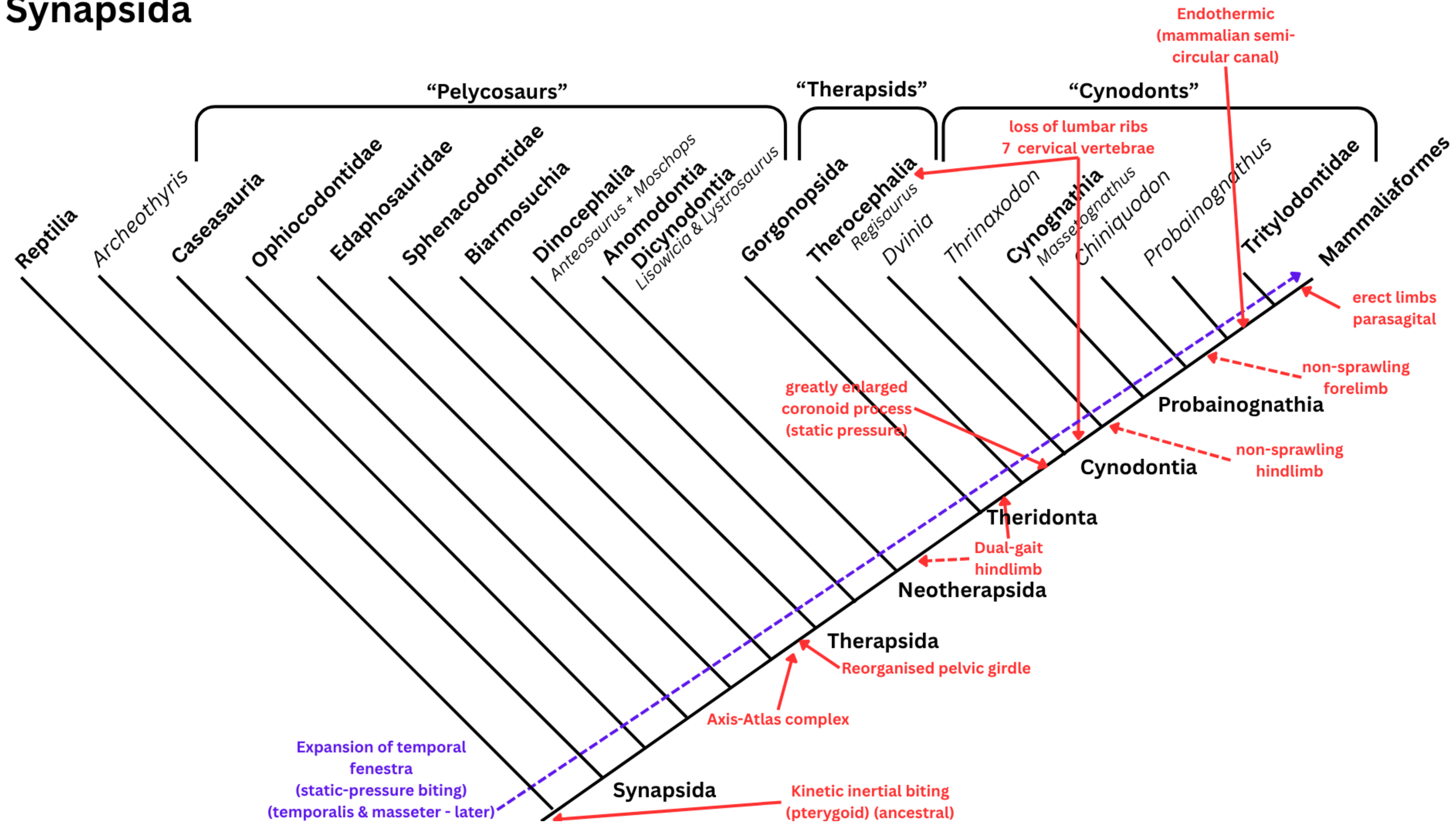
Synapsida



"Pelycosaurs"
"Therapsids"
"Cynodonts"
Reptilia
Archeothyris
Caseasauria
Ophiocodontidae
Edaphosauridae
Sphenacodontidae
Biarmosuchia
Dinocephalia
Anteosaurus + Moschops
Anomodontia
Dicynodontia
Lisowicia & Lystrosaurus
Gorgonopsida
Therocephalia
Regisaurus
Dvinia
Thrinaxodon
Cynognathia
Massetognathus
Chiniquodon
Probainognathus
Tritylodontidae
Mammaliaformes
Endothermic (mammalian semi-circular canal)
loss of lumbar ribs
7 cervical vertebrae
erect limbs parasagital
non-sprawling forelimb
Probainognathia
greatly enlarged coronoid process (static pressure)
non-sprawling hindlimb
Cynodontia
Theridonta
Dual-gait hindlimb
Neotherapsida
Therapsida
Reorganised pelvic girdle
Axis-Atlas complex
Expansion of temporal fenestra (static-pressure biting) (temporalis & masseter - later)
Synapsida
Kinetic inertial biting (pterygoid) (ancestral)

