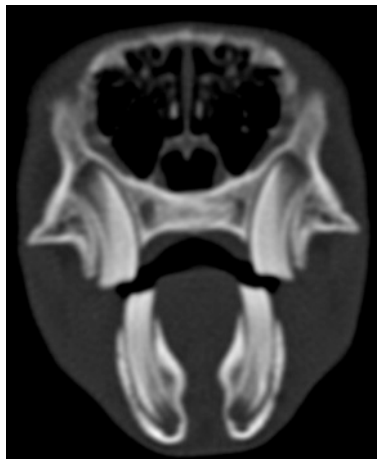
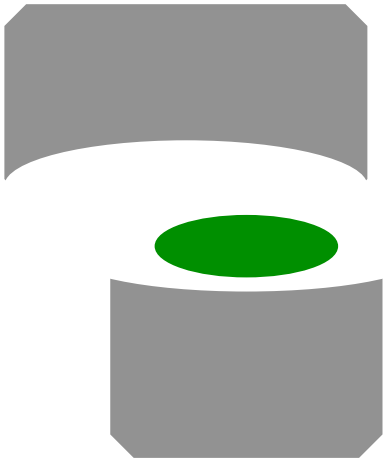
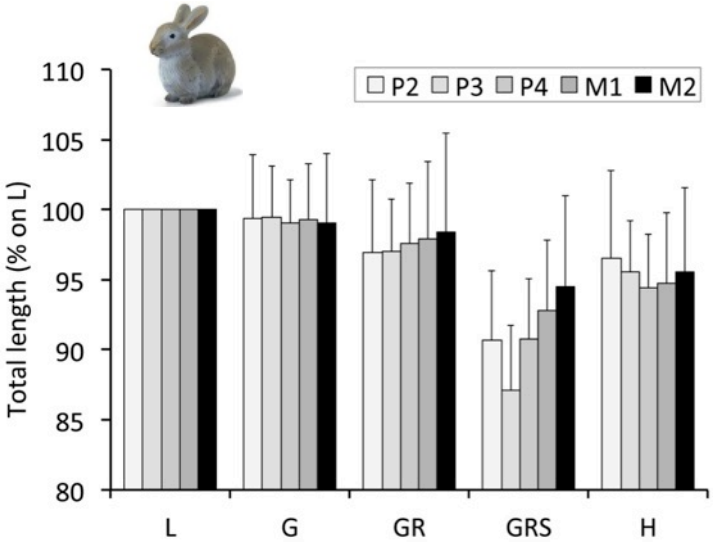
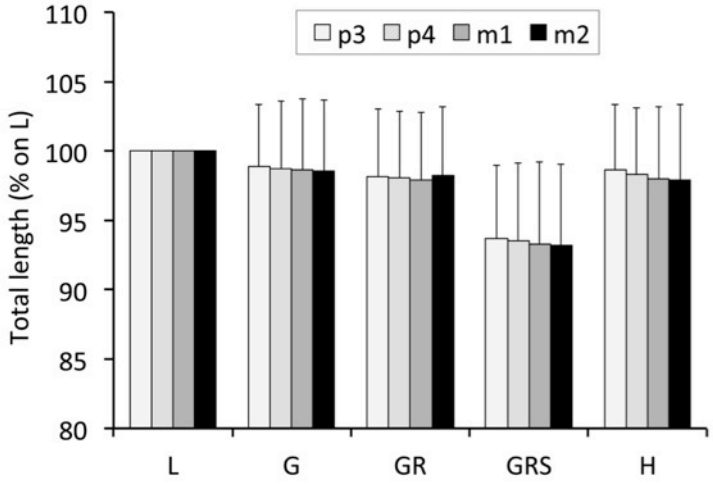


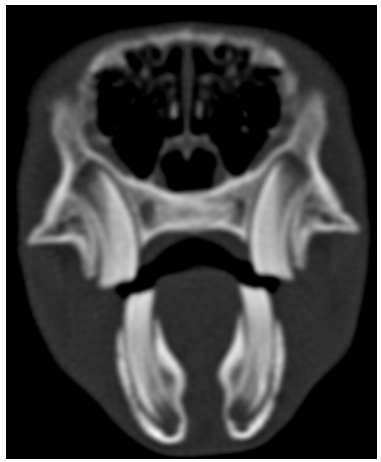


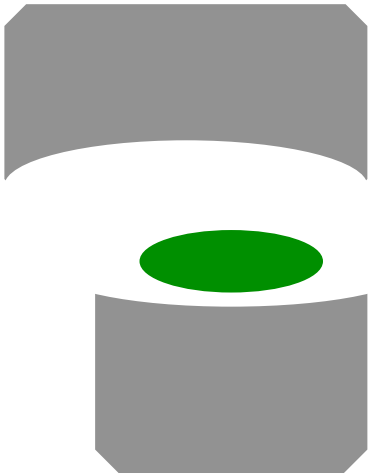
Maxilla-Mandible-Difference





Inverted pestle-and-mortar system:





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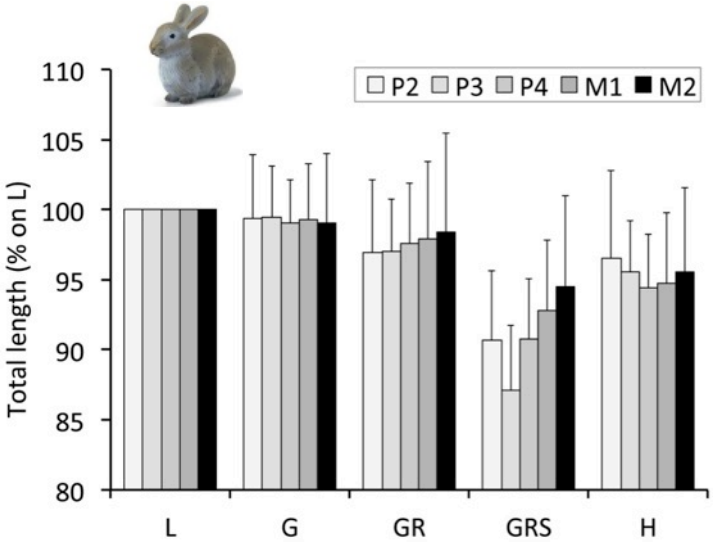

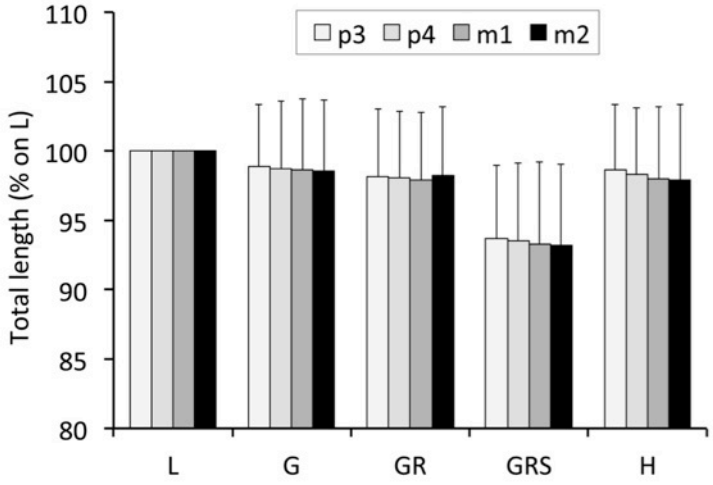

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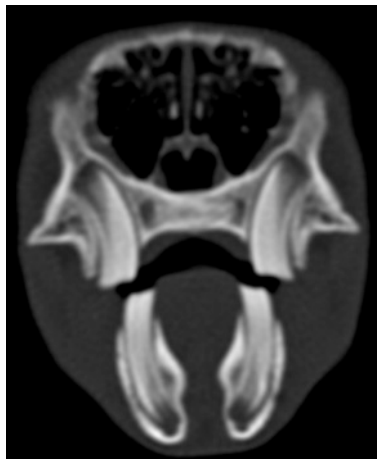

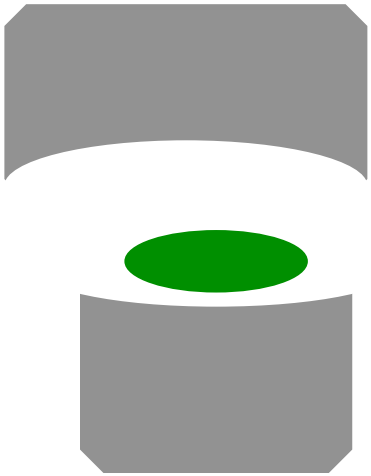

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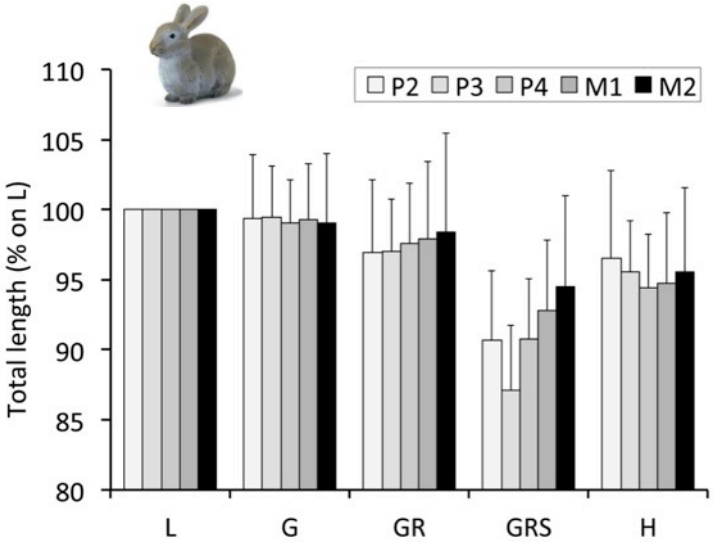

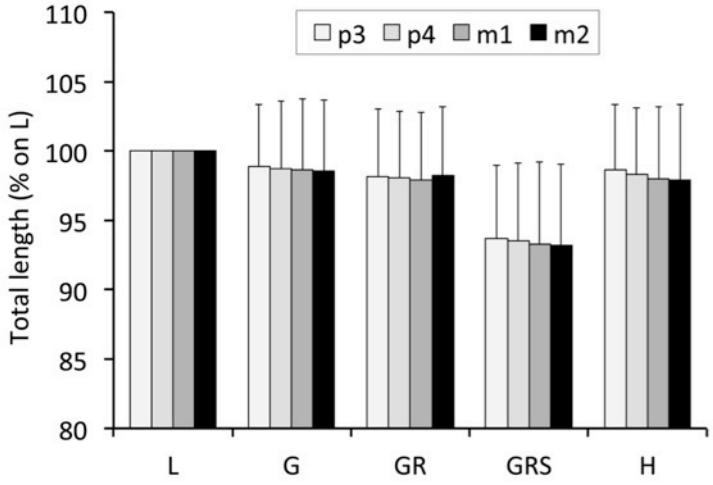

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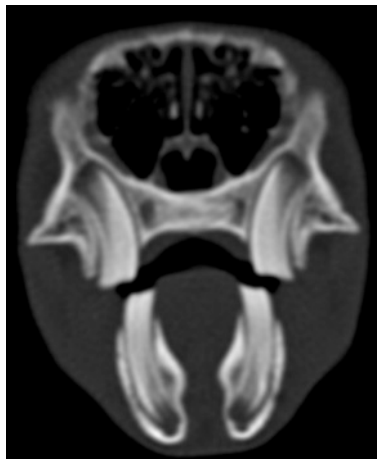

