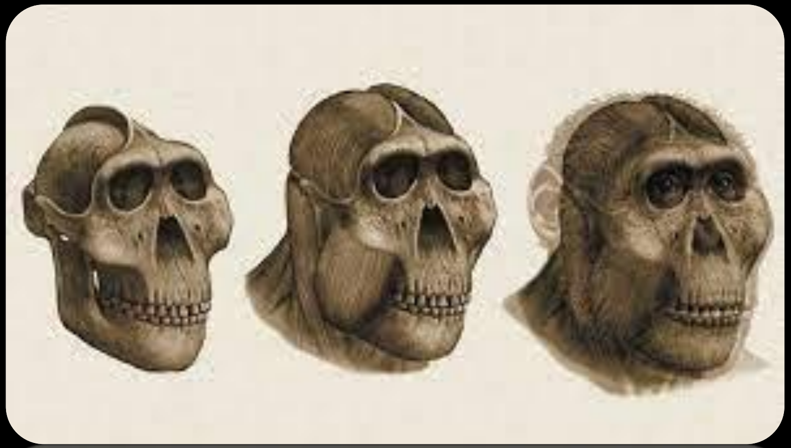
Teeth & Evolution



Arwa Kharobi, PhD

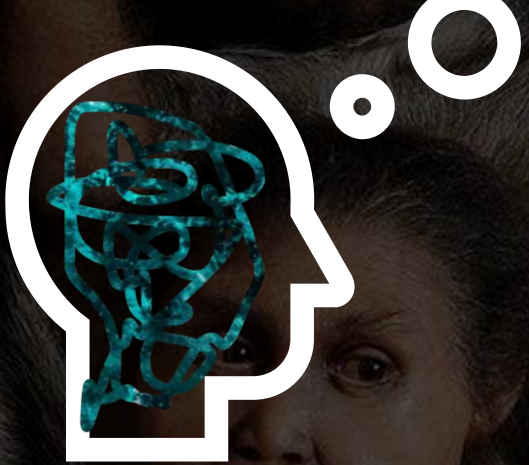
Assistant Professor

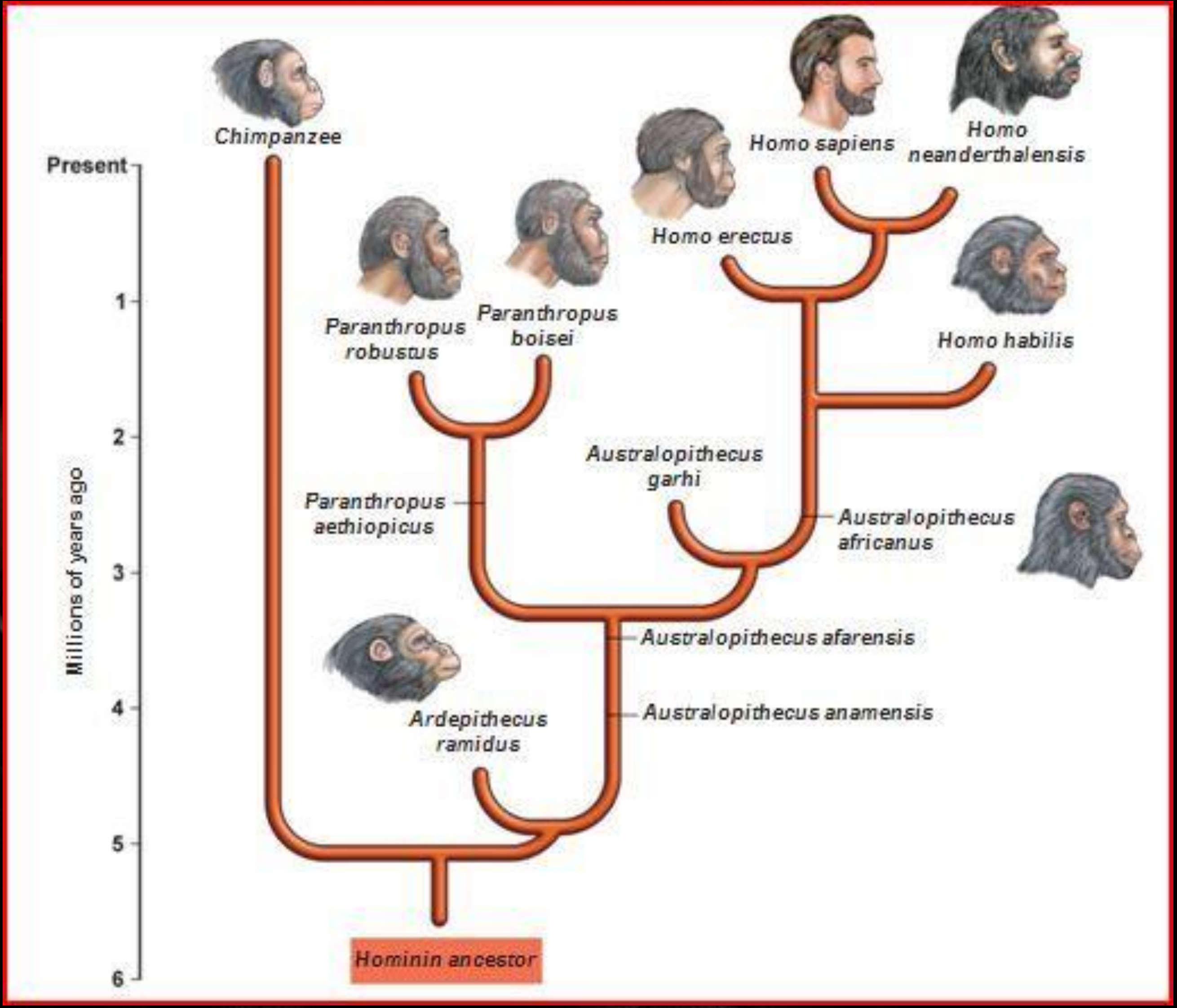
arwakharobi@sci.muni.cz

MUNI SCI

HR EXCELLENCE IN RESEARCH

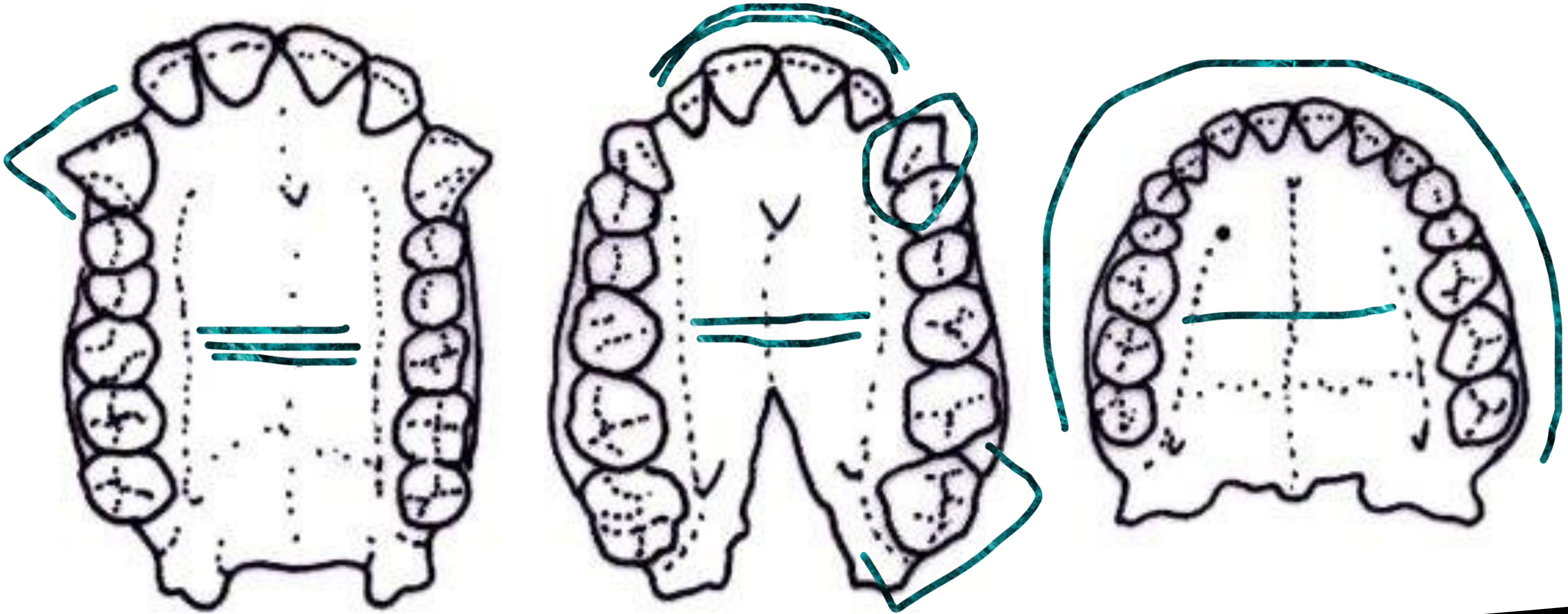
how genetic changes contribute to morphologic variations that are subjected to natural selection?





For this, are invaluable:

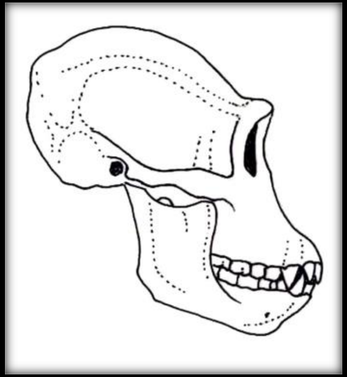
1. found in multiple locations in the vertebrate body
2. great variation in shape, size, number & rows of teeth = easy to characterize
3. readily fossilized vertebrate structures with excellent preservation of morphology → a large number of specimens for comparative genomic, anatomic, and phylogenetic studies.



As our ancestors evolved, their jaws & teeth changed in many ways.

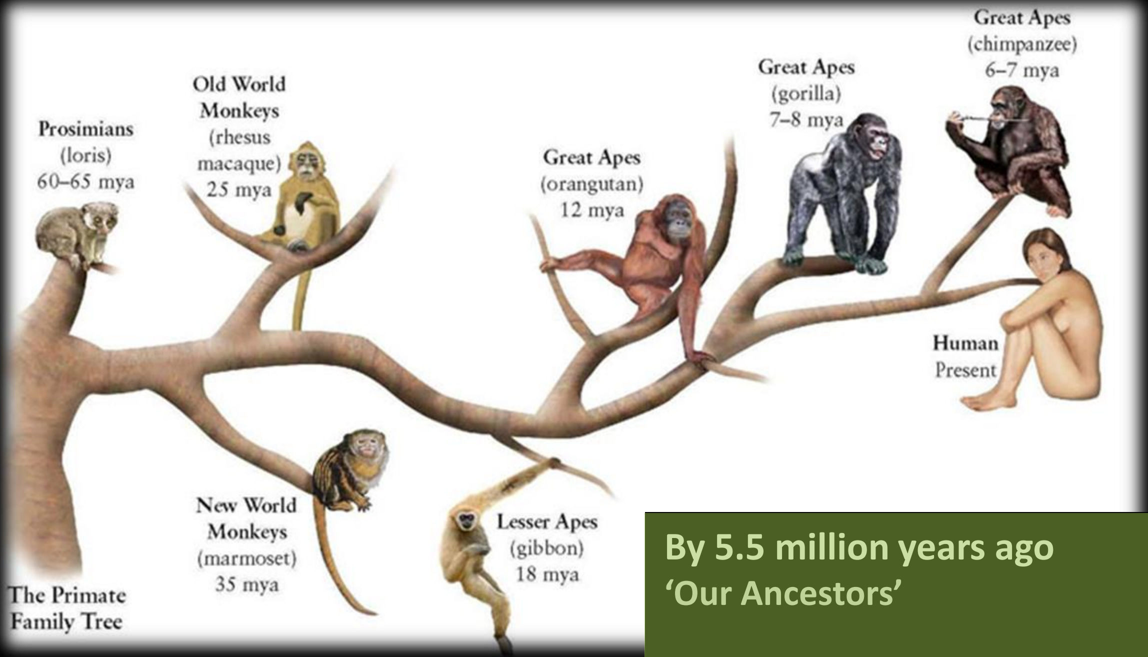
Some tooth changes were apparent five million years ago and additional changes have occurred since then.