318Ma | Late Carboniferous (Pensylvanian) | 299 Ma | Early Permian | 270Ma

Archaeothyris (307)

Most Pelycosaurs (305-300)

Carboniferous Rainforest Collapse

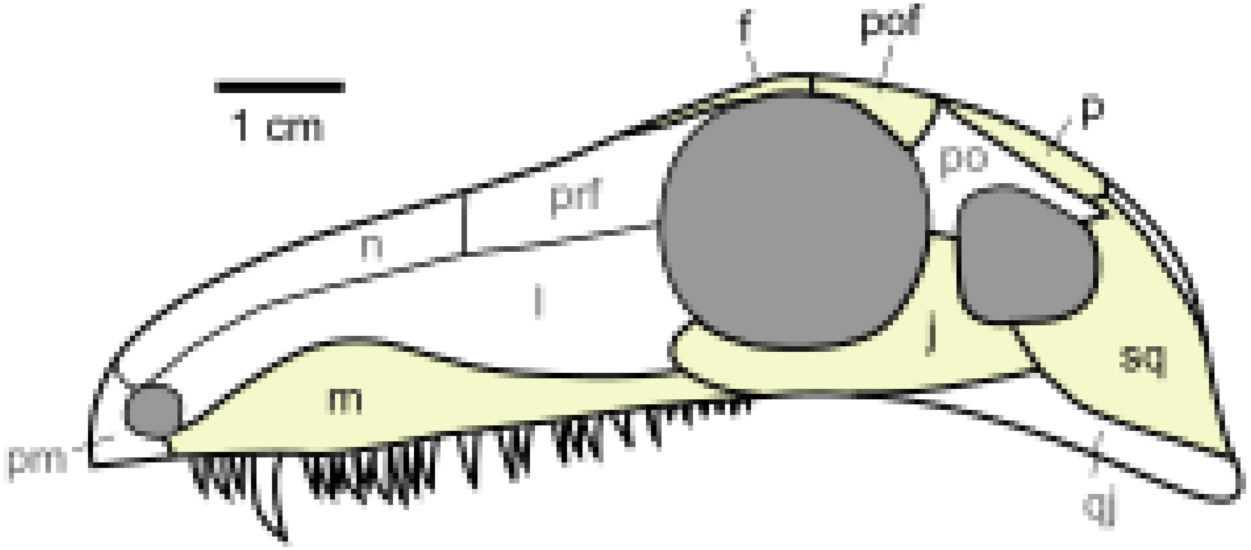
Olsen's Extinction (273)

"Pelycosaurs"

- Caseasauria
- Ophiocodontidae
- Edaphosauridae
- Sphenacodontia

Key Anatomical Traits

- 1 Temporal fenestra
- Sprawling posture
- Ectothermic



Early Permian 299Ma 271 Ma

Middle Permian 260 Ma

Late Permian 251Ma

Carboniferous Rainforest Collapse

Therapsids Appear (279)

Olsen's Extinction (273)

Capitanian ME (All Pelycosaurs & Dinocephalians Extinct)

Cynodonts Appear

End Permian ME (273)

Therapsida

- Biarmosuchidae
- Dinocephalia
- Anomodontia
- Gorgonopsia
- Therocephalia
- Cynodontia

Faunal Composition

Early Permian Fauna is dominated by Pelycosaurs

Middle-Late is dominated by Therapsids with:

- Anomodonts & Dinocephalians in the Middle
- Theriodonts & Dicynodonts in the Late

Key Anatomical traits and trends

- Slow transition from sprawling posture to parasagittal gaits (hindlimb first)
- Expansion of dentary in lower jaw
- Differentiated teeth (canines, incisors, postcanines)
- Transition to mesothermy and eventually endothermy