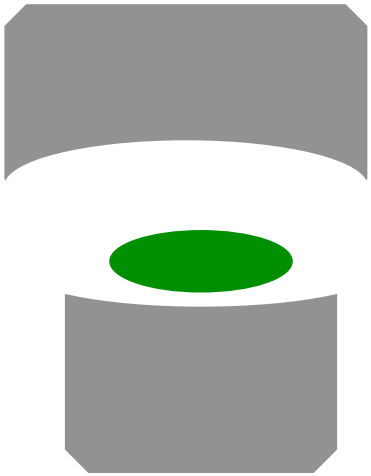

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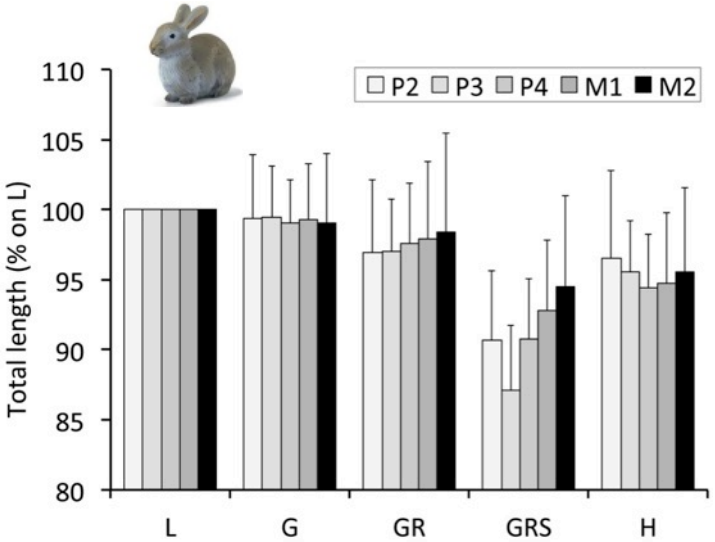

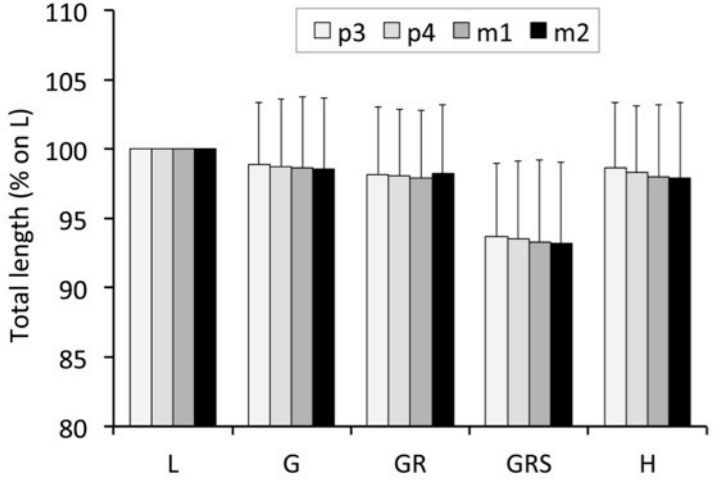

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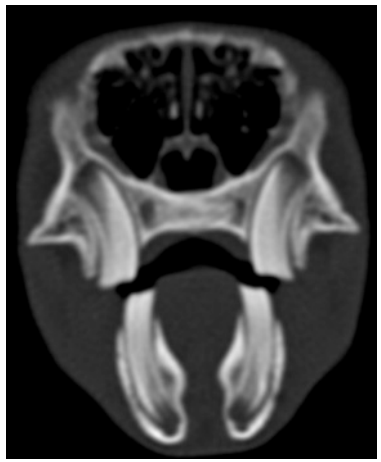
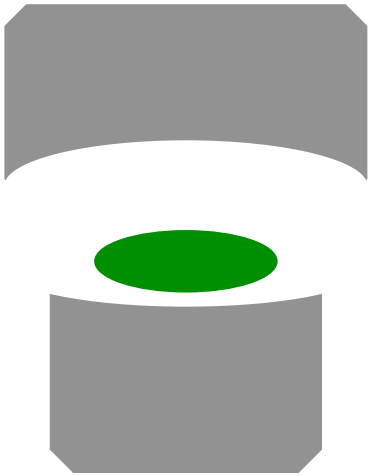




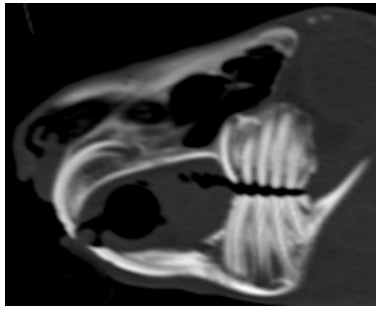
Hypotheses IV

Abnormal tooth wear will occur more frequently with excessive external abrasives (sand), and affect the cheek teeth according to their position in the tooth row (anterior ones more affected).

If ‘bridge formation’ of the cheek teeth is caused by diets of low abrasiveness, the tooth angle of the cheek teeth should be flatter on low-abrasion diets and steeper on high-abrasion diets.

Abnormalities rabbit

Waviness



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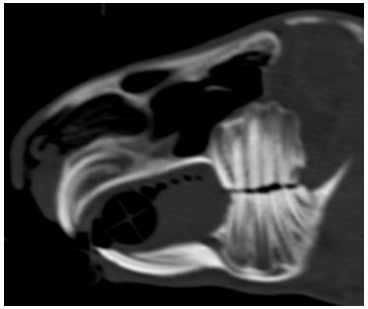

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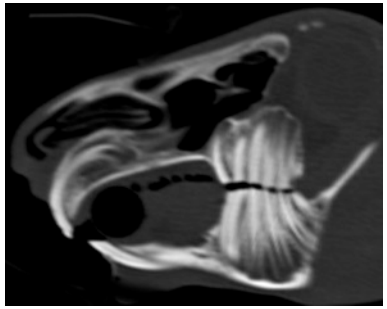

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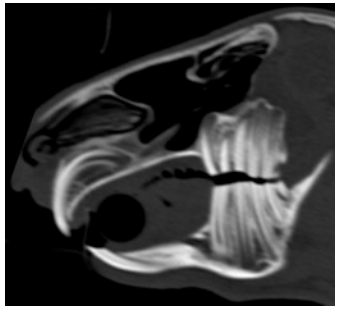

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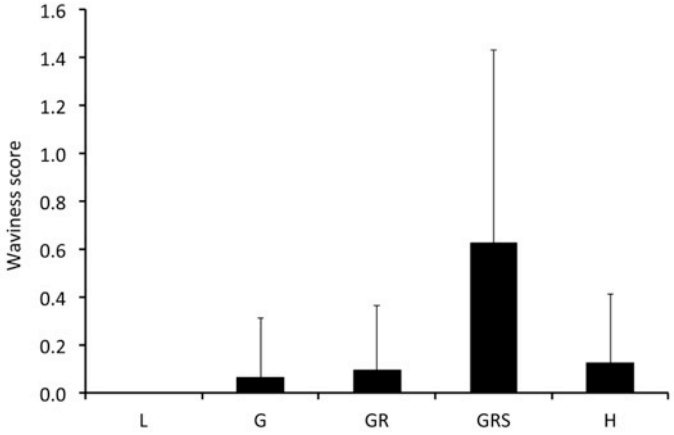
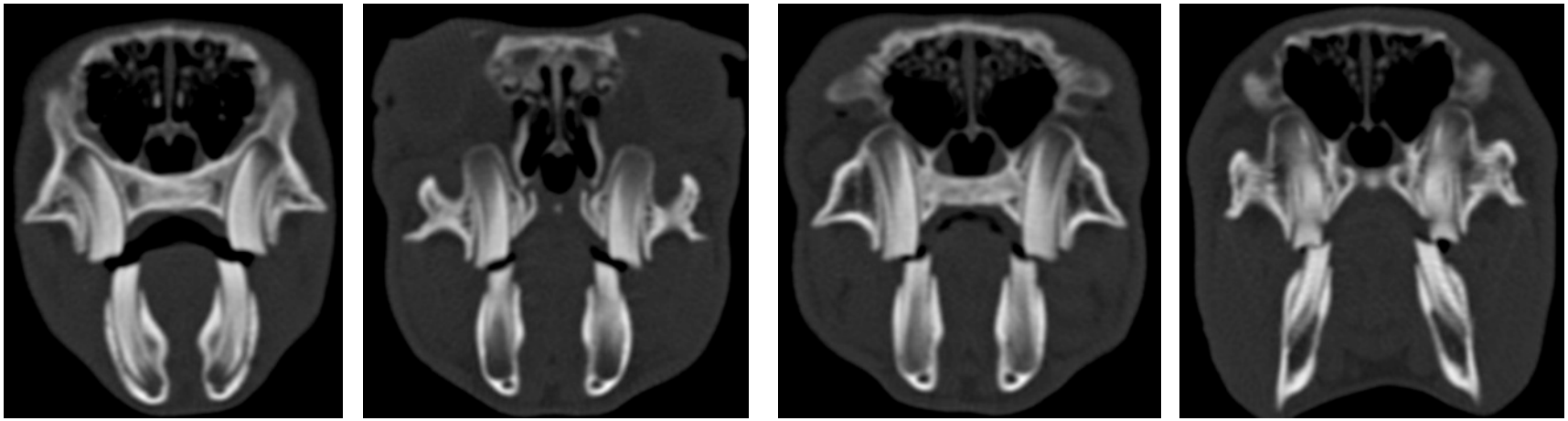