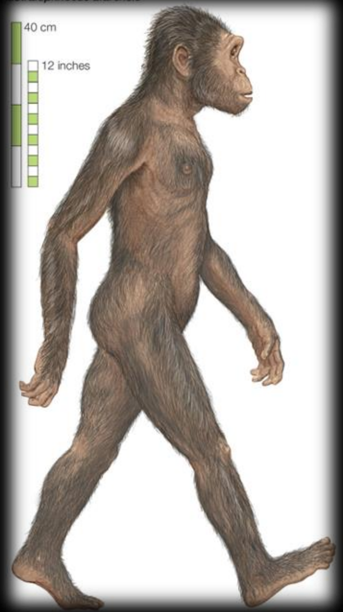
Shorter jaws with smaller teeth



About 7 million yrs ago our early ancestors had:

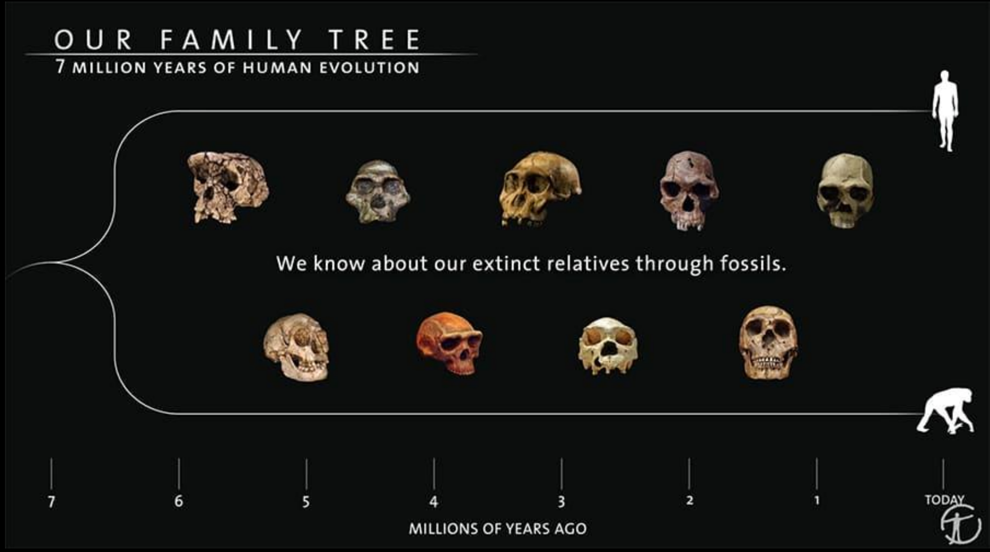
1. long jaws which resulted in projecting face profiles
2. long, pointed canines
3. parallel tooth rows





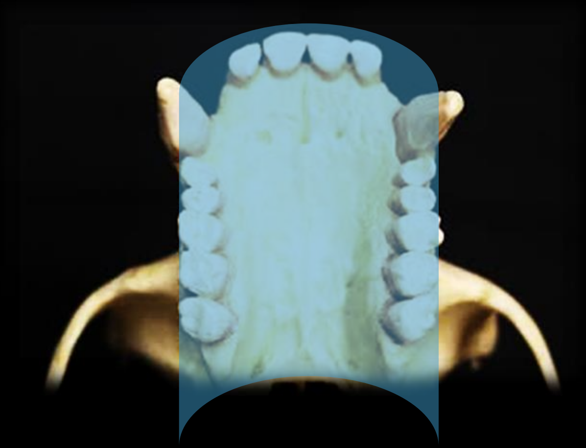
By 5.5 million years ago **'Our Ancestors'**	canines starting to become smaller
By 3.5 million years ago 'Our Ancestors'	teeth arranged in rows slightly wider apart at the back than at the front
By 1.8 million years ago 'Our Ancestors'	shorter canines & relatively blunt (like ours) shorter jaws. → made the face more vertical → forced the side rows of teeth to bend into a rounded arc shape
By 250,000 years ago **'Direct Ancestors'**	• very short jaws • developed a pointed chin for added strength. • teeth were now smaller & arranged in a tightly parabolic arc • faces were now vertical rather than projecting

<u>Comparing then to now</u> : **7 million yrs ago**, our ancestors' jaws and teeth were similar to those of modern chimpanzees.



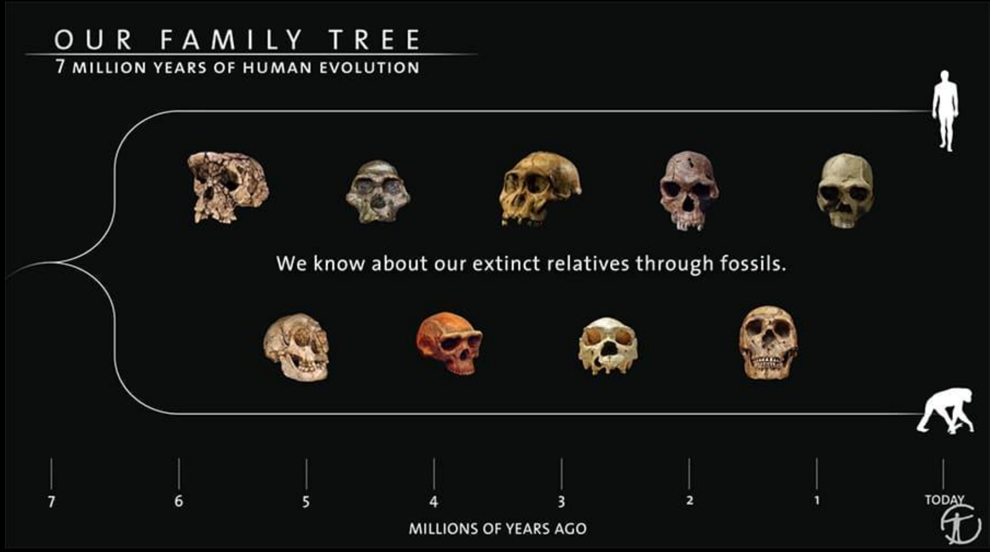
1. Dental arcade & tooth rows:

1. teeth were arranged in the jaw in a rectangular or U-shape
2. a diastema next to each canine



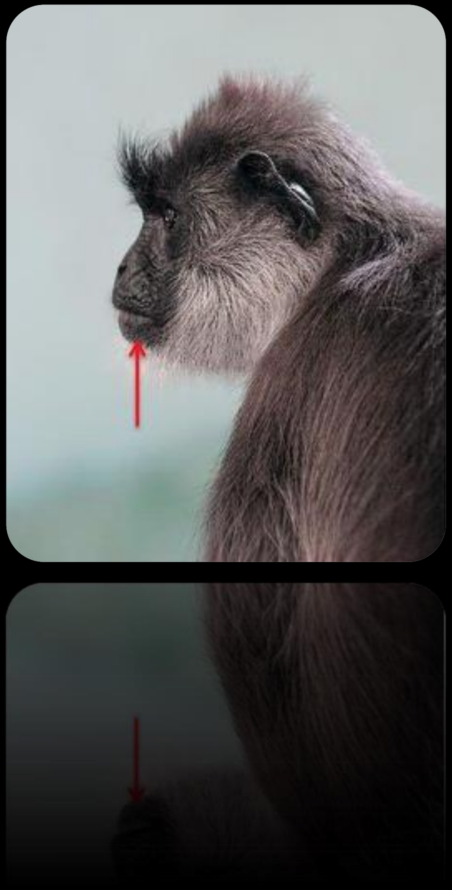
- gaps were spaces the large canines could fit into when the jaws closed
- <u>In the upper jaw:</u> in front of the canine
- <u>In the lower jaw</u>: behind the canine

Comparing then to now : **7 million yrs ago**, our ancestors' jaws and teeth were similar to those of modern chimpanzees.

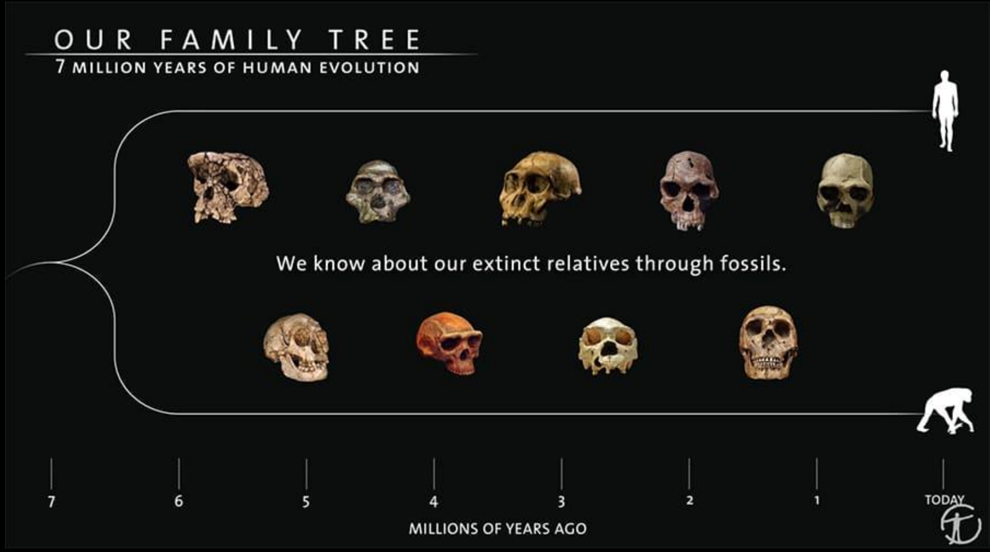


2. Jaw & face profile:

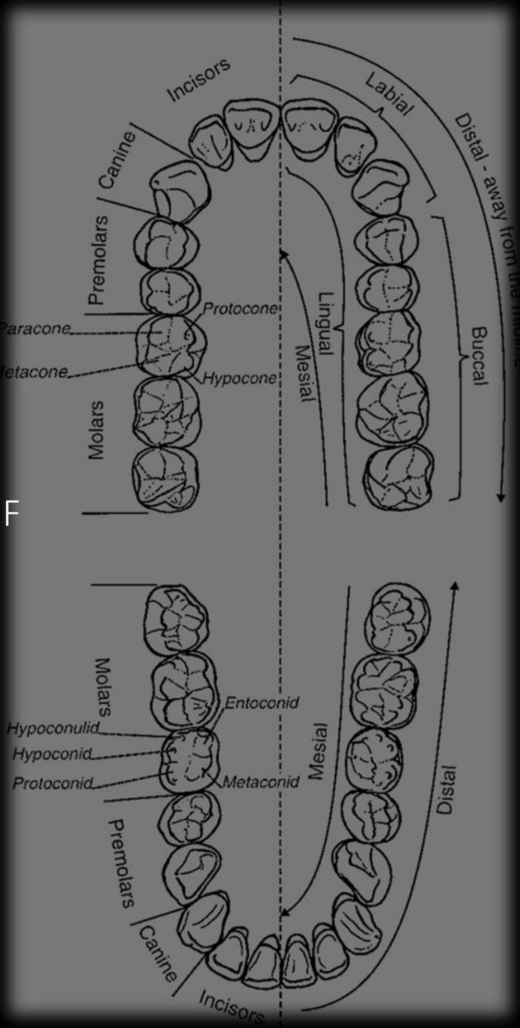
1. jaw was long which resulted in a projecting face profile
2. no chin



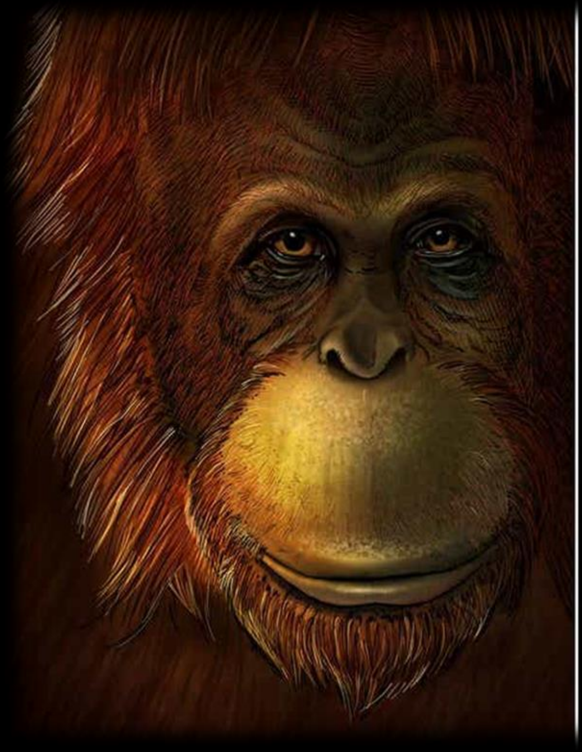
Comparing then to now : **7 million yrs ago**, our ancestors' jaws and teeth were similar to those of modern chimpanzees.