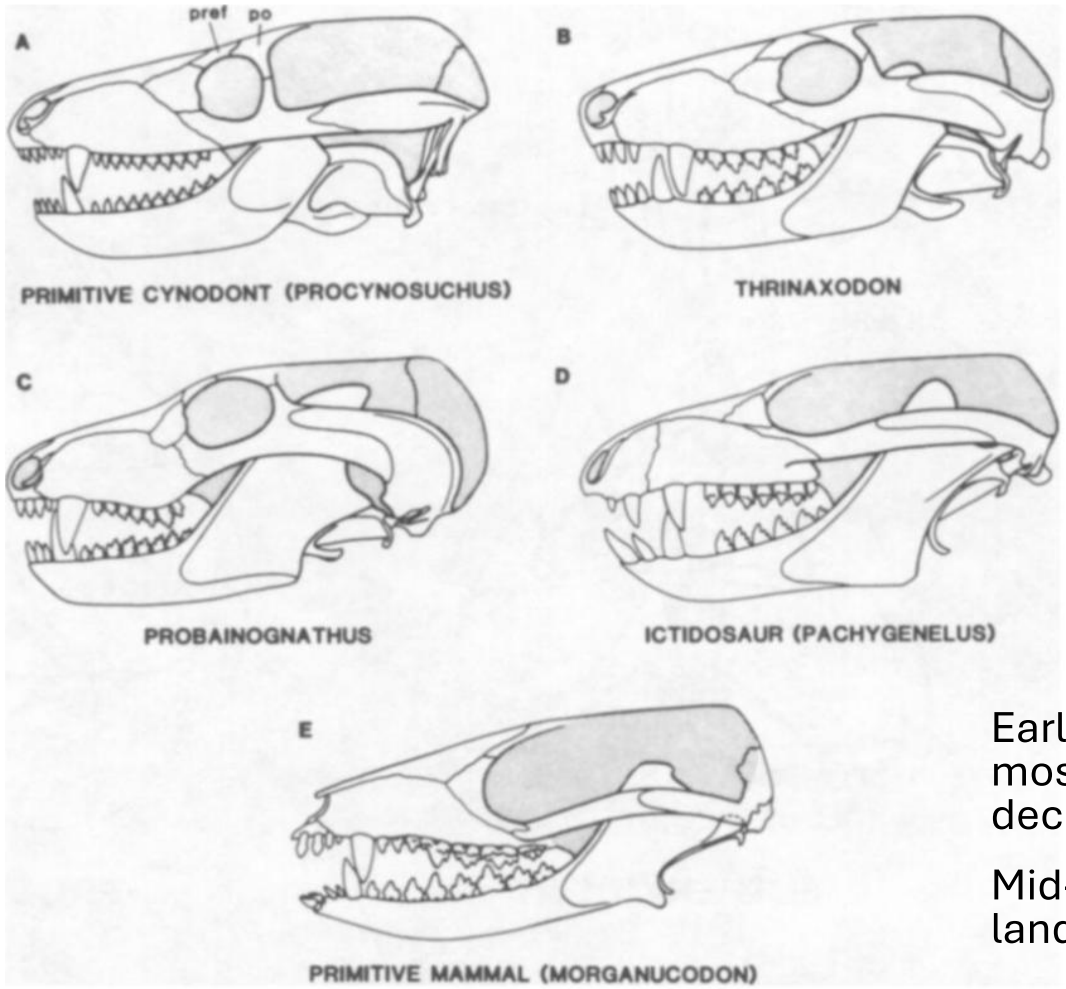
Late Permian	Early Triassic	Middle Triassic	Late Triassic
260Ma – 251 Ma	251 Ma – 247 Ma	247 Ma – 235 Ma	235 Ma – 201Ma

End Permian ME
Cynodonts,
Therocephalians,
Dicynodonts Survive

Carnian Pluvial Episode
Therocephalians
Extinct

Archosaur Dominance

End Triassic ME
Only Cynodonts
Survive



Key Anatomical traits and trends

- Dicynodonts, Therocephalians, Cynodonts all independently evolve endothermy and parasagittal gaits
- Cynodonts (particularly the Probainognathians) experienced a miniaturization trend
- Developed large cheek teeth and superficially rodent-like features as well as true endothermy (we think)

Cynodontia

- Early Cynodonts
- Cynognathia
- Probainognathia
- Tritylodontids (survive)
- Tritheledontids (survive)
- Mammaliaformes (survive)

Faunal Composition

Early Triassic - Dicynodonts (lystrosaurus) briefly most dominant species ever but Theriodonts in decline

Mid-Late Triassic – Archosaurs become dominant land animals until the end cretaceous (66MA)

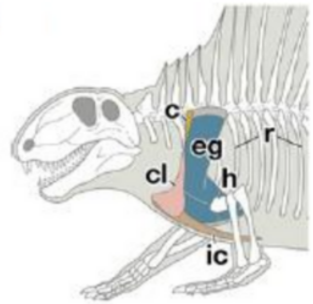
Front Limb

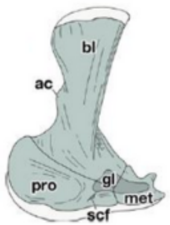
"Pelycosaurs"