Abnormalities rabbit

Tooth spurs



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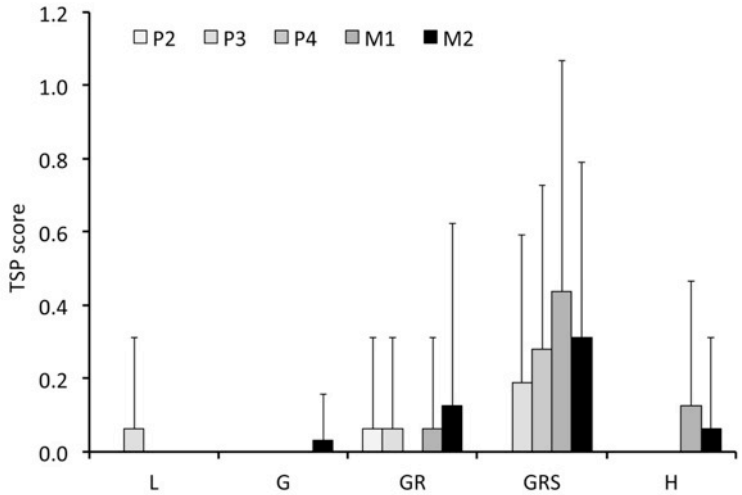
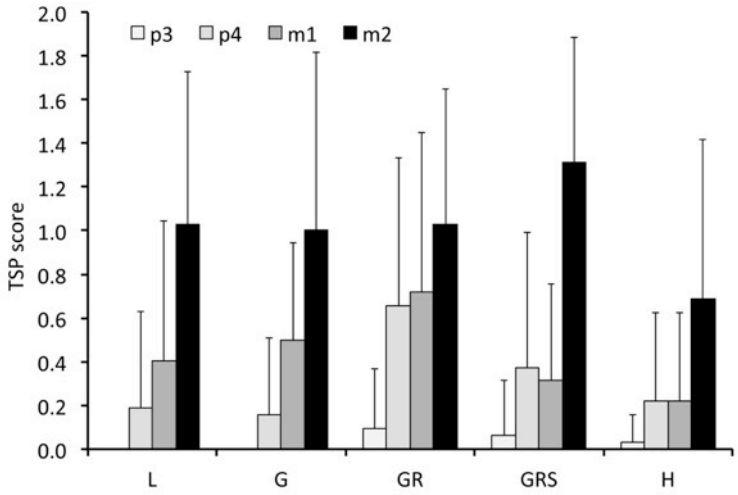
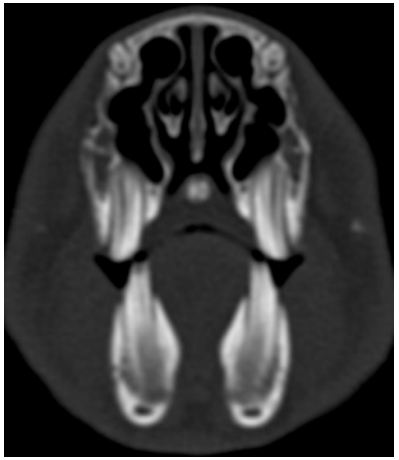




Abnormalities rabbit

Tooth surface



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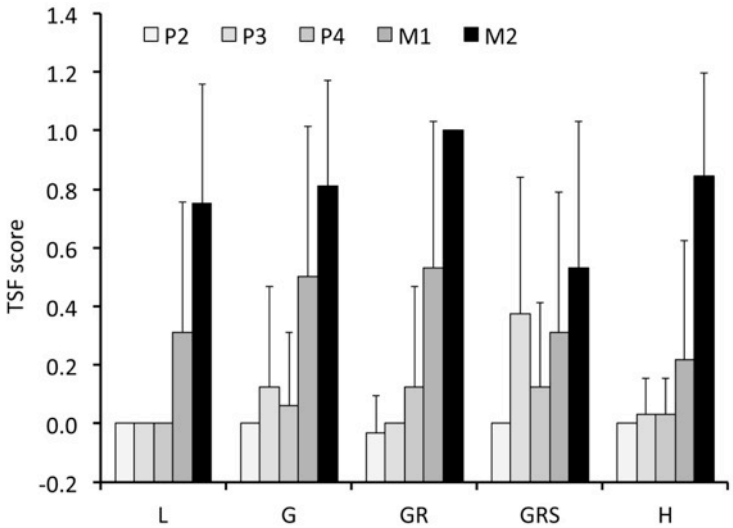
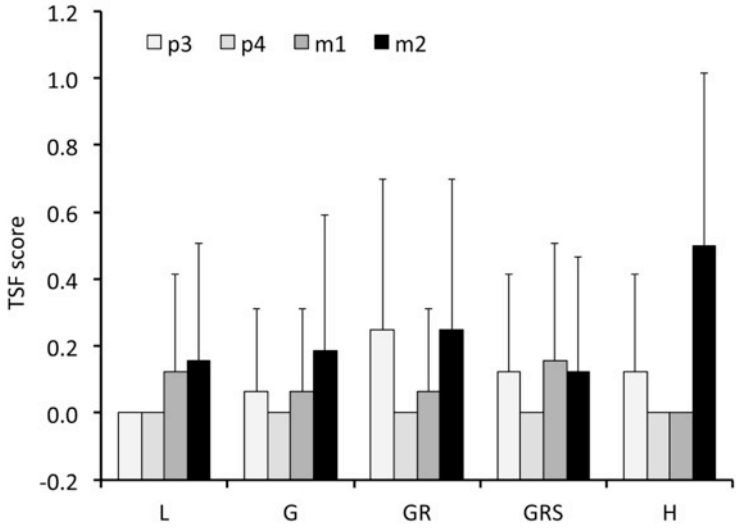
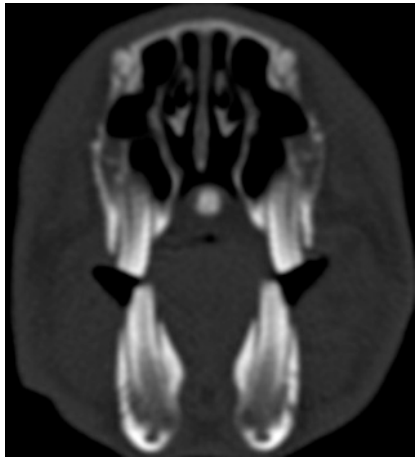




Abnormalities rabbit

Tooth angle



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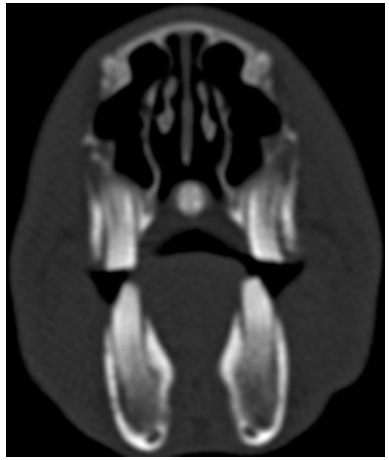

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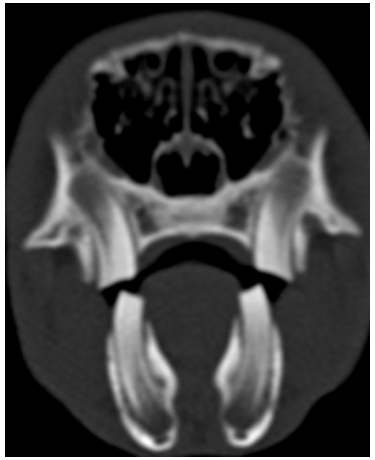

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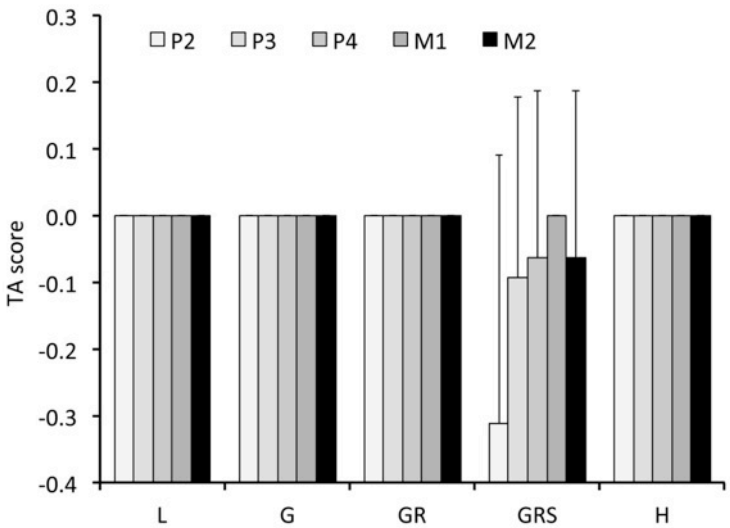
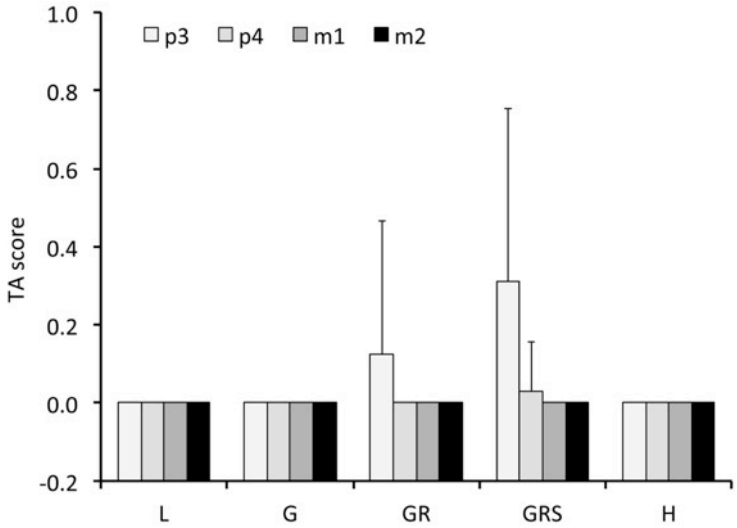
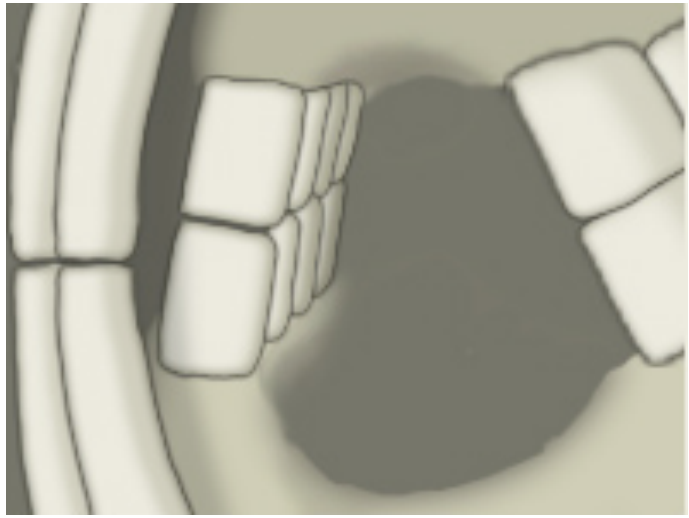
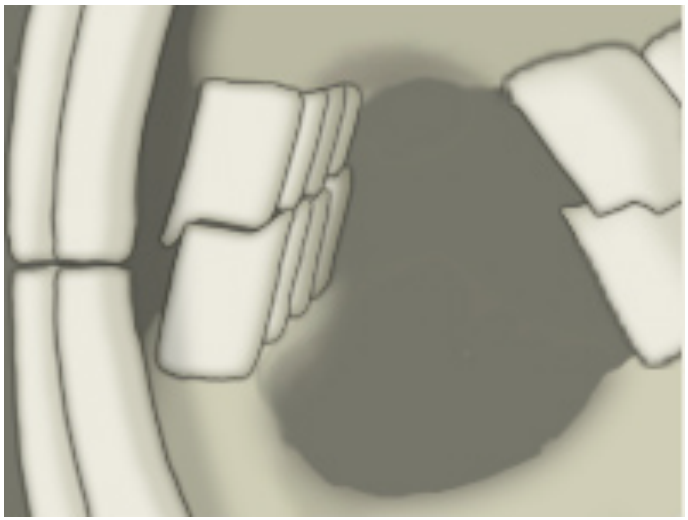
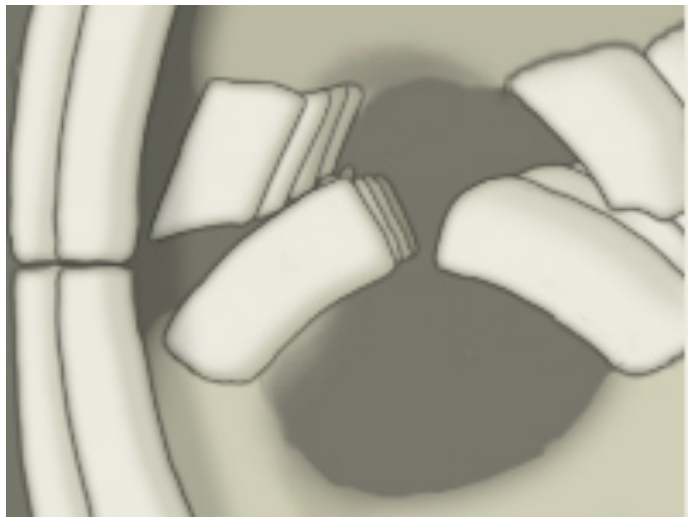