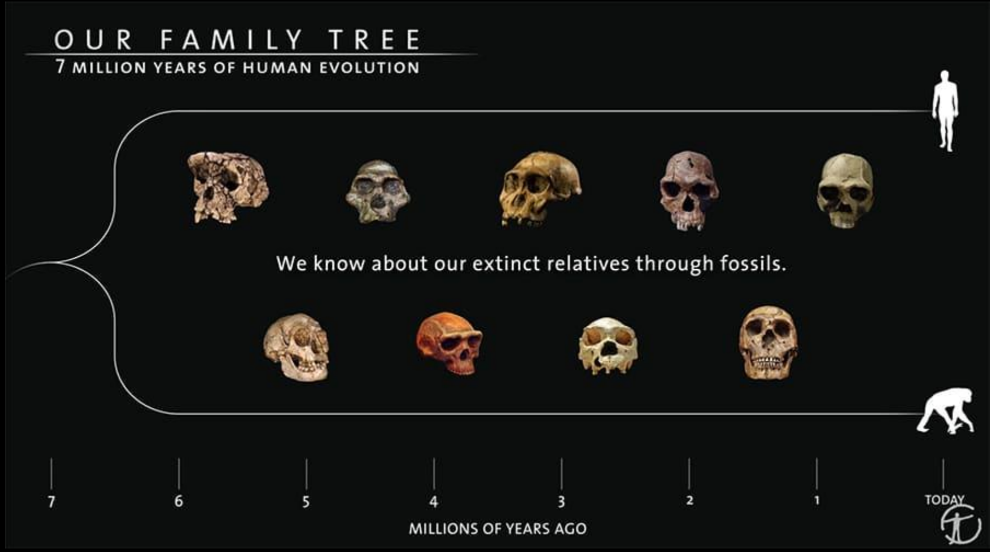
3. Teeth:



1. Incisors: relatively large
2. upper incisors: broad & projected outward
3. canines: very long, pointed/larger in M than in F
4. molars: large
5. premolars & molars: high cusps
6. covered by a thin layer of enamel

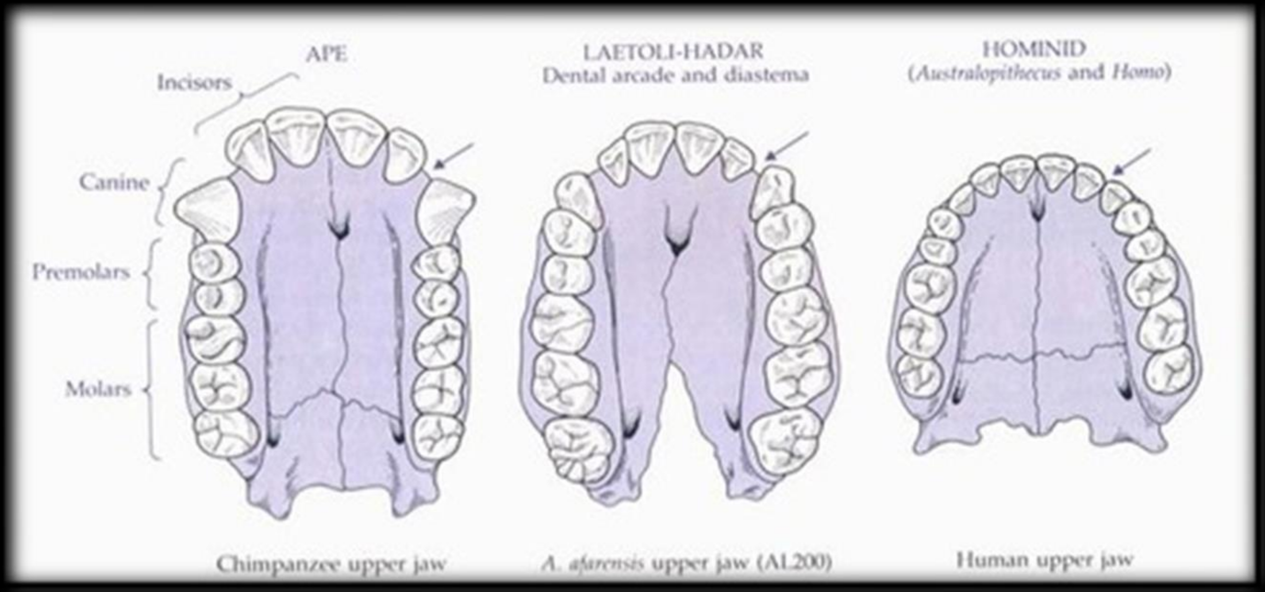


Comparing then to now : **Now**, the evolution of modern humans has involved the development of distinctive facial & dental features.

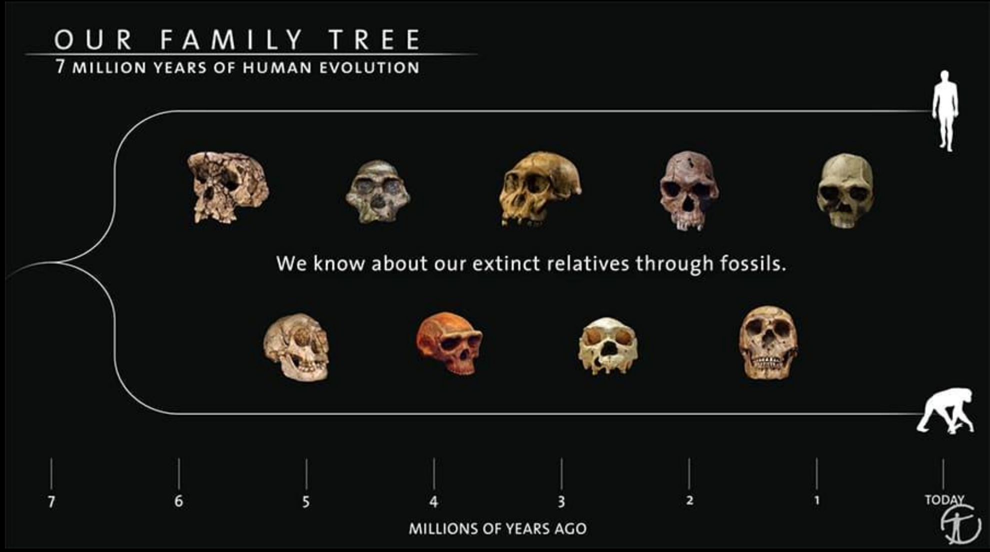


1. Dental arcade & tooth rows:

1. teeth are arranged in a parabolic or rounded arc shape
2. no diastema next to the canines

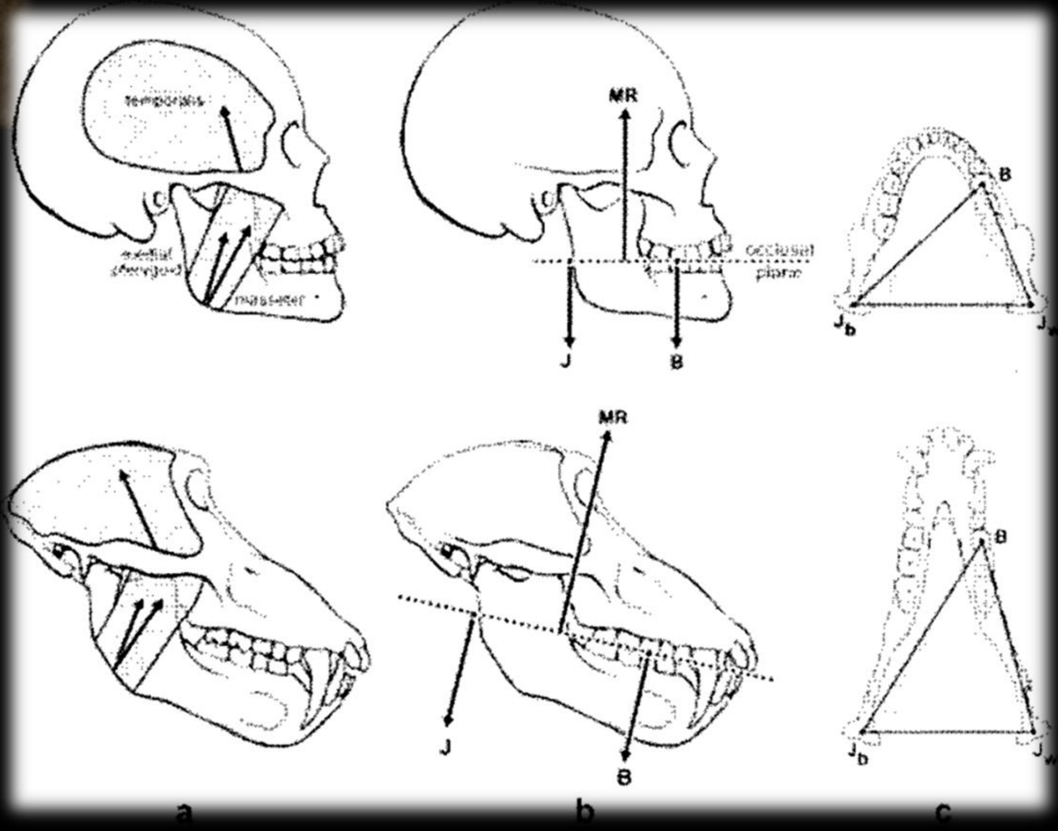


Comparing then to now : **Now**, the evolution of modern humans has involved the development of distinctive facial & dental features.

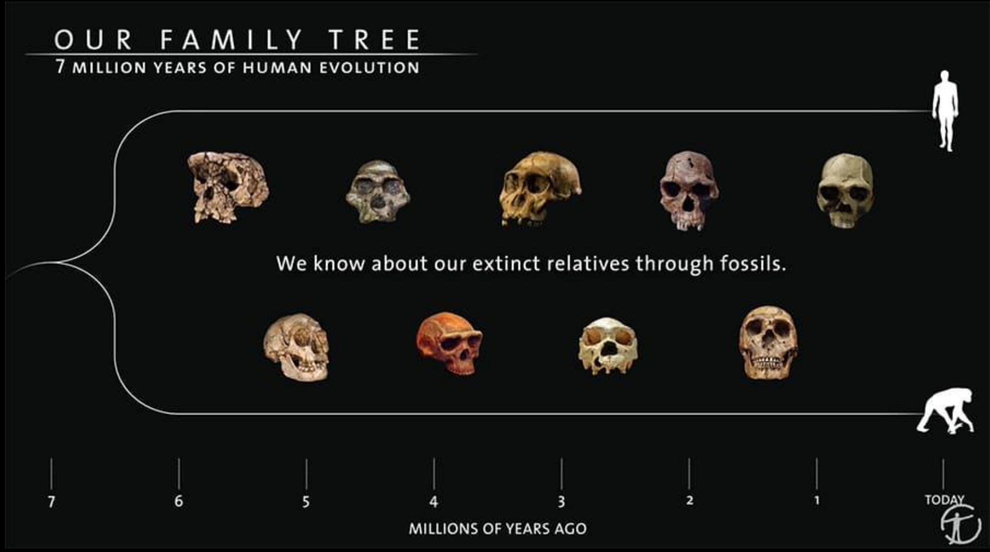


2. Jaw & face profile:

1. jaw is very short /almost no projection of the face
2. a pointed chin

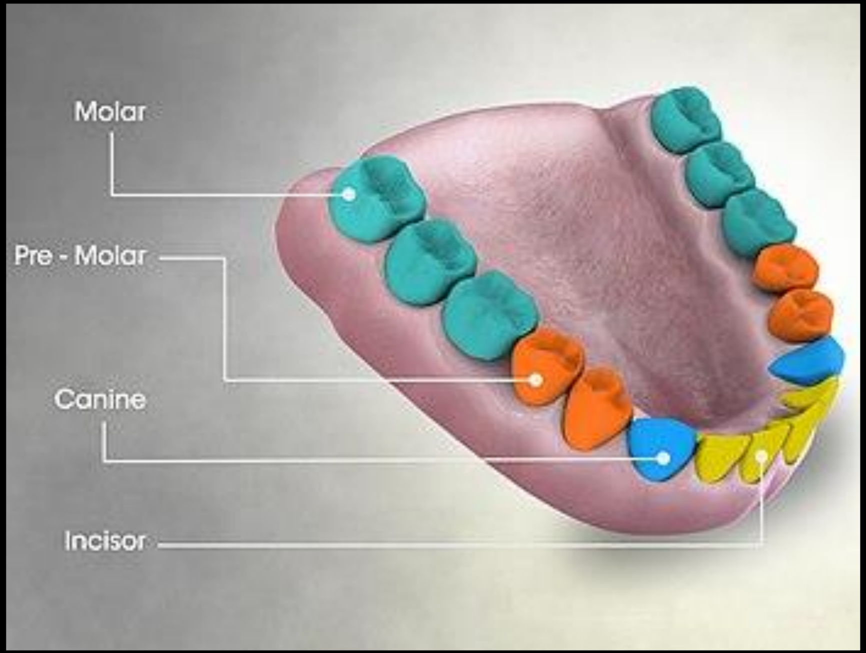


<u>Comparing then to now</u> : **Now**, the evolution of modern humans has involved the development of distinctive facial & dental features.