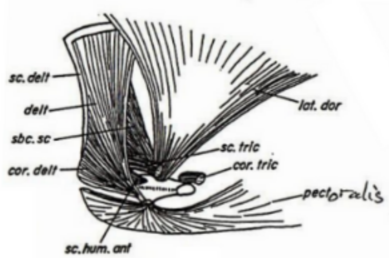
- Girdle suspended by serratus muscle
- Consisting of scapula, coracoids, clavicle, & interclavicle
- Screw-shaped genloid - automatic long-axis of humerus
- **Retractors** - latissimus dorsi & pectoralis
- **Protractors** - deltoids

Mammals

- Glenoid faces ventrally
- Protractors & Retractors are the same
- Rotator cuff muscles stabilise shoulder during movement
- Loss of coracoid (mobility) & scapula swing during stride







- bl = scapular blade
- cl = clavicle
- delt = deltoid
- gl = glenoid
- ic = interclavicle
- lat.dor = latissimus dorsi
- met, pro = metacoracoid, procoracoid

Locomotion

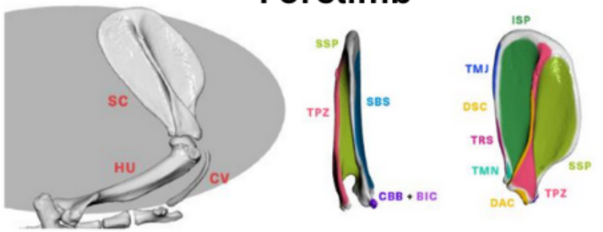
Hindlimb

- Hindlimb parasagittal first
- Dual gait in **gorgonopsians** & **therocephalians**
- Allowed by rotational joint between **calcaneum** and **astragalus**
- Dual gait lost in later **cynodonts**

Forelimb

- Retained for longer than sprawling hind limb
- Glenoid loses constraining bones generating screw shape
- Rearrangement of shoulder muscles to provide **active stability**
- Recently called into question by digital analysis of fore & hindlimb mobility in extant and extinct taxa - postulates **fully erect** posture in stem **therians**

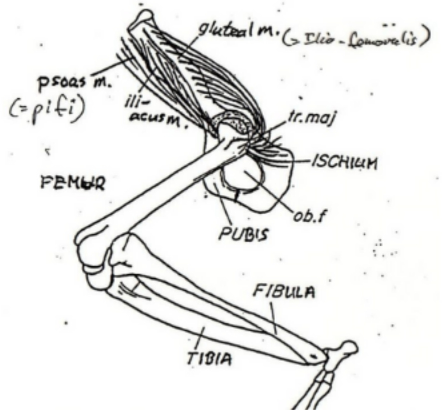
Forelimb



- SC = scapula
- HU = humerus
- CV = clavicle

- DSC, DAC = deltoid
- rotator cuff muscles:
  - ISP = infraspinatus
  - SSP = supraspinatus
  - SBS = subscapularis
  - TMN = teres minor

Hindlimb



Hind Limb

"Pelycosaurs" (old)

- **Caudofemoralis** - retraction/pronation of femur
- **iliofemoralis** - lifiting leg
- **puboischiofemoralis internus** - protract/supinate limb during swing

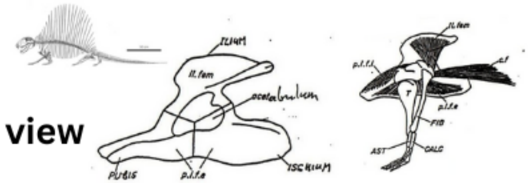
"Pelycosaurs" (new)

- **Puboischiotibialis** - main retractor/pronator

Mammals

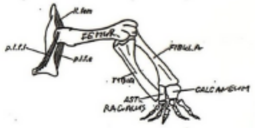
- **Gluteus** complex (iliofemorlaris + tibialis) - retraction
- **Iliopsoas** (puboischiofemoralis internus) - protractor
- **Gracilis** (pubuischiotibularis) - hip + knee flexion

Old view

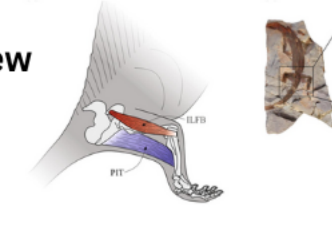


- c.f. = caudofemoralis
- il.fem = iliofemoralis
- p.i.f.i. = pubo-ischio-femoralis internus
- p.i.f.e. = pubo-ischio-femoralis externus