Abnormalities guinea pig

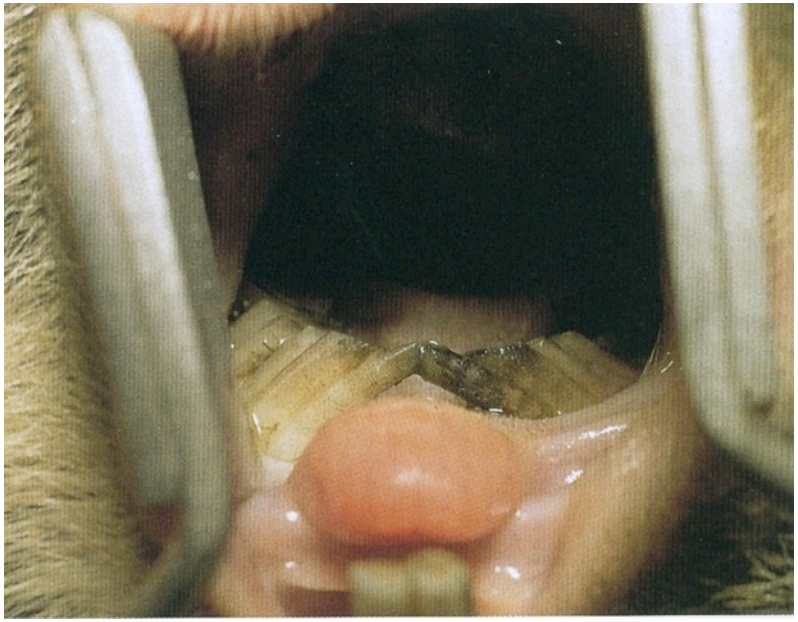






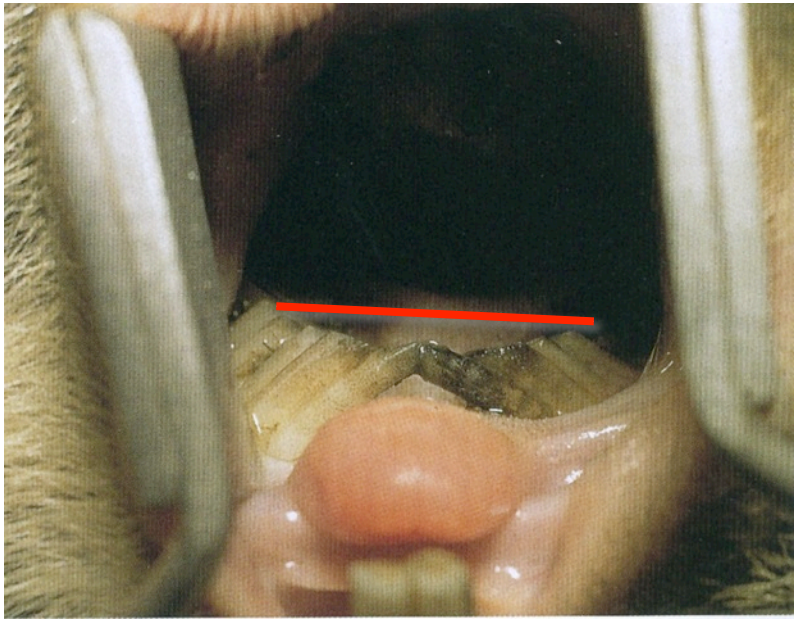
http://www.ostseeschnuten.de/info/zahnprobleme.html

Abnormalities guinea pig



bridge formation
means a lesser angle of
the tooth surface

Abnormalities guinea pig



bridge formation
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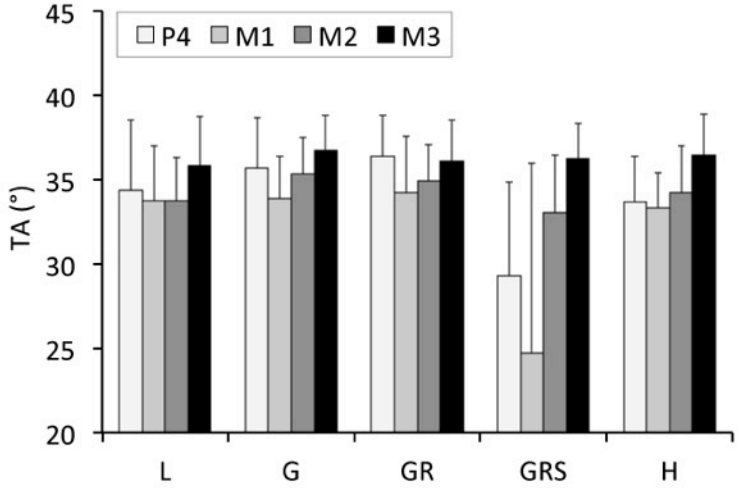
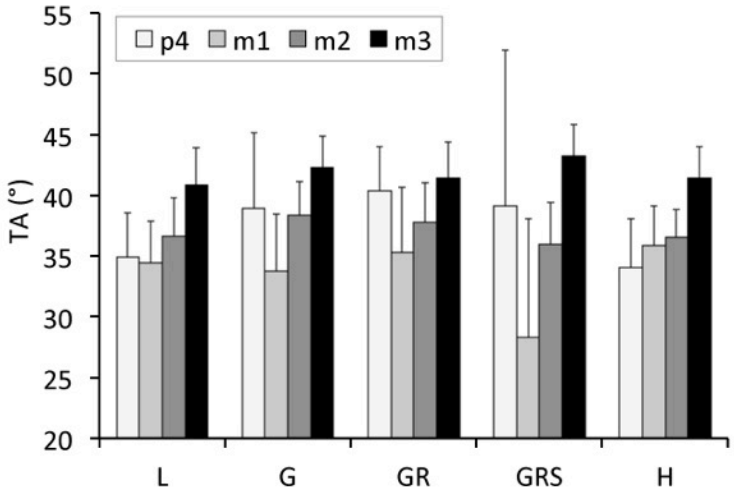
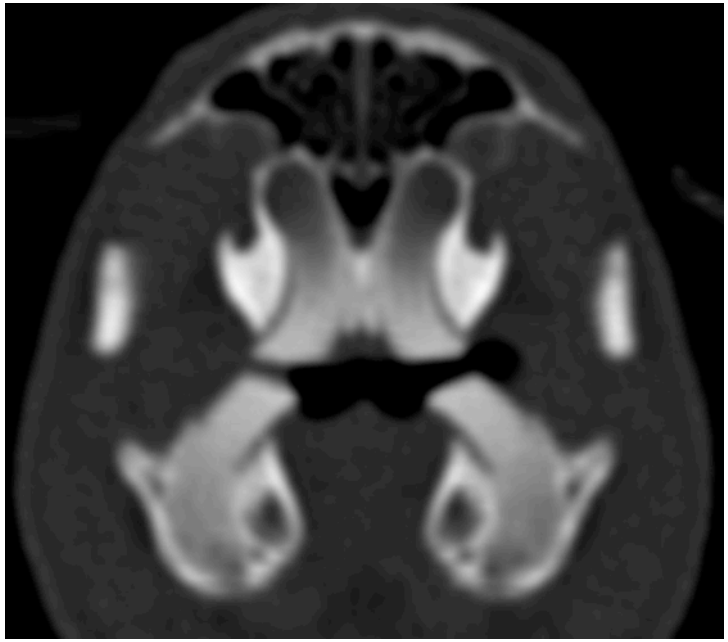
Abnormalities guinea pig

Abnormalities guinea pig





Abnormalities guinea pig



more abrasive diet does not lead to a steepr angle
less abrasive diet does not lead to shallower angle

no indication of bridge formation

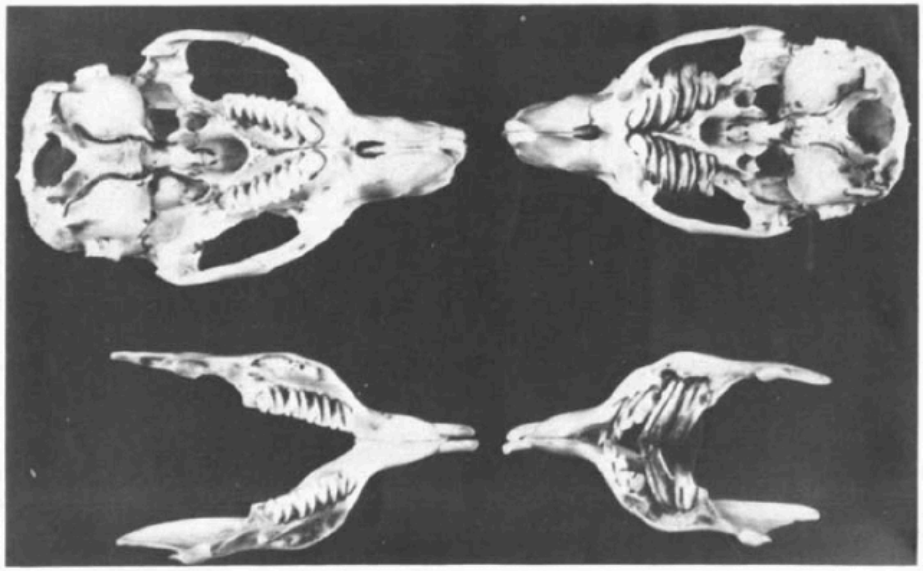
Genetics

Malocclusion in inbred strain-2 weanling guineapigs

JOAN R. REST, TREVOR RICHARDS & SARAH E. BALL

Laboratory Animals (1982) 16, 84-87

The incidence of malocclusion was recorded for 4 years. The incidence was significantly reduced ($P > 0{\cdot}001$) by breeding from animals without affected siblings: it is suggested that malocclusion in this colony has a genetic basis.