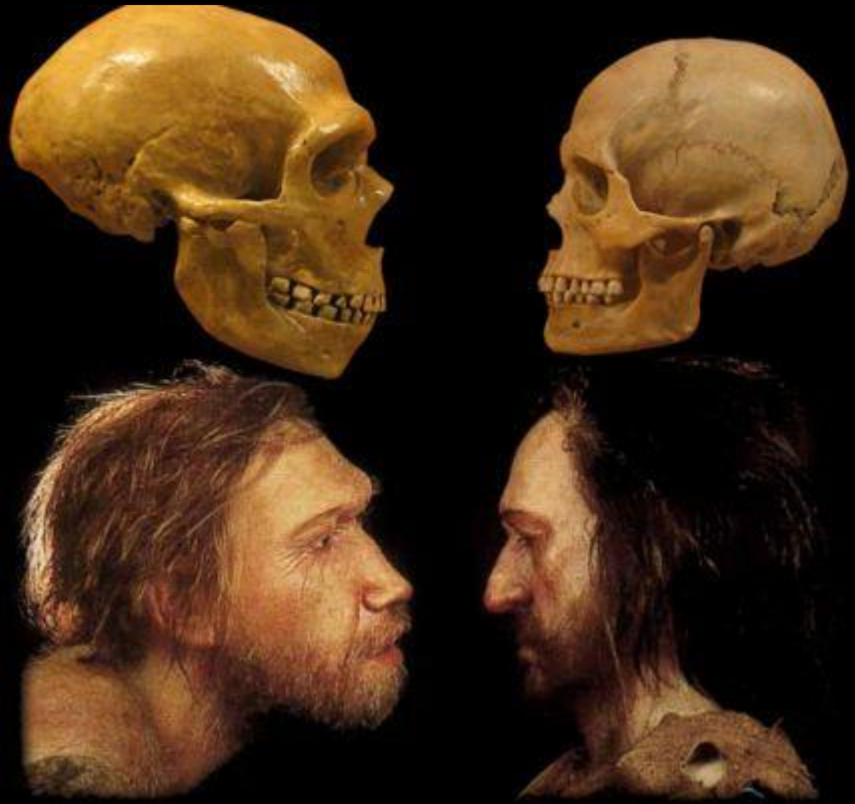
3. Teeth:

1. incisors: relatively small
2. incisors: narrow & quite vertical
3. canines: short, relatively blunt/ similar in size in males and females
4. molars: small & impacted
5. premolars & molars: relatively flat with low, rounded cusps
6. covered by a thick layer of enamel

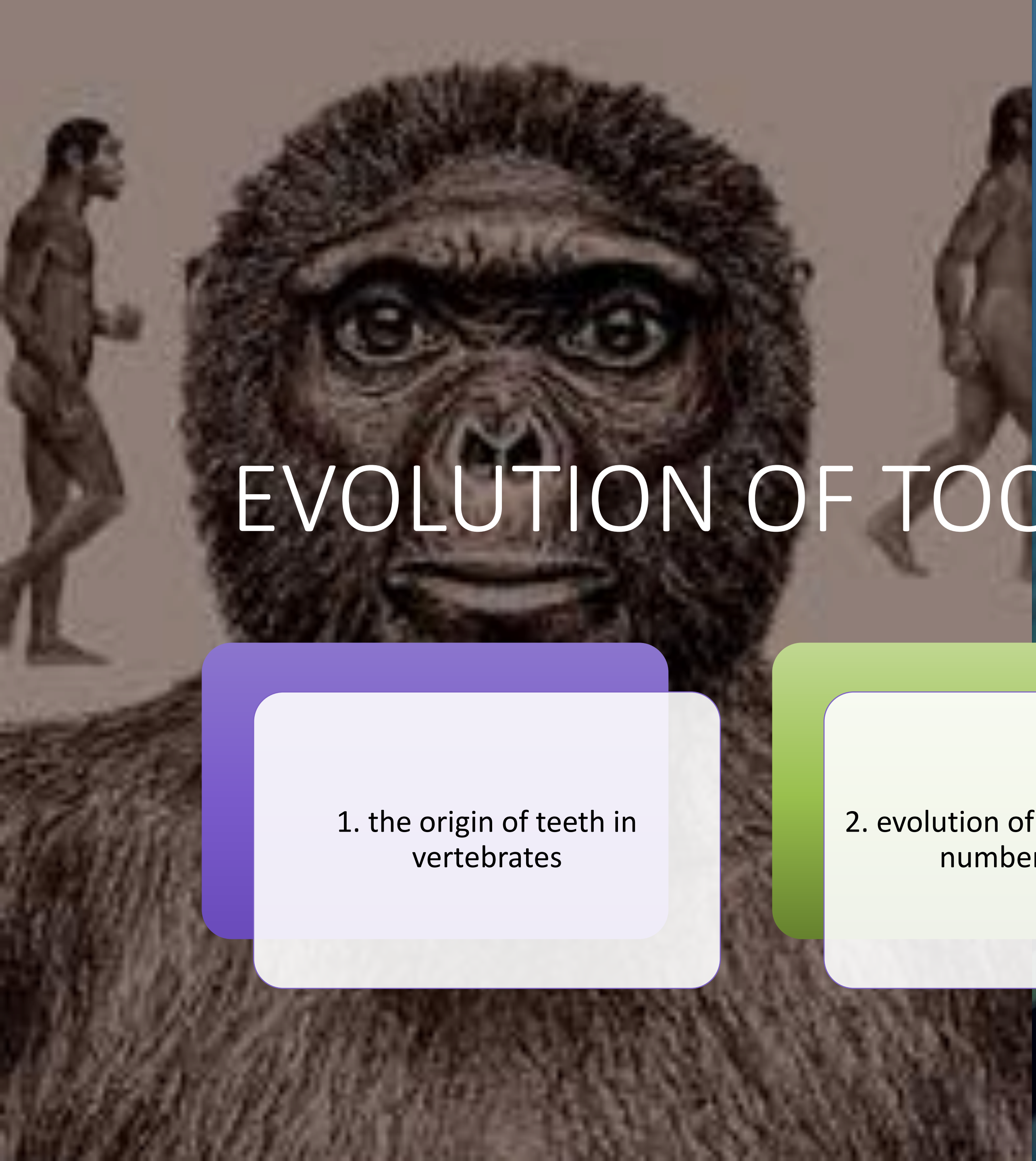




	Then	Now
teeth were arranged in the jaw in a	rectangular or U-shape	parabolic or rounded arc shape
diastema	next to each canine	no
Jaw/face	long /projecting face profile	short /almost no projection of the face
chin	no	Yes



	Then	Now
Incisors	relatively large	relatively small
upper incisors	broad projected outward	narrow quite vertical
canines	very long – pointed - High sexual dimorphism	short - relatively blunt - No sexual dimorphism
molars	large	small & impacted
cusps on premolars & molars	high	Low→ flat & rounded
layer of enamel	thin	Thick



EVOLUTION OF TOOTH DEVELOPMENT

1. the origin of teeth in vertebrates

2. evolution of tooth shape, size, number, and rows

3. comparative tooth morphology and mammalian evolution

1. the origin of teeth in vertebrates

still unclear if oral teeth evolved with jaws for predation & mastication or first appeared as external dental armor as protection from predation

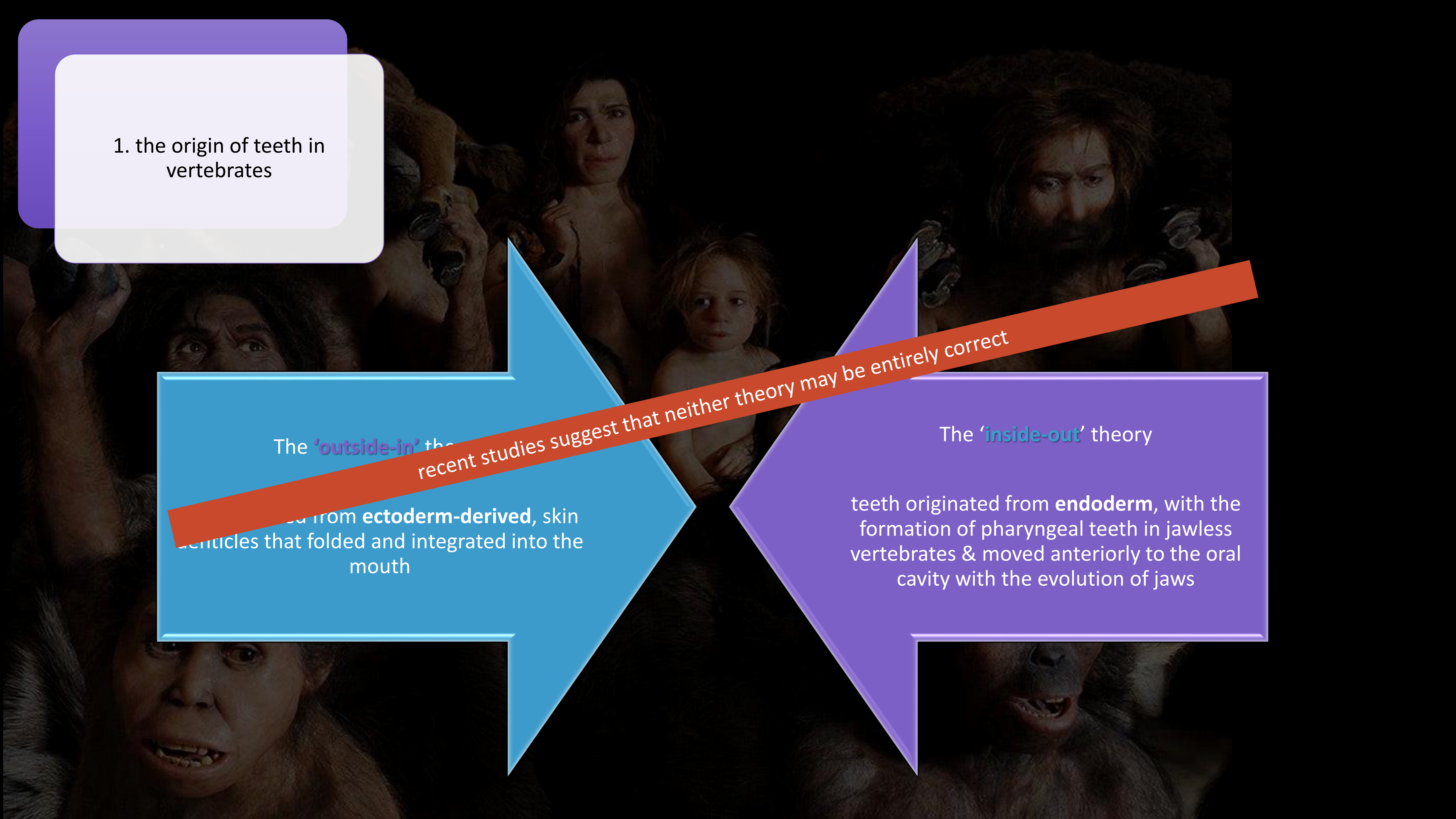
two opposing theories regarding the evolution of oral teeth

The 'outside-in' theory

teeth evolved from **ectoderm-derived**, skin denticles that folded and integrated into the mouth

The 'inside-out' theory

teeth originated from **endoderm**, with the formation of pharyngeal teeth in jawless vertebrates & moved anteriorly to the oral cavity with the evolution of jaws