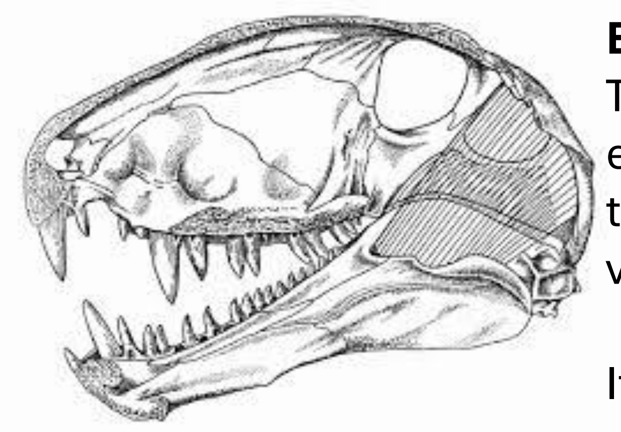
Kemp 2005



New view



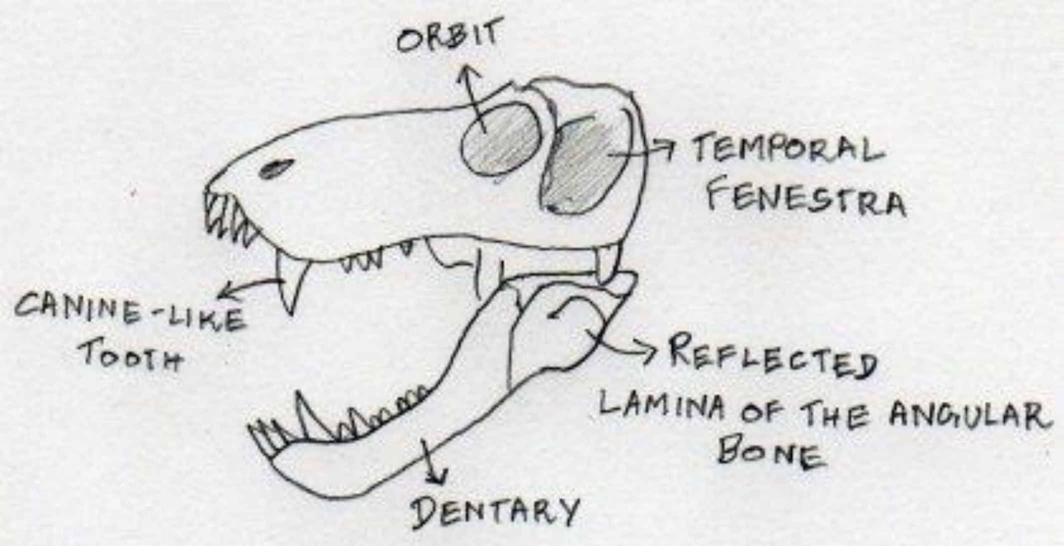
PIT = puboischiotibialis (=mammalian gracilis)
ILFB = iliofibularis



Evolution

This process was accompanied by the evolution and development of larger temporal fenestrae with more dorsal-ventral orientation.

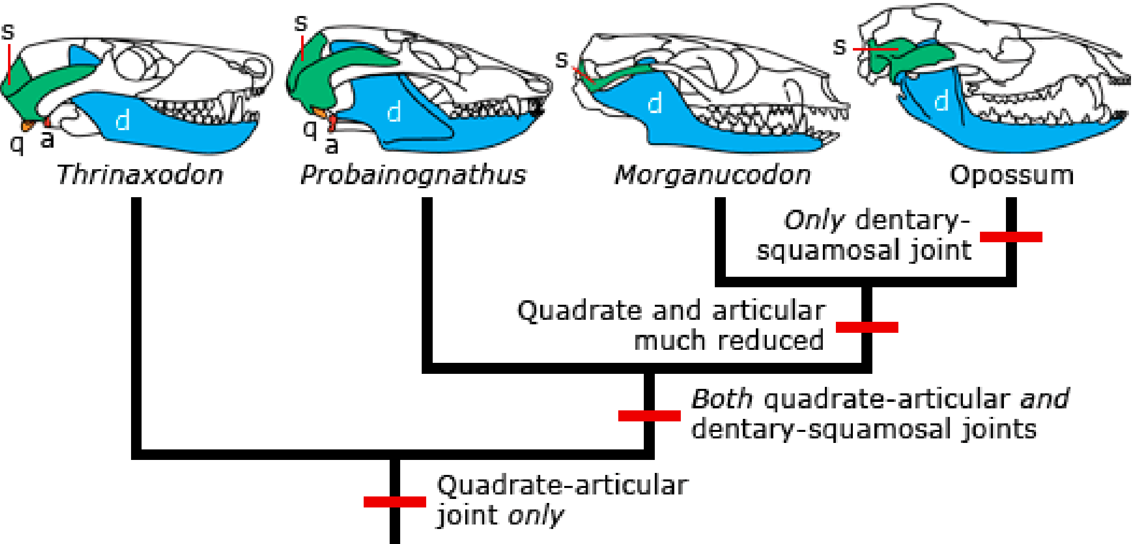
It was evolved likely due to a more varied diet (herbivory, omnivory, carnivory) that required constant pressure to be applied throughout the jaw. This change went hand in hand with heterodont tooth differentiation