Aus dem Institut für Zuchthygiene der Universität Zürich
(Direktor: Prof. Dr. K. Zerobin)
Abteilung Zoo-Heim-Versuchstiere (Leiter: Dr. E. Isenbügel)

MALOKKLUSION UND ZAHNÜBERWACHSTUM

Schädelmessungen bei

Cavia aperea f. porcellus Linnaeus, 1758

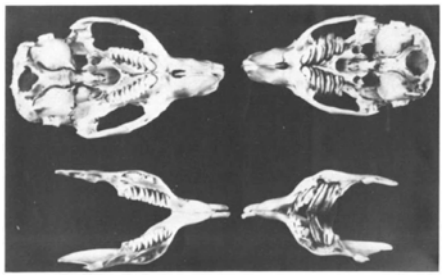
INAUGURAL—DISSERTATION
zur Erlangung der Doktorwürde
der Vet. Med. Fakultät der Universität Zürich

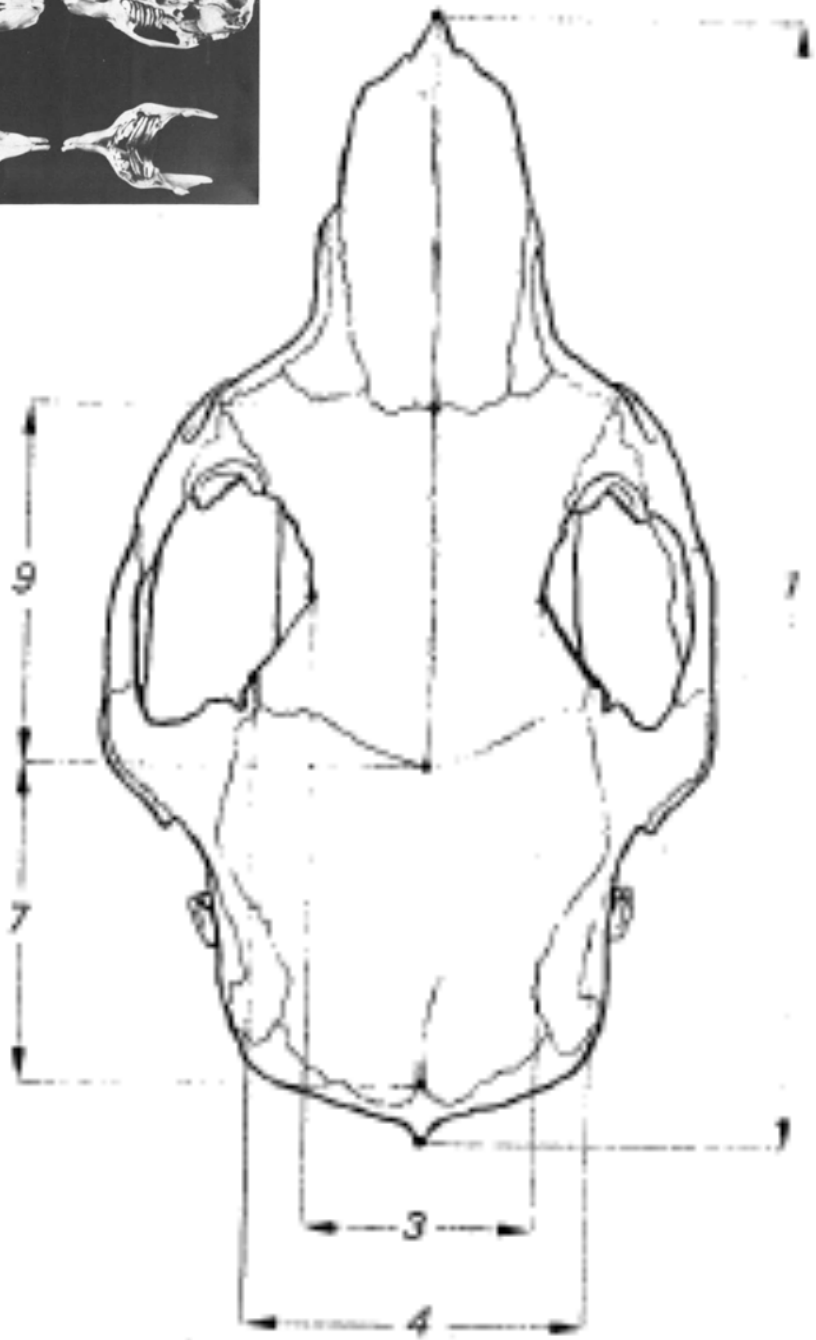
vorgelegt von

SILVIA STUDER
von Niederried/BE

Genehmigt auf Antrag von
Prof. Dr. H. U. Winzenried, Referent
Prof. Dr. J. Frewein, Korreferent

aku-Fotodruck
Zürich
1975

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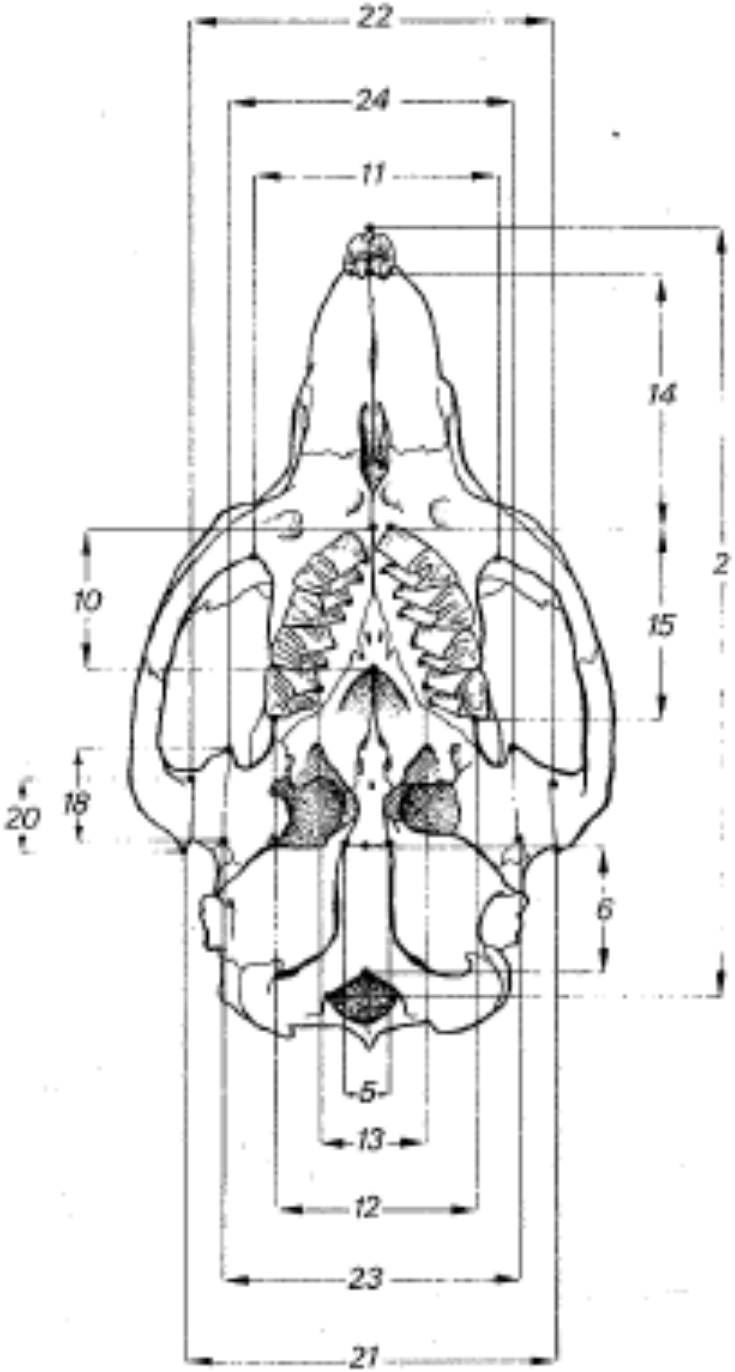
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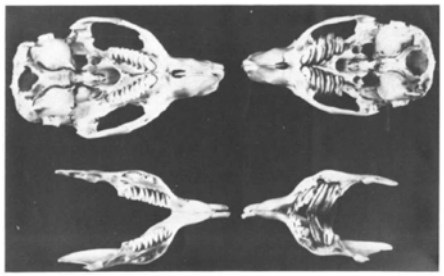

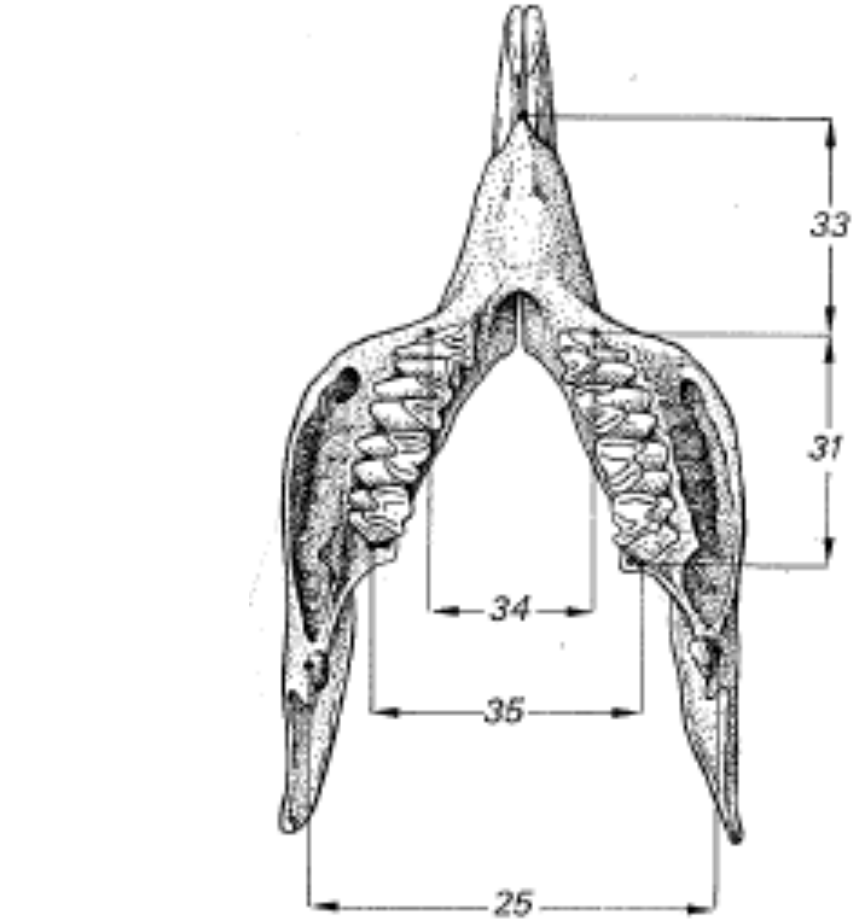
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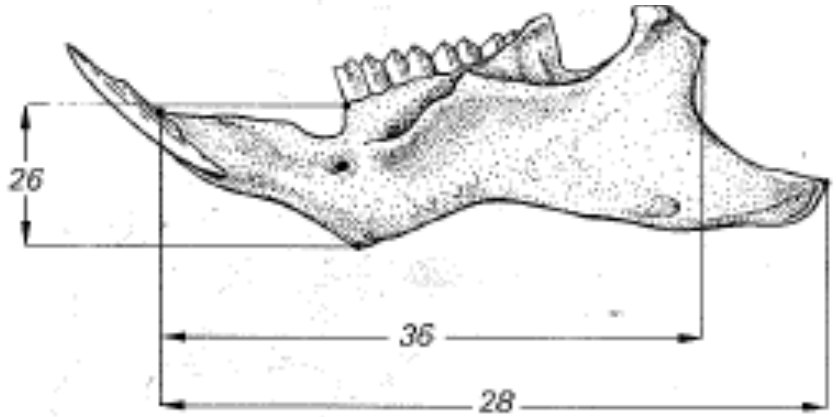
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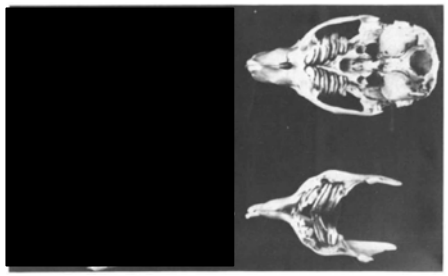