1. the origin of teeth in vertebrates

The 'outside-in' th…

…from **ectoderm-derived**, skin …nticles that folded and integrated into the mouth

recent studies suggest that neither theory may be entirely correct

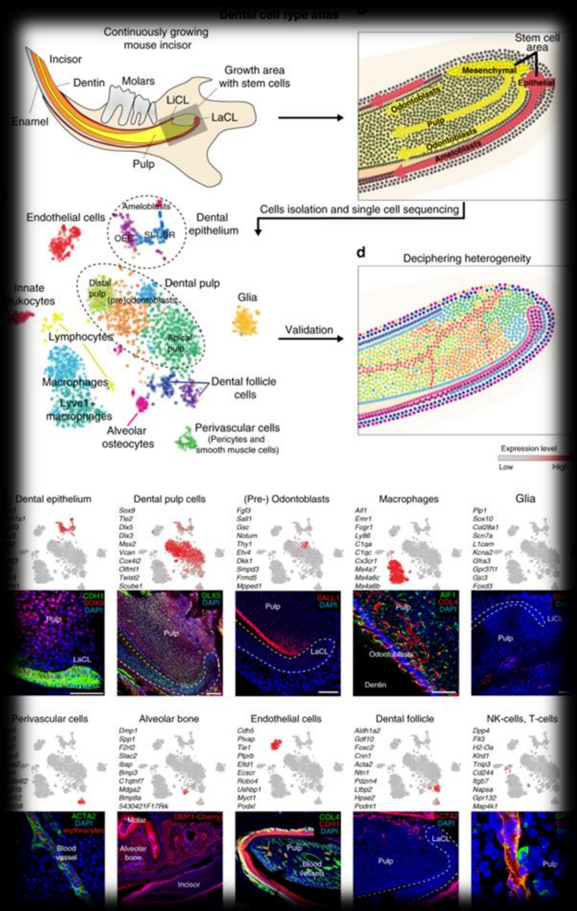
The 'inside-out' theory

teeth originated from **endoderm**, with the formation of pharyngeal teeth in jawless vertebrates & moved anteriorly to the oral cavity with the evolution of jaws

1. the origin of teeth in vertebrates

1. Fate-mapping approaches using transgenic axolotls showed that teeth formed normally regardless of whether the oral epithelium was derived from **ectoderm** or **endoderm**

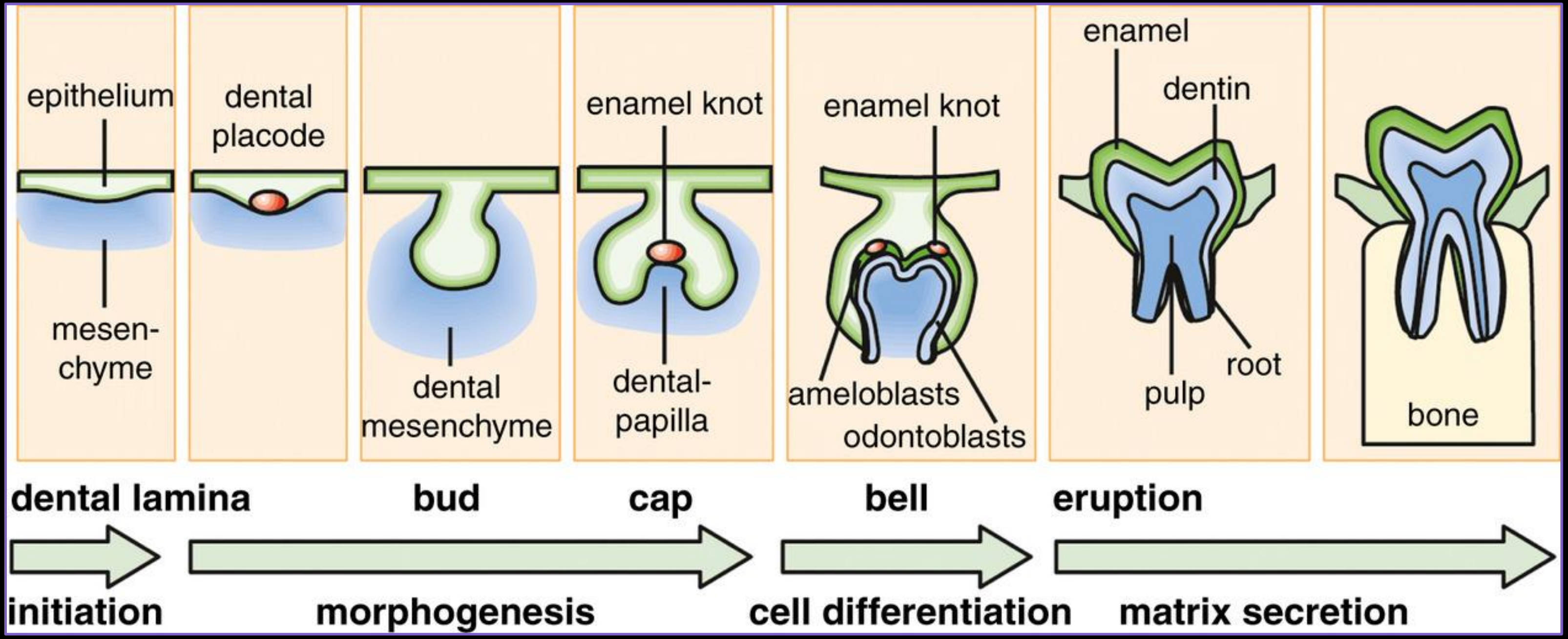
The ectoderm is one of the three primary germ layers formed in early embryonic development. It is the outermost layer, and is superficial to the mesoderm (the middle layer) and endoderm (the innermost layer). It emerges and originates from the outer layer of germ cells.



1. the origin of teeth in vertebrates

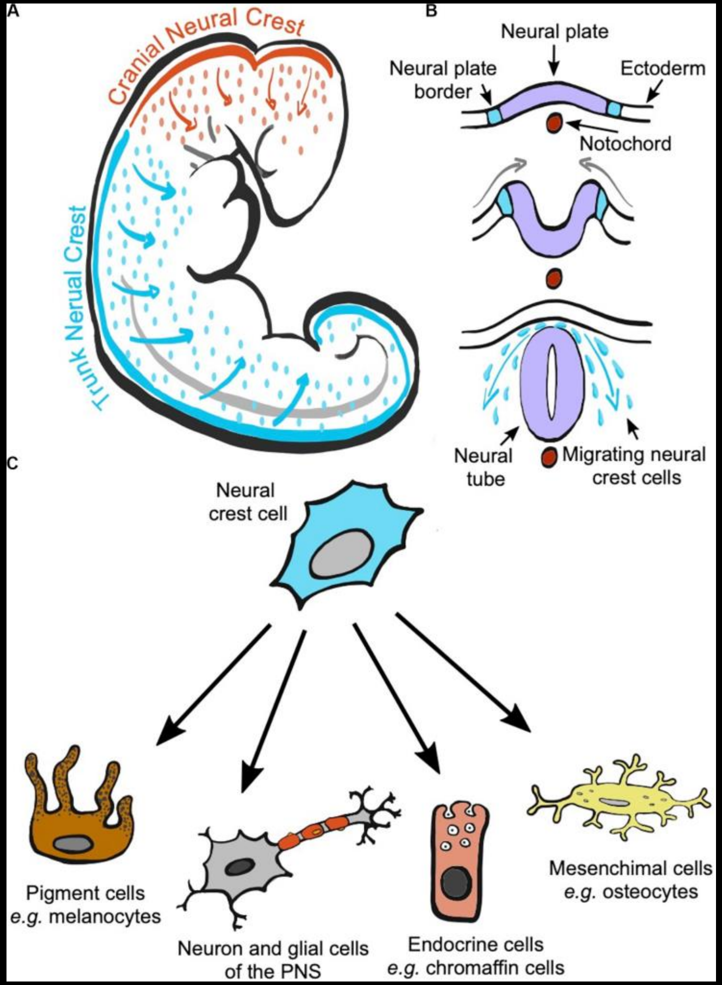
2. Experiments utilizing chicken embryos, which have lost the ability to form teeth, have demonstrated the dominant role of **mesenchyme** in the initiation of tooth development

Mesenchyme (/ˈmɛsənkaɪm ˈmiːzən-/) is a type of loosely organized animal embryonic connective tissue of undifferentiated cells that give rise to most tissues, such as skin, blood or bone.

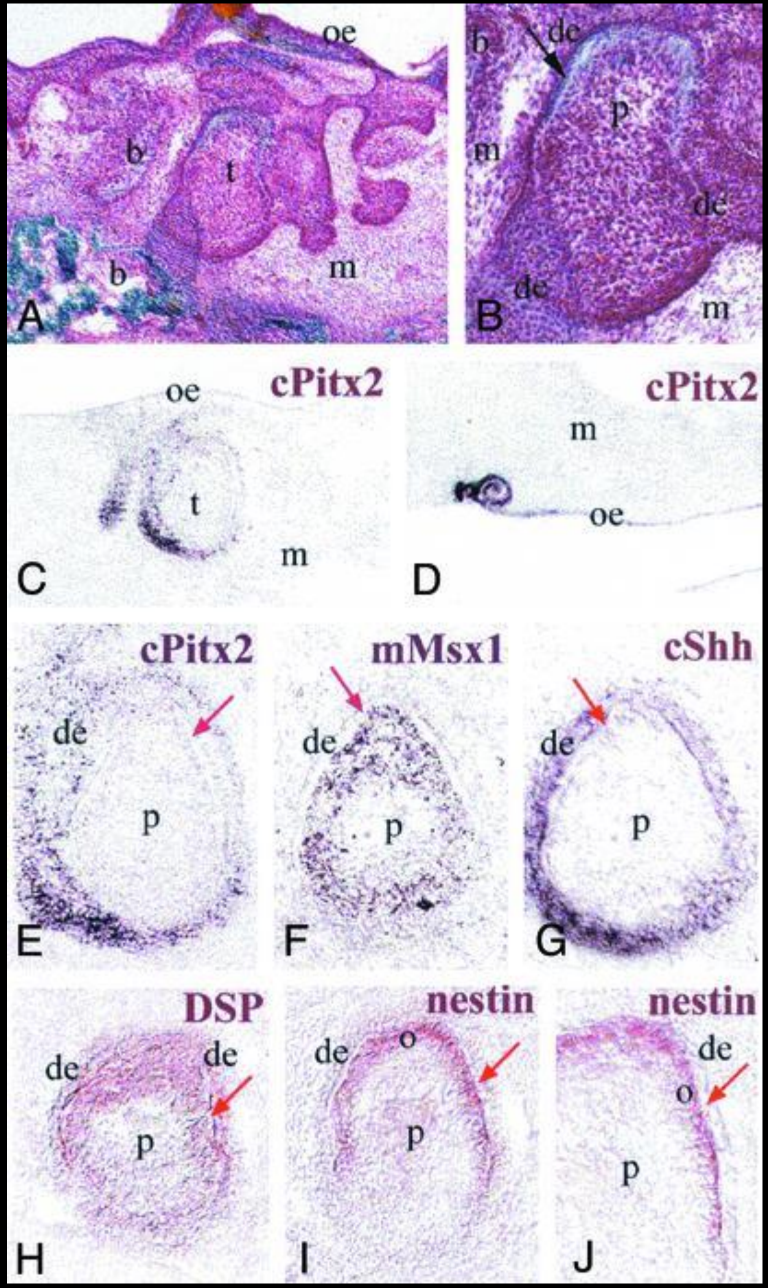


1. the origin of teeth in vertebrates

3. Specifically, transplantation of mouse neural crest cells into developing chicken embryos showed the formation of tooth germ-like structures



The neural crest is a transitory structure of the vertebrate embryo that initially locates on the most dorsal part of the neural tube



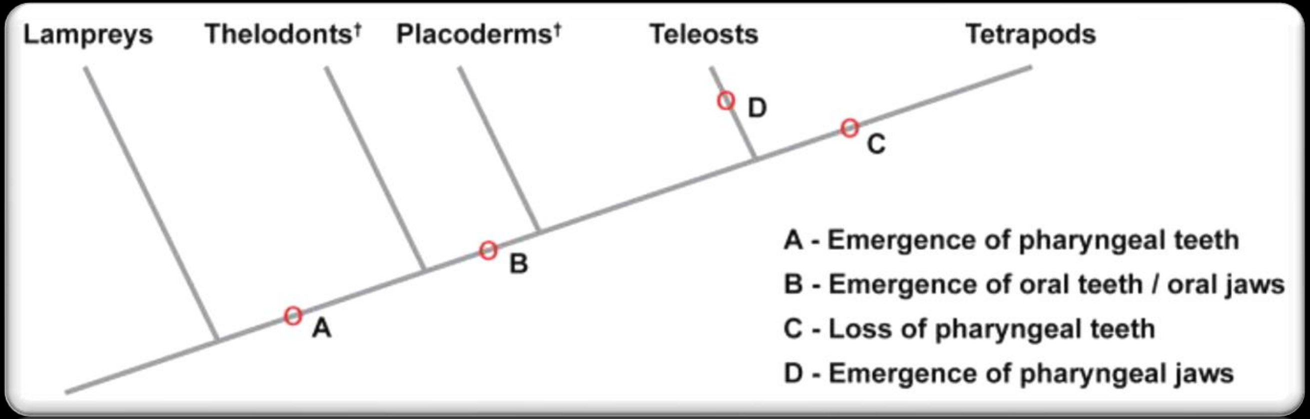
Formation of tooth-like structures in mouse/chick chimeras