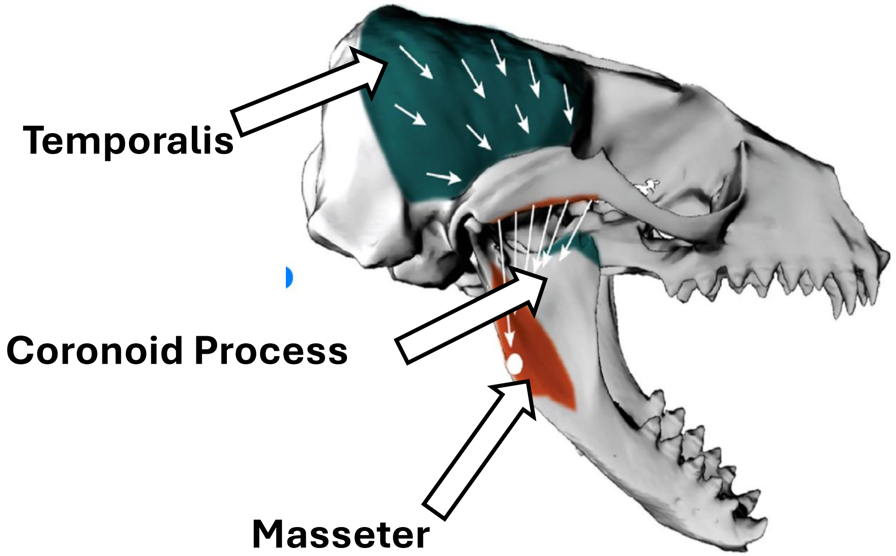


"Pelycosaur"
- Kinetic-inertial biting (pterygoid)
- Little to no coronoid process

Therapsid (Theriodont)
In-between biting style -
Beginnings of coronoid process -

Cynodonts
- Full transition to static pressure biting (temporalis & masseter)
- Enlarged coronoid process





DOI:10.1007/s10914-020-09524-7
Franco et al 2021

Other important notes on Anatomy

- Increased core flexibility by reduction of lumbar ribs
- This aids in dorso-ventral flexing of the spine during parasagittal locomotion.
- A parasagittal gait then also allows the breathing while locomoting and the eventual development of a diaphragm.
- Furthermore, the motion of the limbs was reduced towards a single plane (forwards and backwards) which would eventually allow the simplification of the ankle joints in more derived mammaliaformes

Thermoregulation-first model of endothermic evolution

(I think this is dumb personally)

Endothermic benefits only really reaped with many adaptations

Individual adaptations towards endothermy have negligible effects

No immediate benefit means no selection pressure

Evolution of individual endothermic traits or evolution of complete endothermy

Therefore

Individual endothermic adaptations must have evolved in a setting already reaping the benefits of endothermy without the adaptations present