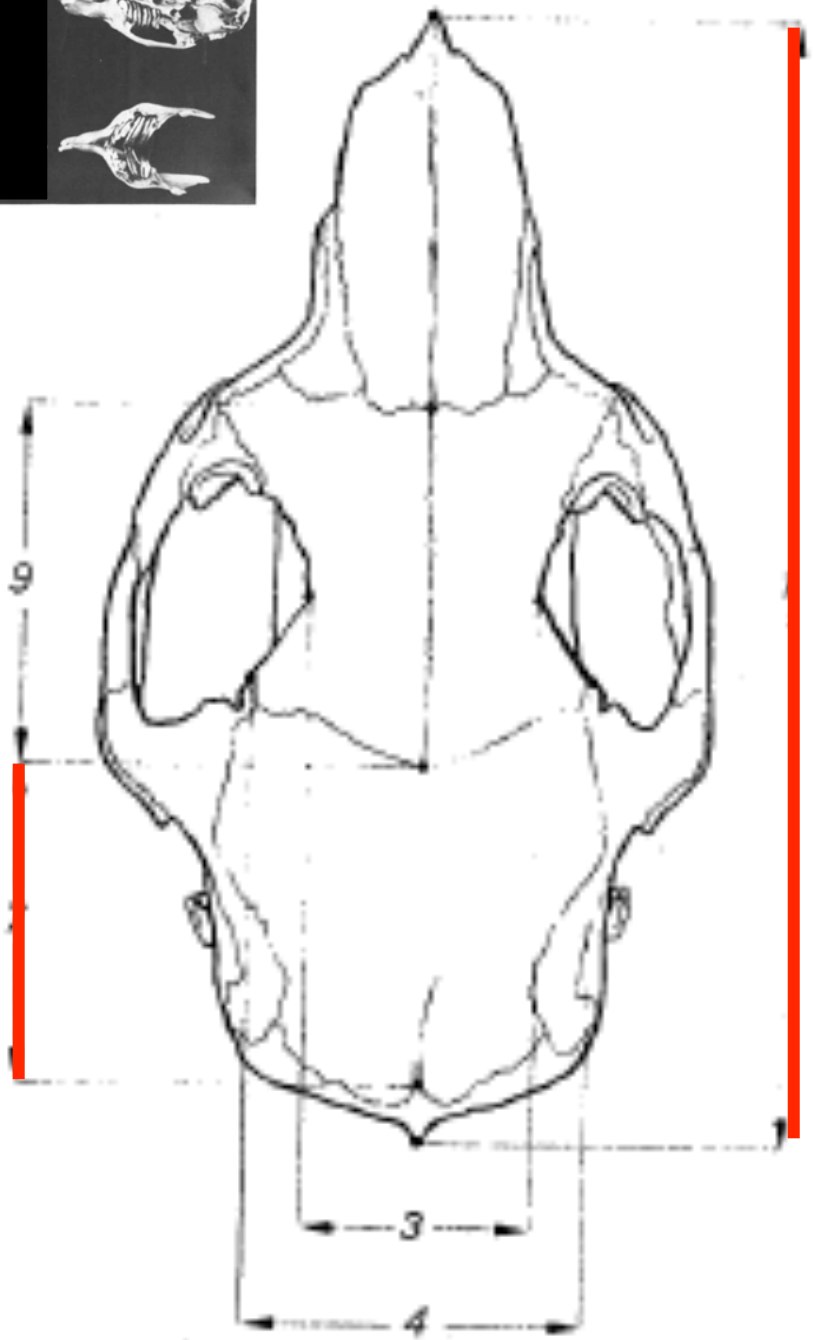
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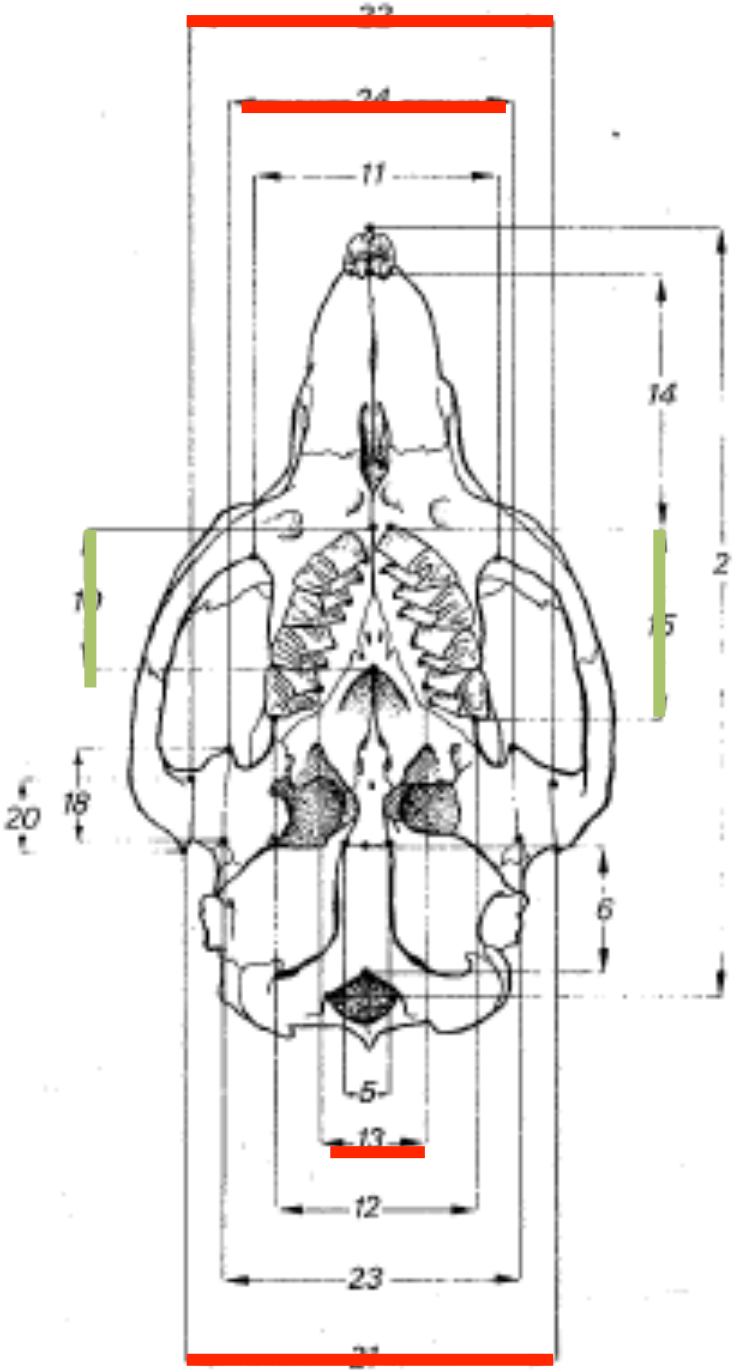
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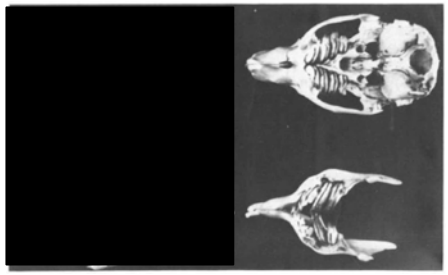