1. the origin of teeth in vertebrates

Some extant fish (cichlids) **has both oral & pharyngeal teeth**

Pharyngeal teeth develop on discrete pharyngeal jaws in hox-positive, endoderm-derived sites

Oral teeth develop in hox-negative, ectoderm-derived regions



Simplified evolutionary progression of dentitions and jaws Point A indicates the origin of pharyngeal teeth in extinct (†) jawless fish. Oral teeth and jaws are thought to have arisen at point B. The pharyngeal teeth were lost in common ancestors to tetrapods at point C. In some extant teleosts such as cichlids, both oral and pharyngeal teeth are present and pharyngeal jaws are thought to have arisen at point D. Adapted from Fraser et al.[99]

1. the origin of teeth in vertebrates

Pharyngeal teeth of **jawless vertebrates** appear to utilize an ancient gene network that predates the origin of oral jaws, oral teeth & ectodermal appendages

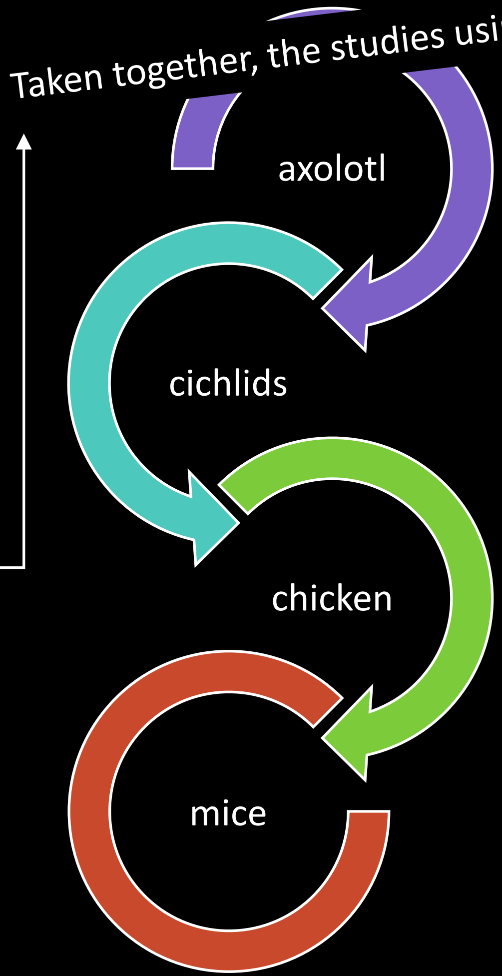
During mouse development, expression of various genes is observed in the presumptive **molar region** but not in the **incisor region**

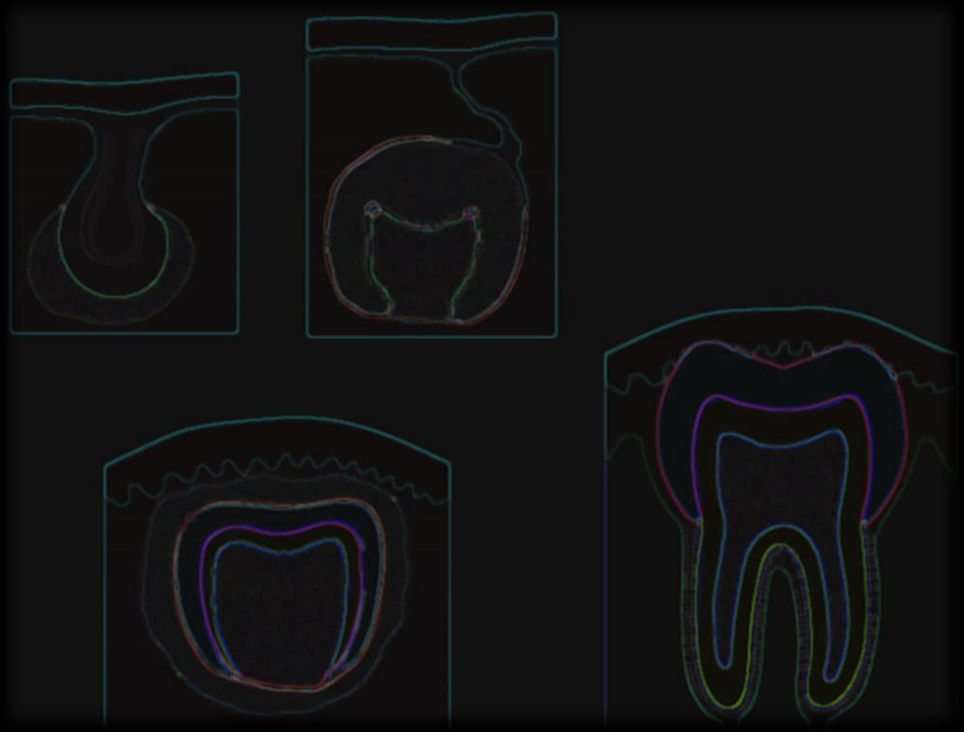
In *Chuk null mice*, there was abnormal epithelial evagination in **incisors** but not in **molars**

suggesting

- differences in the epithelium from which incisor & molar develop = different molecular mechanisms that result in heterodont dentition,
- However, despite this distinct developmental environments, both oral and pharyngeal teeth also show striking similarities in their gene regulatory networks

1. the origin of teeth in vertebrates





Demonstrate

→ teeth can form despite different epithelial origins

→ important role of mesenchyme in the initiation of tooth development

→ challenging the primacy of oral ectoderm in this role

→ conservation of gene regulatory networks across lineages with origins in different germ layers

→ role of deep homology in the evolution & development of teeth

1. the origin of teeth in vertebrates

The 'outside-i...

...ectoderm-derived, skin ...es that folded and integrated into the mouth

Thus, teeth appear to have evolved both 'inside and out', wherever and whenever the odontogenic-specific gene network of the mesenchyme was present

The '**inside-out**' theory

teeth originated from **endoderm**, with the formation of pharyngeal teeth in jawless vertebrates & moved anteriorly to the oral cavity with the evolution of jaws

2. evolution of tooth shape, size, number, and rows

- Both humans & rodents evolved from a common mammalian ancestor that is thought to have had a full complement of teeth comprising:

3 incisors,

1 canine,

4 premolars

3 molars <u>in each dental quadrant</u> that replaced a single time.

During mammalian evolution, teeth were lost along the lineages:

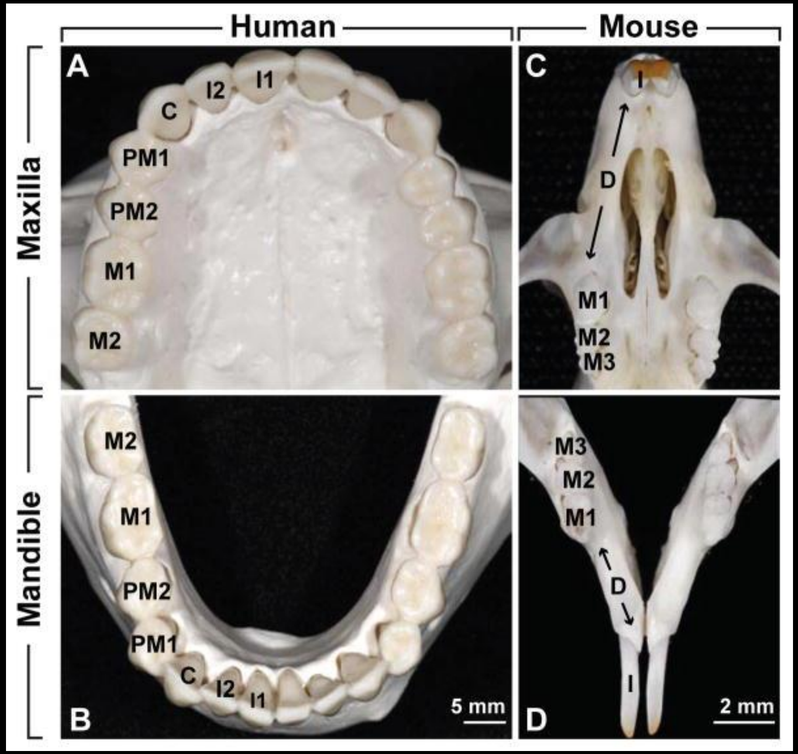
- <u>Humans</u>: four major types of teeth
- <u>Humans</u>: lost members of several of these types;

e.g., 2 incisors & 2 premolars

- <u>Rodent ancestors</u>: further reduction;

e.g., mice have only 1 incisor & 3 molars per quadrant,

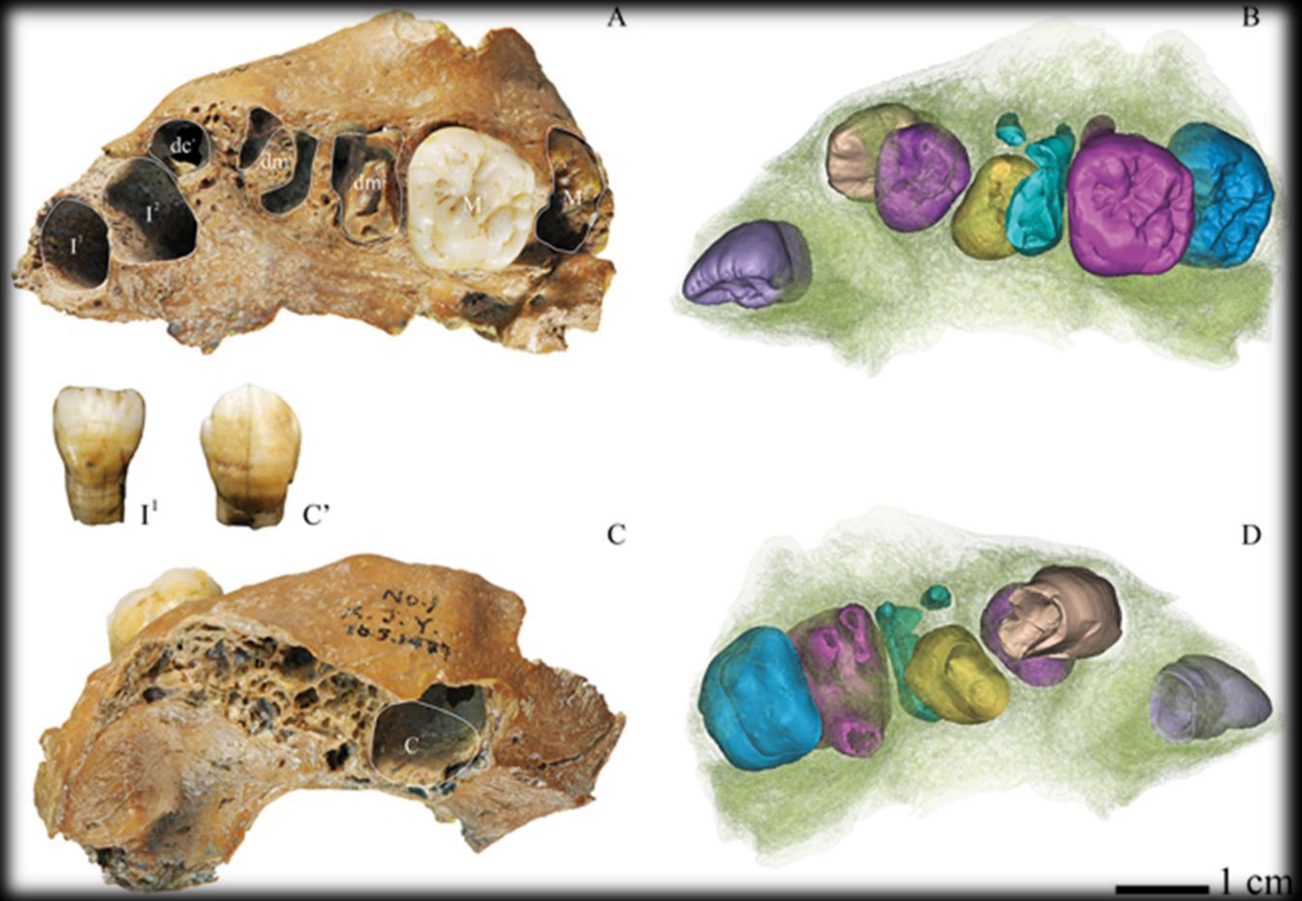
and no replacement teeth



2. evolution of tooth shape, size, number, and rows

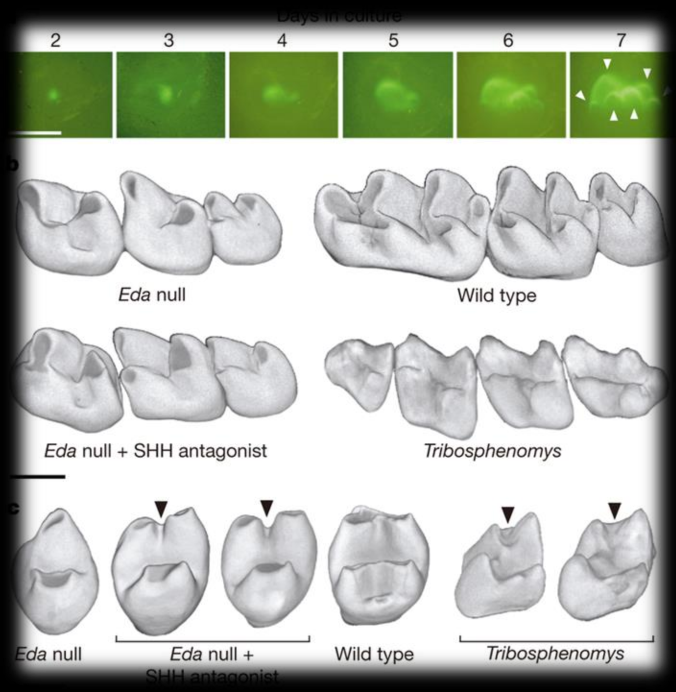
Not only the number of teeth but also the morphology:

- variations in cusp shape
- variations in crest organization



2. evolution of tooth shape, size, number, and rows

- The various tooth shapes observed in heterodont animals are believed to have evolved from ancestral conical teeth, perhaps similar to canines, through the addition of cones and grooves
- Little is known regarding the molecular mechanisms underlying such changes, and therefore they are the subject of much current interest
- Two recent studies have provided important information about the developmental regulation of the relative size and number of molars by using mouse molar cultures



it was proposed that a combination of activators & inhibitors governs the relative relationship between size & number of teeth.

Detailed studies of tooth shape indicated that the complexity of the cusps directly reflects the animal’s diet across many mammalian species

These studies pointed to higher order, generalizable principles that govern tooth shape and size

2. evolution of tooth shape, size, number, and rows

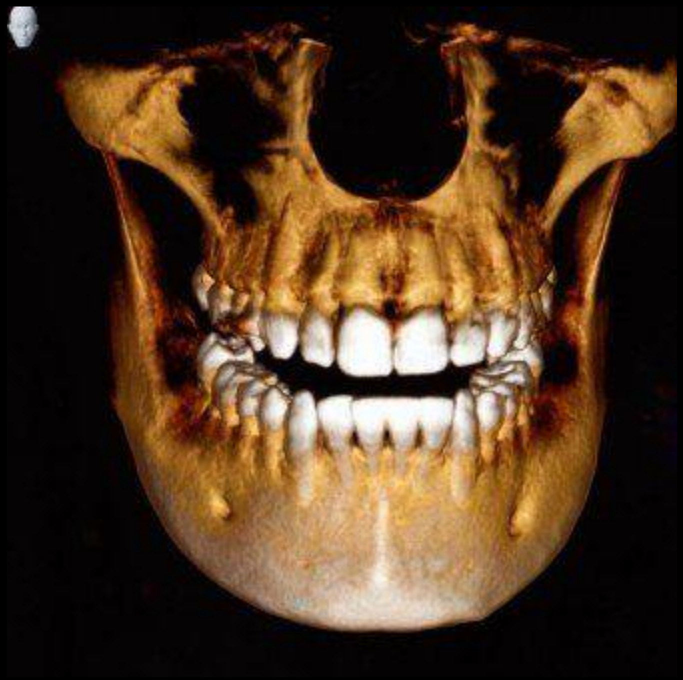
Mammals:

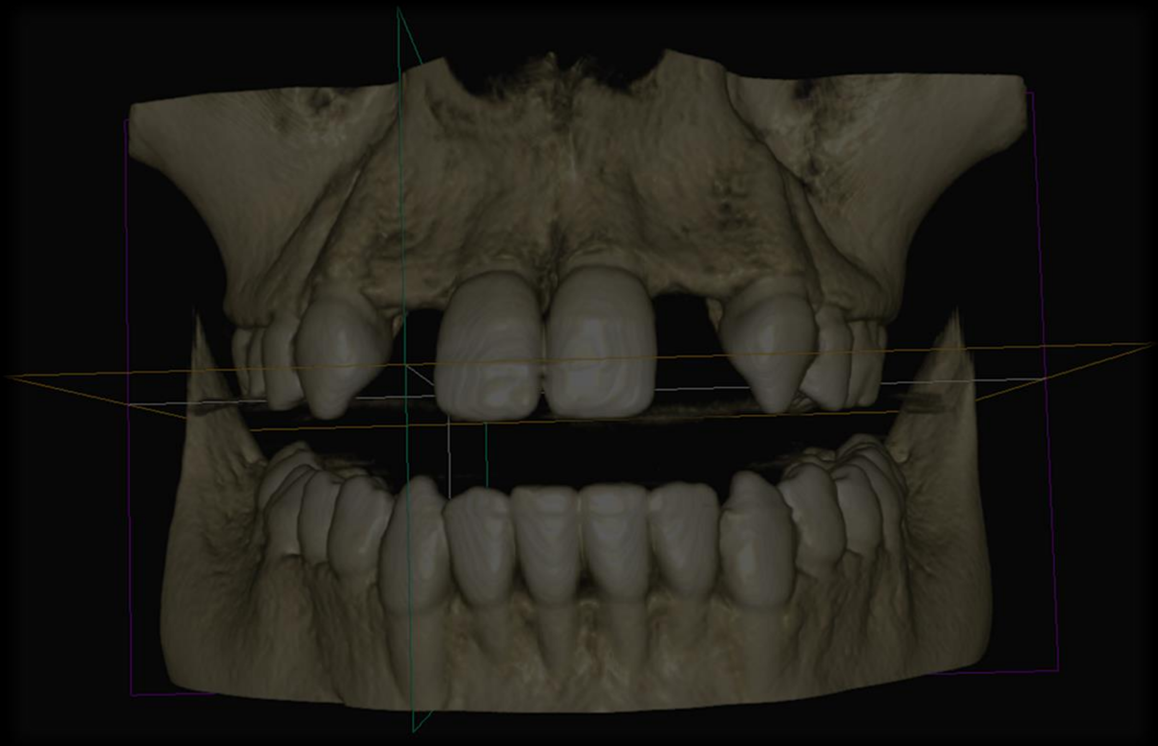
1. have a single row of teeth in the upper and lower jaws, unlike the multiple rows observed in some non-mammalian species such as fish and snakes

2. Teeth are replaced only once, whereas in many non-mammalian species, teeth are continuously replaced

3. comparative tooth morphology and mammalian evolution

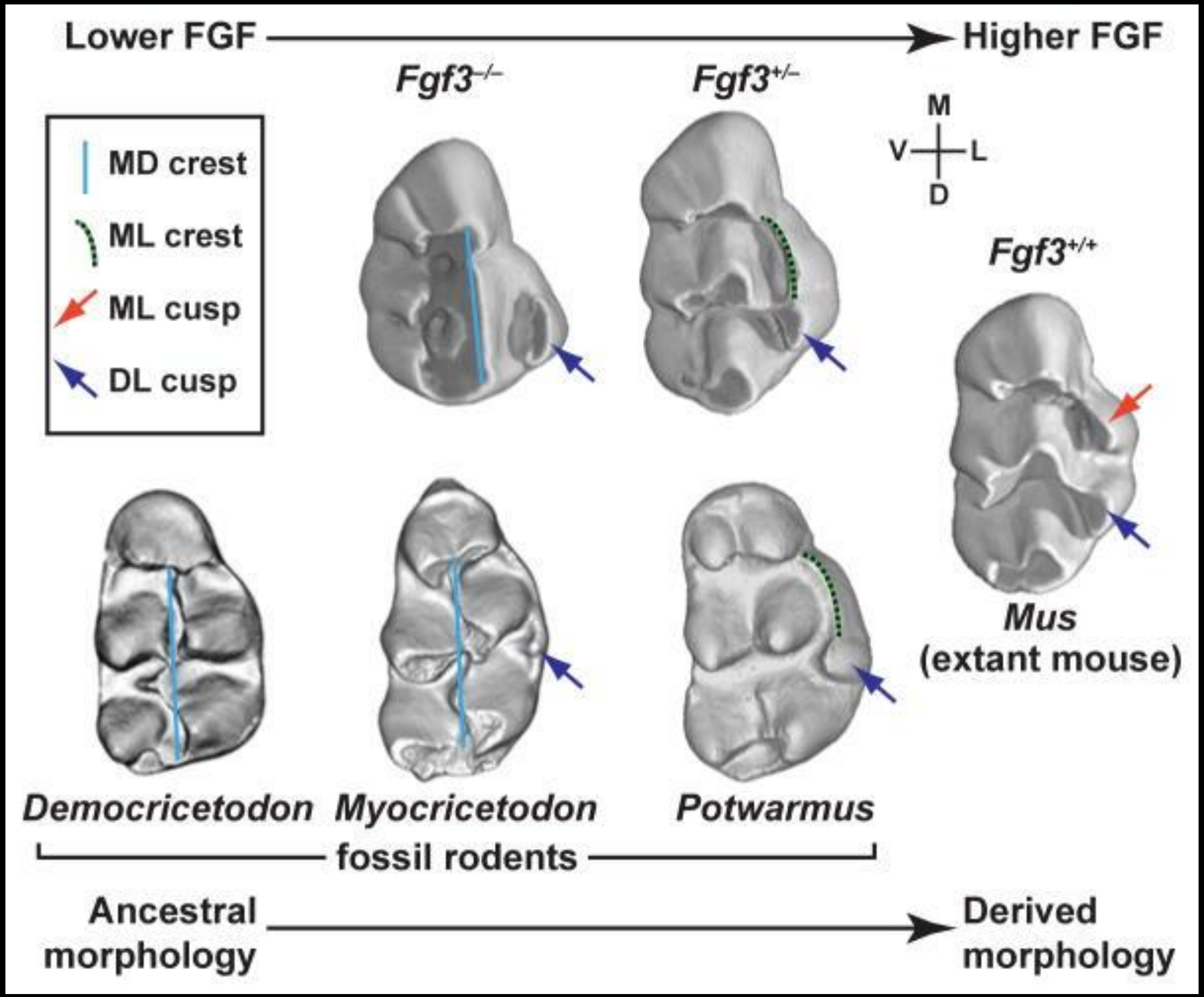
- Due to the highly mineralized nature of enamel, there is excellent preservation of detailed dental features in teeth from extant and extinct species.
- Using this vast repository of specimens, detailed 3D images can be constructed to compare subtle differences in tooth morphology.
- This information can be applied in interesting ways to further our understanding on the evolution of tooth development.





3. comparative tooth morphology and mammalian evolution

Comparative morphologic studies of mutant mice and various extinct and extant species have shed light on the role of specific genes in the evolution and development of tooth morphology.



3. comparative tooth morphology and mammalian evolution

A large amount of information can be extracted from the analysis of fossilized teeth.

1. a record of growth from enamel & dentin → reconstruction of the developmental history & timing of crown & root formation
2. Measurements of daily enamel cross-striations → information on timing & rate of enamel/crown formation
3. accentuated neonatal lines in the enamel of deciduous & permanent molars → denote the time of birth
4. incremental markings in the dentin → timing of root completion
5. quality of the enamel-dentin junction → a window to tooth development & the actions of the enamel knot

Using such techniques, tooth development in Neanderthals was shown to closely resemble that of human populations, underscoring the similarities between humans and Neanderthals

What makes a hominin a hominin?