"Pelycosaurs" were large and likely acted as inertial homeotherms

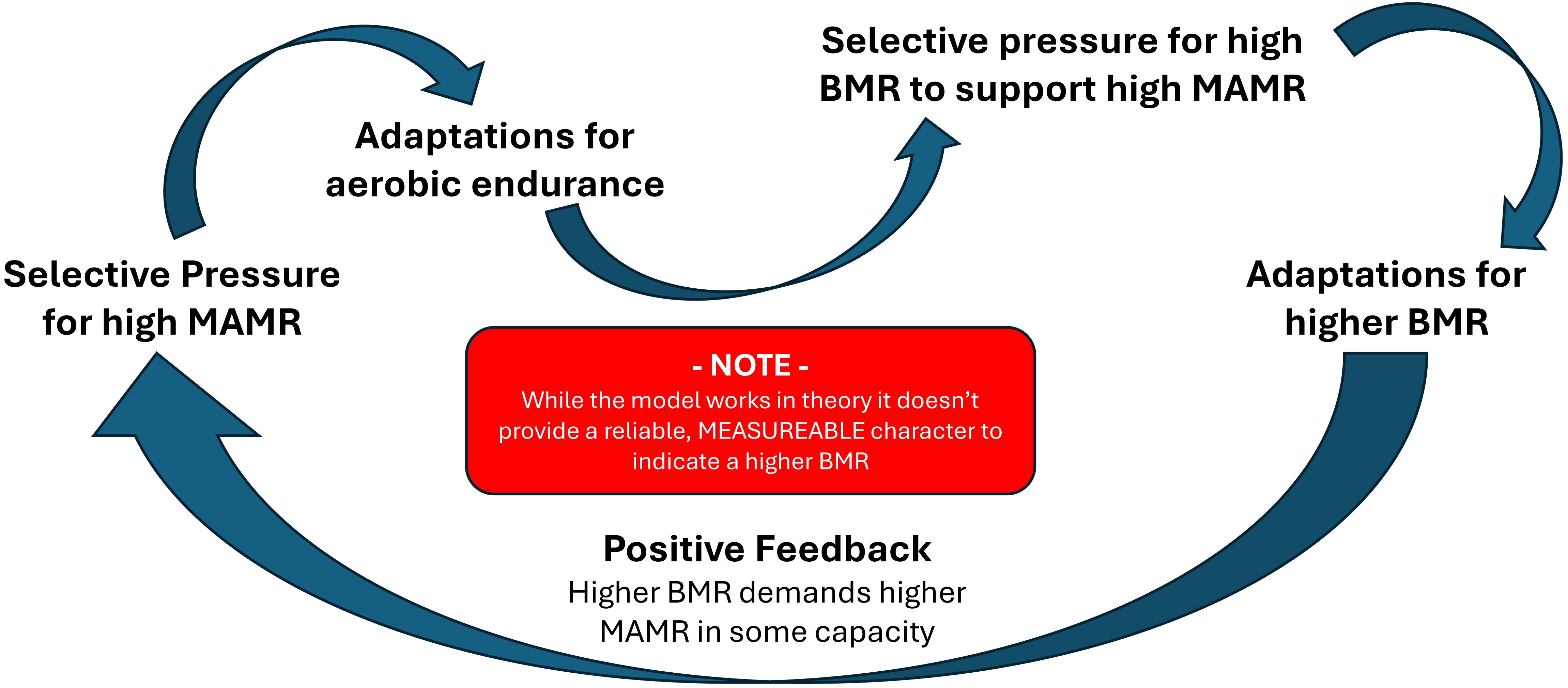
More derived synapsids to get smaller – losing their homeothermy

Selection acts to retain homeothermic benefits via endothermic adaptations

Selection for higher MAMR

Aerobic-first model of the evolution of endothermy

(Most likely in my opinion – see monitor lizards, archosaurs, & crocodilians)



Other notes about Endothermic Evolution

Mutual aerobic-thermoregulation hypothesis

- Is what is says on the tin
- Also dumb – runs into same problems as previous two but doesn't solve them, such as:

• No initial selection pressure on any trait
• Individual adaptations towards a higher MAMR or BMR are negligible
• Simultaneous evolution of both traits from the beginning is not supported by modern species.

- Importantly, it does suggest different timings for the evolution of endothermy itself.

Puzzling stuff and overall summary

• Often 1 trait associated with endothermy is accompanied by another associated with ectothermy, for example:

- Basal theriodonts having evidence of hair, nocturnality, and parasagittal gaits but are missing many physiological characters
- Morganucodon satisfies most endothermic indicators but likely had lifespans more in line with ecothermic animals of the same mass – **I disagree with this though**.

• Grigg et al. 2022 showed that mammal and bird thermogenic calcium uncoupling mechanisms are shared, pushing the origin of key endothermic adaptations to the crown amniotes – thus suggesting most amniotes are secondarily ectothermic.

- However, this doesn't do much other than push back the question/reasons for endothermic evolution to a more archaic set of animals.

• Overall, by the Triassic most surviving synapsids were on the way towards endothermy, if not already there – along with their rivals, the archosaurs.
• My take – endothermic evolution accelerated during the Triassic and was established by the mid Triassic due to the arms race between Archosaurs and Synapsids – read Benton 2021

Traits associated with a higher BMR

• Heterodont dentition & and static-pressure biting
• Secondary Palate
• Respiratory Turbinates
• Infraorbital canal
• Closure of parietal fontanelle
• Narrow semi-circular canals
• Size of the orbit/sclerotic ring
• Bone histology
• Bone microvascularisation
• O2 isotope ratios (this works better on reptiles)
• Parasagittal gait/loss of lumbar ribs
• Anterior vertebral column lateral/torsional flexibility