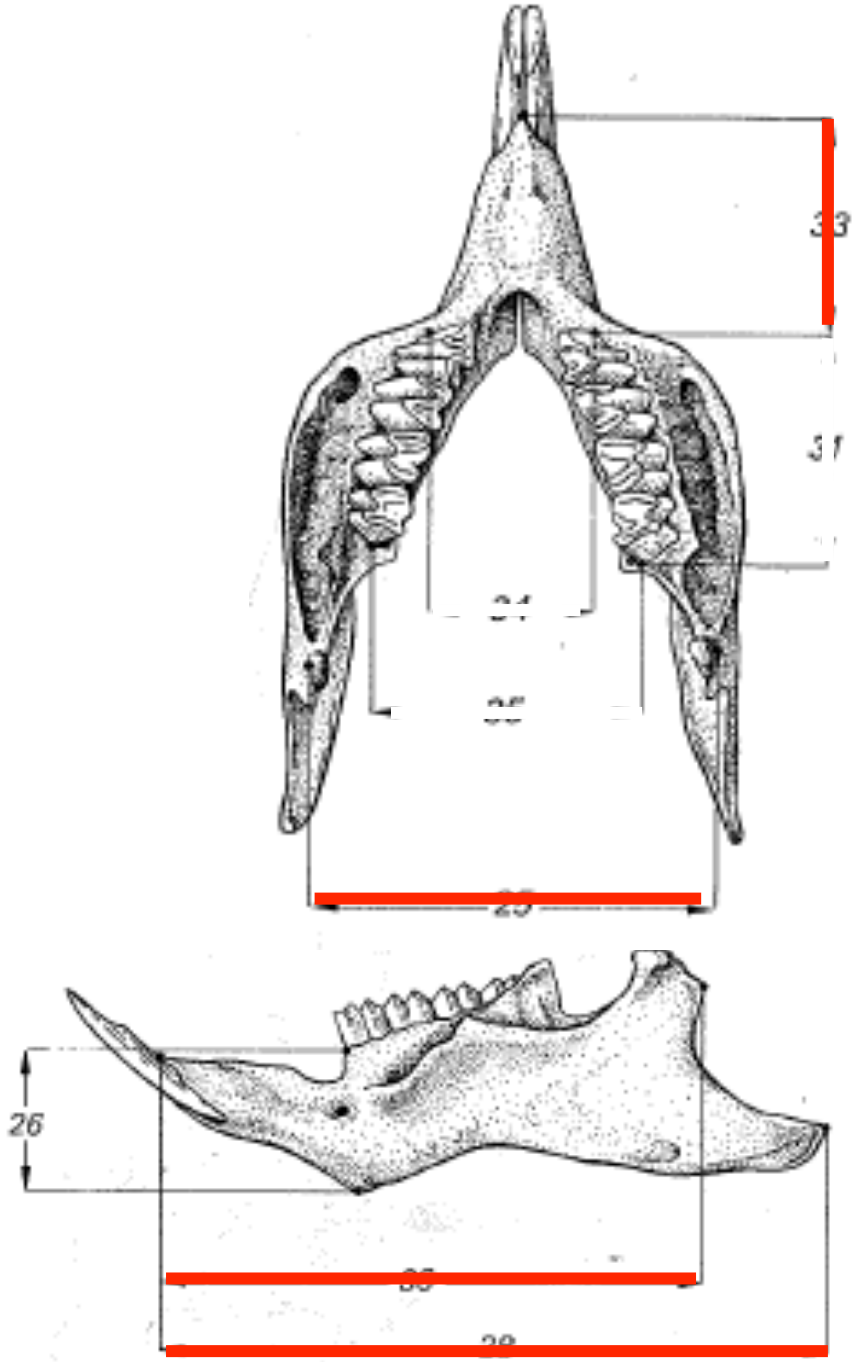
26

Tooth problems in exotic pets

Breeding hygiene probably more important than the correct diet – because ‘good’ teeth will adapt to basically any situation.

Outlook I

3D texture analysis of different-diet teeth, incl. tooth row gradients and maxillary-mandible-gradient, and diet switch experiment.

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Dietary Abrasiveness Is Associated with Variability of Microwear and Dental Surface Texture in Rabbits

Ellen Schulz[1*], Vanessa Piotrowski[1], Marcus Clauss[2], Marcus Mau[3], Gildas Merceron[4], Thomas M. Kaiser[1]

1 Biocenter Grindel and Zoological Museum, University of Hamburg, Hamburg, Germany, 2 Clinic for Zoo Animals, Exotic Pets and Wildlife, University of Zurich, Zurich, Switzerland, 3 Dental Institute, King's College London, Guy's Hospital, London, United Kingdom, 4 Institut de Paléoprimatologie, Paléontologie Humaine, Evolution et Paléoenvironnements, Unité Mixte de Recherche Centre National de la Recherche Scientifique 7262, Université de Poitiers, Poitiers, France

Abstract

Dental microwear and 3D surface texture analyses are useful in reconstructing herbivore diets, with scratches usually interpreted as indicators of grass dominated diets and pits as indicators of browse. We conducted feeding experiments with four groups of rabbits (*Oryctolagus cuniculus*) each fed a different uniform, pelleted diet (lucerne, lucerne & oats, grass & oats, grass). The lowest silica content was measured in the lucerne and the highest in the grass diet. After 25 weeks of exposure to the diets, dental castings were made of the rabbit's lower molars. Occlusal surfaces were then investigated using dental microwear and 3D areal surface texture analysis. In terms of traditional microwear, we found our hypothesis supported, as the grass group showed a high proportion of (long) "scratches" and the lucerne group a high proportion of "pits". Regardless of the uniform diets, variability of microwear and surface textures was higher when silica content was low. A high variability in microwear and texture analysis thus need not represent dietary diversity, but can also be related to a uniform, low-abrasion diet. The uniformity or variability of microwear/texture analysis results thus might represent varying degrees of abrasion and attrition rather than a variety of diet items per se.

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*E-mail: ellen.schulz@uni-hamburg.de

Introduction

Plant phytoliths (opaline silica and plant silica) are considered defenses against herbivory because they decrease the digestibility of plant components and abrade mammalian teeth due to the greater hardness of phytoliths compared to enamel [1,2], although the question whether they are actually harder than enamel has not been resolved conclusively to date [3,4]. Herbivory by voles, for example, induced silica incorporation in grasses [5] and reduced growth rates and digestion efficiency of the voles [6]. Field studies indicate that ingested soil abrades teeth in ungulates [7,8]. Therefore, the importance of external abrasive particles such as soil, dust, sand, and grit [9] as causative factors for tooth abrasion in ungulates has received significant attention. Phytoliths might have a greater role in causing variation in tooth wear [8]. But until now, apart from a feeding experiment of Baker et al. [1] testing for the wear of sheeps' incisors due to soil ingestion, controlled feeding experiments testing the role of phytoliths on tooth wear, and in particular on the microwear patterns of molar surfaces, are still missing.

In most mammalian groups it is assumed that the consumption of grass, which is rich in phytoliths, causes a two-dimensional microwear pattern of mainly scratches, while ingestion of browse, and hard items like seeds, produces pits [10–12]. These patterns were also observed in rodents, with typical grazers presenting an abundance of scratches, while insectivores and frugivores display more pits [13–16].

Since the traditional dental microwear analysis is limited to two dimensions, surface texture analysis, a more quantitative three-dimensional (3D) method, has become established for dental dietary reconstruction [17–20]. Most such studies are based on museum specimens and information on the natural diet of a species is usually taken from the literature. Comprehensiveness, accommodation of effects of seasonality and habitat conditions covered, as well as methods applied result in inconsistency of data provided. Only a few reports are based on long term observation and provide data with strong statistical evidence. For most species, it is nevertheless possible to assign a general dietary strategy that allows understanding occlusal surface features that are related to this dietary strategy. However, we do not know how much variability in diet is reflected by occlusal surface textures, nor the exact mechanism of texture formation.

This gap of knowledge in relating textures to actual diets led us to conduct feeding experiments with controlled diets of known silica content, and relate them to occlusal parameters. The study thus aims at quantifying surface textures and to relate them to the proportions of abrasives (silica) in the diet. This should enhance our understanding of the equilibrium between abrasion and attrition (e.g. [21]) in mammal post canine teeth. Abrasion is due to food-tooth or particle-tooth contact while attrition is due to (most closely) tooth-tooth contact [22,23]. Teaford and Walker [24] showed that tooth-tooth wear produces featureless surface in stillborn guinea pigs. We would not expect to see the extreme featureless surface in the rabbits. Since Renneberger [25] recognised

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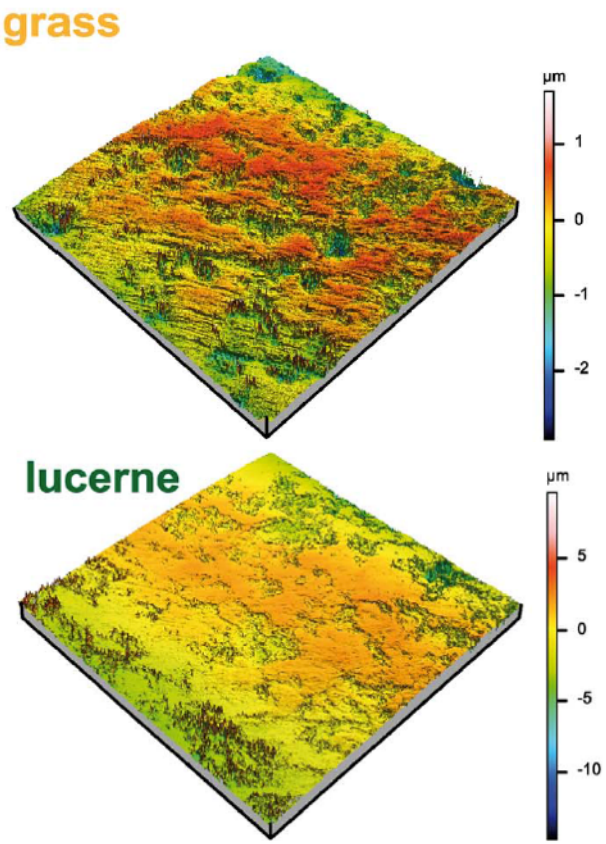
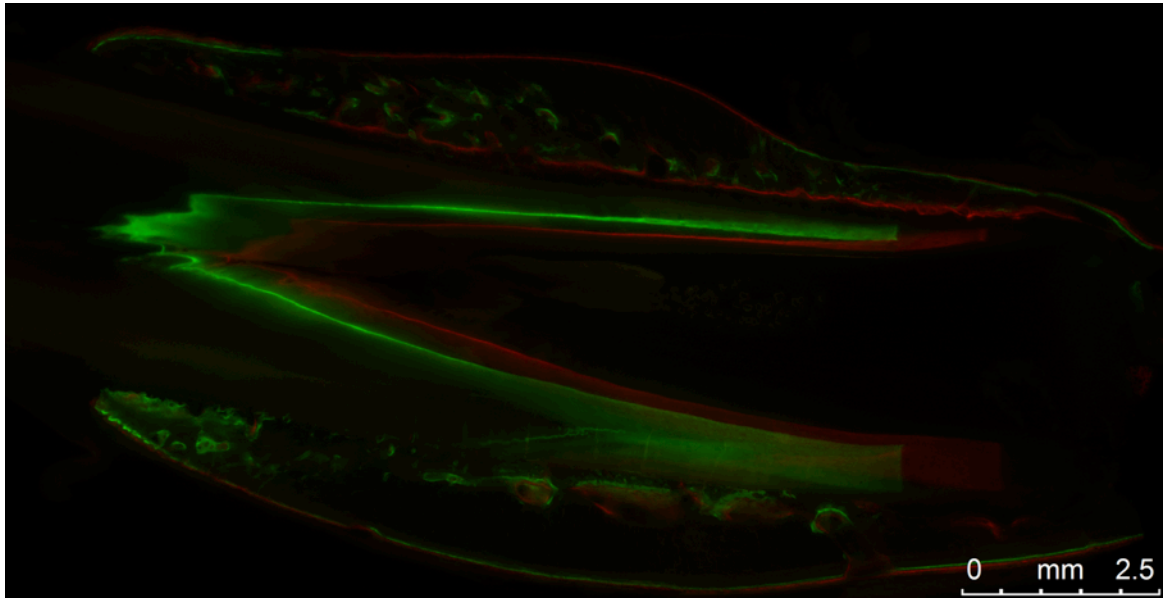