There are two important traits that all hominins share:

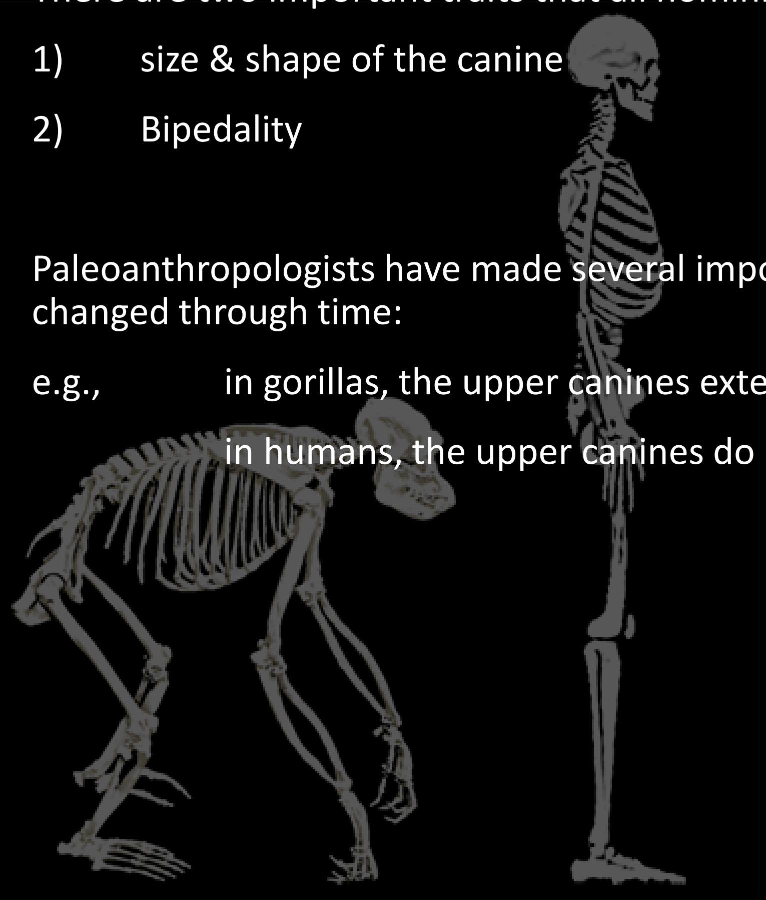
1) size & shape of the canine

2) Bipedality

Paleoanthropologists have made several important discoveries about how our canines have changed through time:

e.g., in gorillas, the upper canines extend past the lower teeth.

in humans, the upper canines do not even reach the gums of the lower jaw.



Why our canines are so small?

Diet & dental evolution

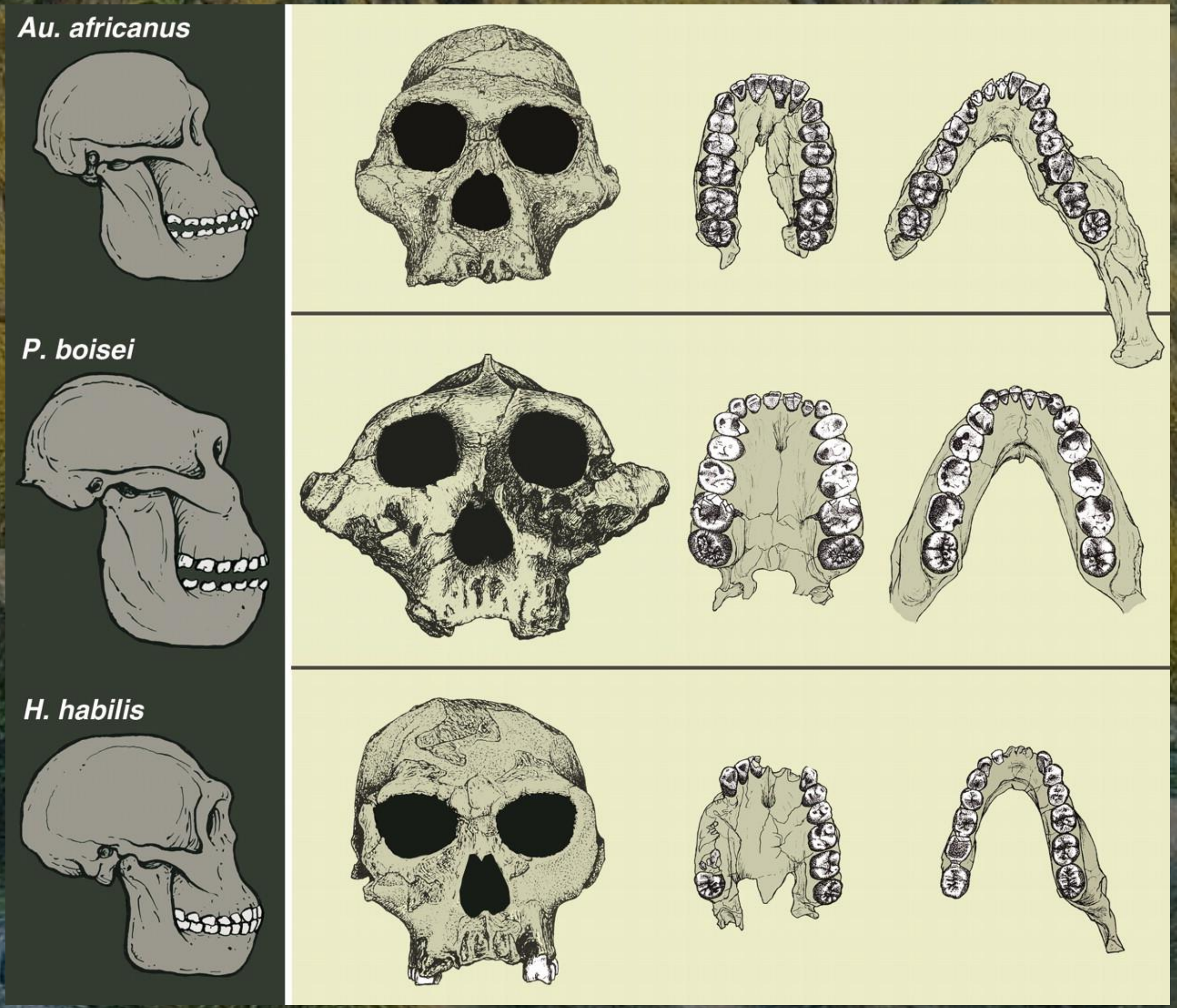
Teaford & Ungar 2000

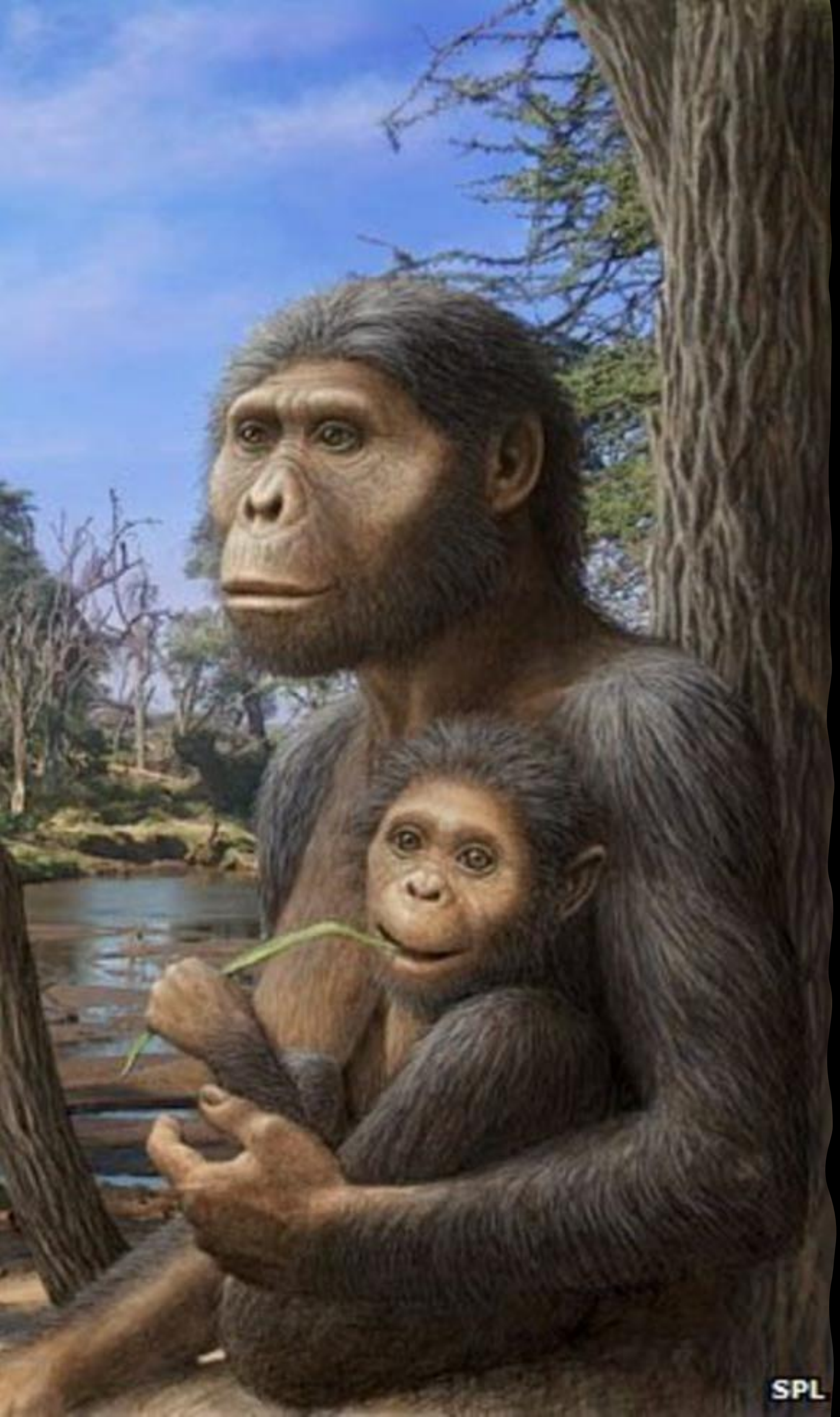
shown that 4.4 to 2.3 million years ago, there have been changes in the dietary capacities of the early hominins (australopithecines) which have provided them the chance to survive in different habitats making them able to eat a larger variety of food

Diet & dental evolution

- Analyses of the tooth shape, tooth size, enamel shape and dental micro wear together with dental biomechanics, suggest that there have been a shift in the dietary capacities of the australopithecines which has helped them survive in climatic variability

- Studies on the teeth of A anamensis to A. Afarensis and to A. Africanus suggest that hard and abrasive foods had gained importance through the Pliocene period





Diet & dental evolution

Jolly 1970

stated that the australopithecines had:

- smaller incisors compared to the molars (this ratio might have been due to terrestrial seed eating)
- large and flat molars (larger than today's orangutan)
- large variety of tooth sizes & variation in tooth size shows adaptation to various types of foods depending on their shapes, sizes and abrasiveness

Teeth & speech

Evolution of human masticatory system is not only related to diet and food processing techniques, but also brain size, bipedalism and speech (language).

Teeth & speech

- Speech & language need a flexible oral system
- This flexibility is maintained by providing processed & softened food, which does not require a strong musculoskeletal build and sharp teeth.
- Language enabled humans to coordinate their actions for providing food and increase the foraging ability of our species.
- human oropharyngeal system differed from other mammals for having communication as a dominant function
- speech is formed by the coordination in the functions of oropharynx, tongue, teeth and lips.
- supralaryngeal airway of humans was different from other mammals, with food following the same path with the air, which increased the risk of airway obstruction while eating by the falling of food into the larynx.
- chewing activity of humans was less efficient when compared to the other mammals and archaic hominids because of the reduced size of the palate and the mandible.
- reduction in the size of maxilla and mandible also lead to the crowding of the teeth and tooth impactions

Teeth & speech

- a larger cranial vault for a larger brain is maintained by the decrease in the size of the mouth
- bipedal posture required a smaller mouth for the arrangement of the center of gravity of human cranium
- Even though most primates, together with some hominins like the australopithecines, have powerful masticatory muscles, members of Homo tend to have smaller masticatory muscles
- masticatory apparatus of the hominin clade shifted towards gracilization accompanied by accelerated encephalization in early Homo

Teeth & speech

- a gene encoding the predominant myosin heavy chain (MYH) expressed in the masticatory muscles was inactivated by a mutation at the time of divergence between humans and chimpanzee:

** back to 2.4 Ma predating the appearance of modern human body size and emigration of Homo Sapiens from Africa

** The loss of this protein isoform resulted in size reductions in the muscle fibers and entire masticatory muscles

** It is believed that the cranial capacity increases as a result of this weakening of the muscles, relaxing the pressure on the sutures leading to larger encephalization

Conclusion

The evolution of human masticatory complex is strongly related to:

1. diet
2. use of tools
3. fire
4. Speech

‘has an important part in the human evolution’