Phylogenetics Terms

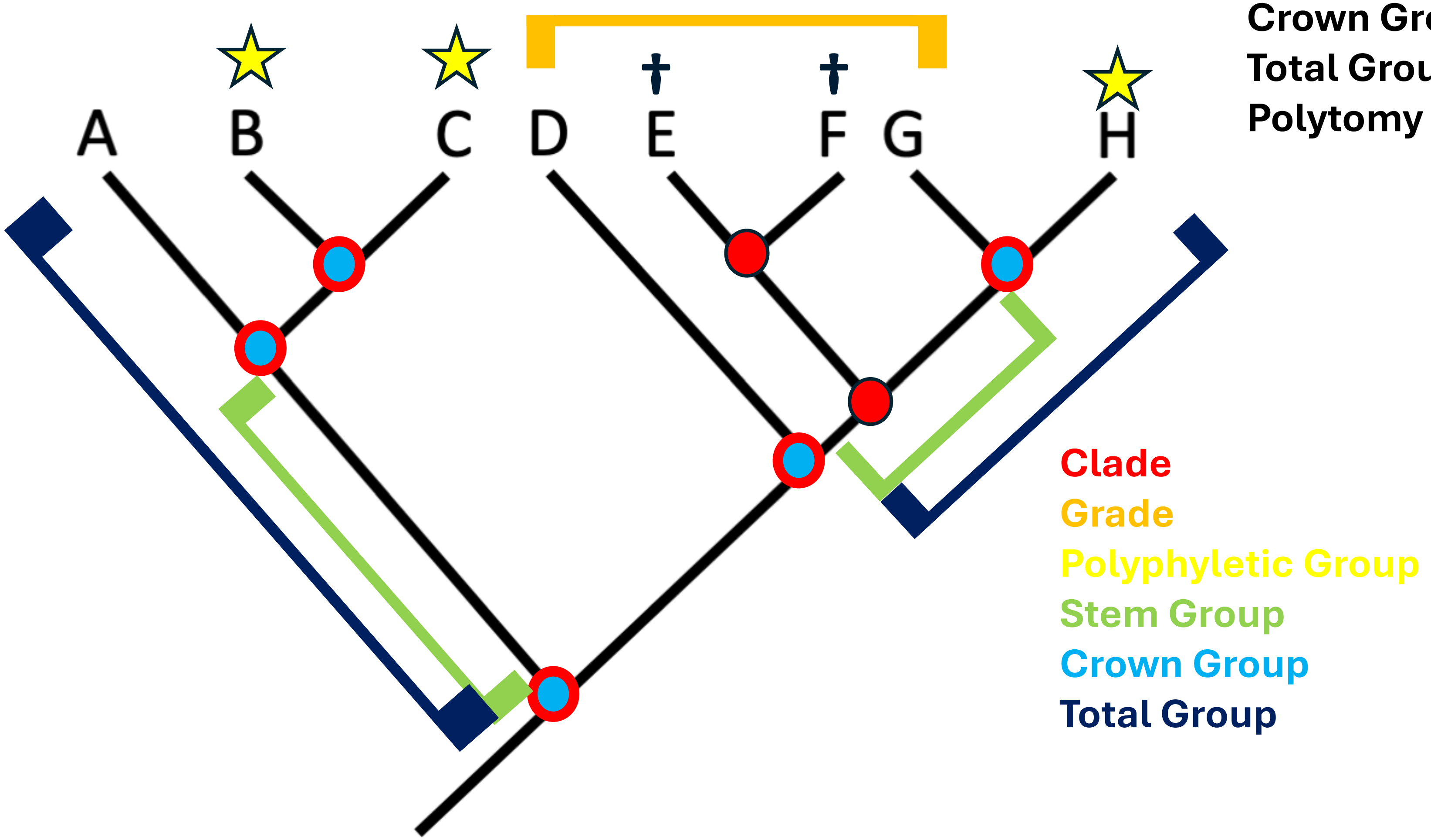
(Node-based) Clade – common ancestor of two organisms and all that ancestor's descendants
Apomorphic/Branch-based Clade – All of the descendants of a taxa more closely related to its descendants than to other close relatives – based upon an apomorphy
Paraphyletic Group/Grade – A group that includes taxa that share a common ancestor but not all of that common ancestor's descendants.
Polyphyletic Group – A group of taxa that do not all share the same common ancestor or close relatives/descendants but are united by another trait.

Crown Group/Clade – The common ancestor and all the descendants of two EXTANT taxa.
Stem Group/Grade – All of the EXTINCT taxa between the nodes of two crown groups.
Total Group/Clade – The crown and stem group combined/All taxa descended from a hypothetical last common ancestor more closely related to the crown group than any other group.
Polytomy – A node that has 3 or more branches extending due to mystery about the relationship between the subsequent clades – typically in taxa that had a rapid diversification event.

Common confusions:

- Yes, a crown group CAN include extinct animals
- Yes, a stem group CAN be included in a crown group
- Stem groups ONLY contain extinct taxa
- Crown groups HAVE to contain extant taxa

Examples



Clade (node-based) – Dinosauria or Therapsida
Clade (branch/apomorphy-based – Avialae or Mammaliaformes
Grade – "Pelycosaurs"
Polyphyletic Group – Mammals with Zalambodont dentition or old "Lipotyphla"
Stem Group – Non-mammalian Synapsids
Crown Group – Mammalia or Carnivora
Total Group – Synapsida
Polytomy – Dinosauria or Placentalia