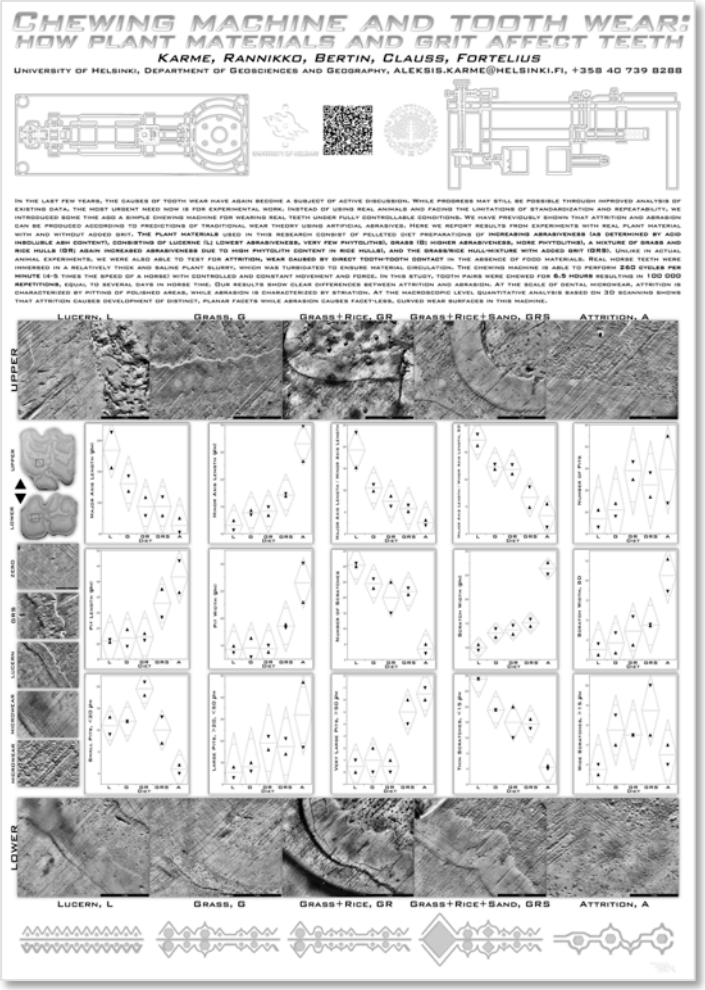
Outlook II

Determine growth rates for all teeth via fluorescence microscopy.



Outlook III

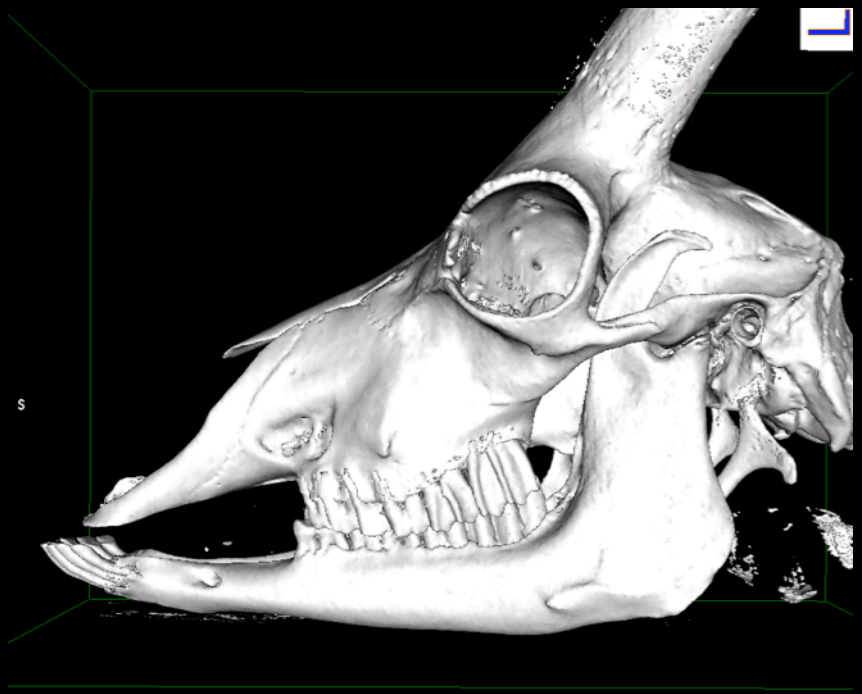
Analyse diets in vitro (chewing machine)



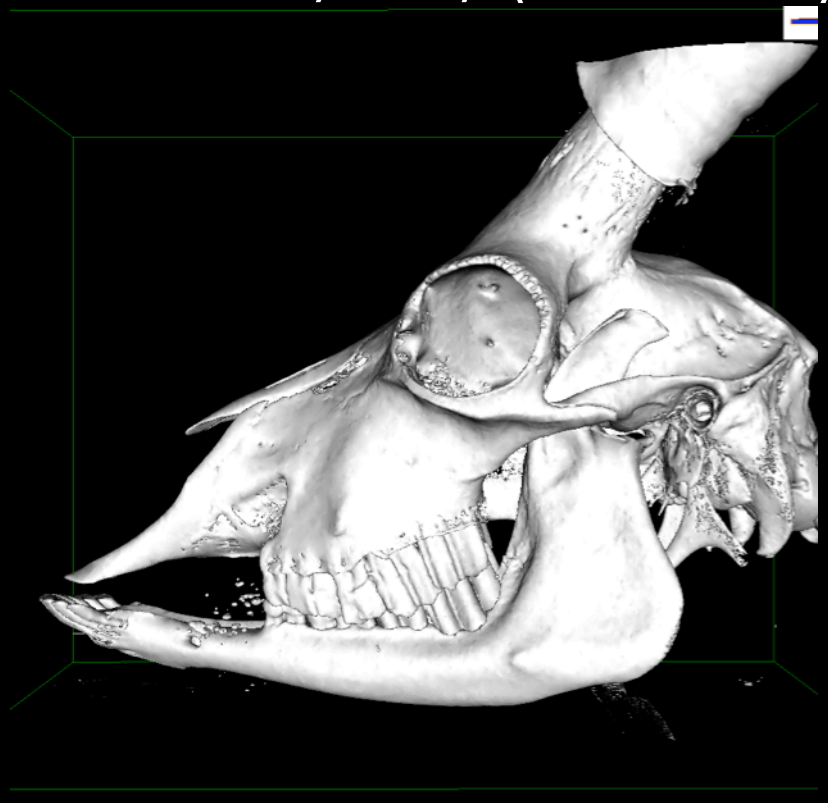
Outlook IV

Evaluate goat CTs and teeth (mesowear, 3D texture, actual tissue loss)

Lucerne hay only (dicot)

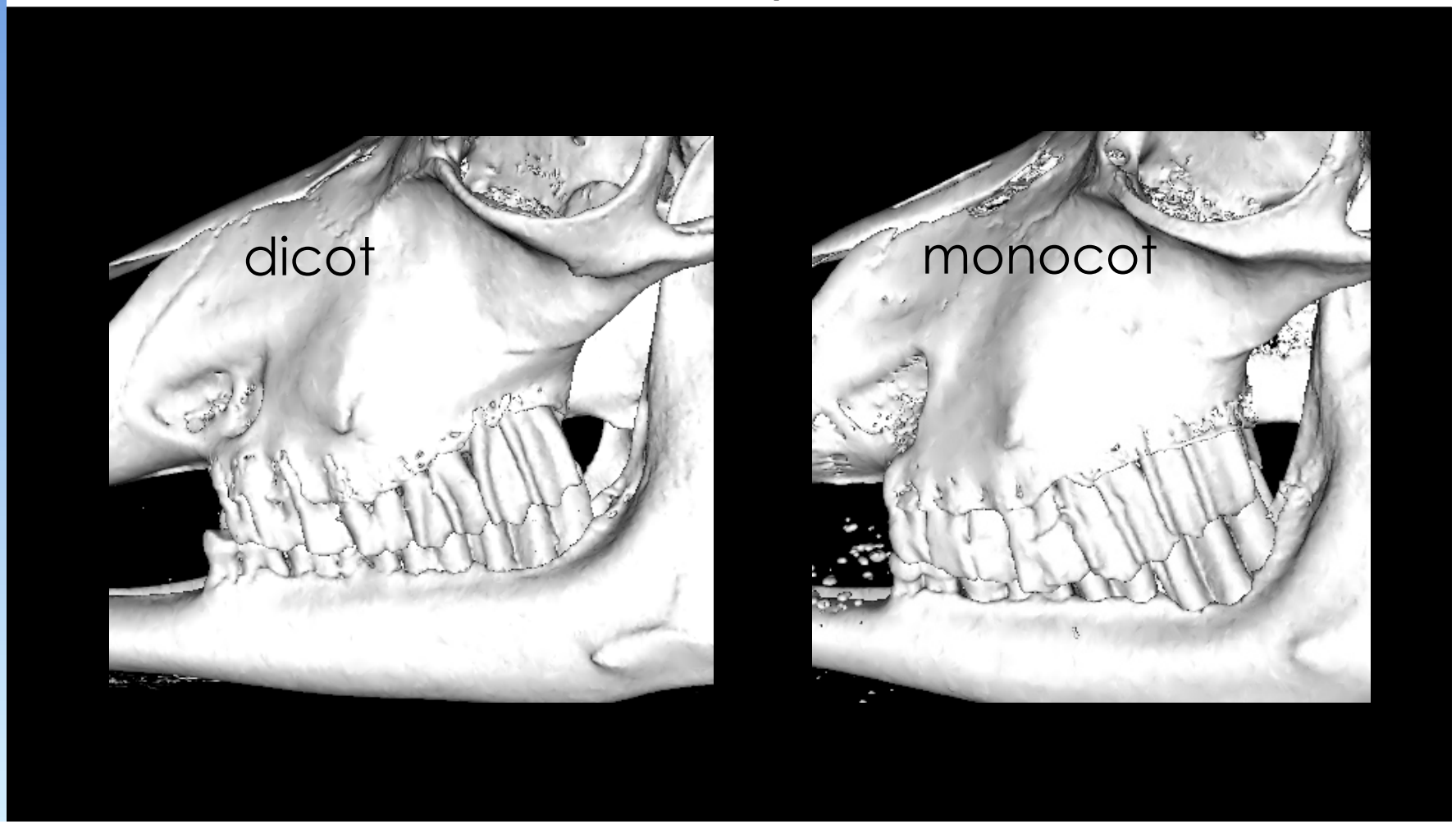


Grass hay only (monocot)



Outlook IV

Evaluate goat CTs and teeth (mesowear, 3D texture, actual tissue loss)



Outlook V

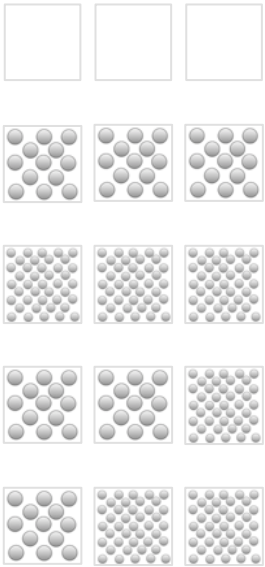
Setup experiment with rabbits, dwarf goats & chewing machine.

More elaborate diets:

a) grass mowed daily – half fed fresh, half prepared as hay for other feeding period

b) standard diet with two kind of abrasives (phytolith-size; smaller)

c) how to manipulate 'toughness'?



Something else

discuss this first