ANKYLOSAURIA, WAYS TO BE AN HERBIVORE AND HOW TO WEIGH A DINOSAUR

I. ANKYLOSAURIA
A. Shared, derived characters of the main groups
Reminder: Ankylosaurs are ornithischian, thyreophoran, genesaurian, eurypods

Ankylosauria means fused or rigid reptile

Derived characters of Ankylosauria

- low skull
- loss of antorbital and upper temporal fenestrae (an evolutionary reversal)
- body armor fused to lower jaw
- long sacrum
- flaring blades on the ilium
- broadly arched ribs → wide gut cavity
- closed hip socket
- reduced pelvis
- dense dorsal shield of osteoderms, some modified to spines and/or tail clubs
- extreme reduction of pubis (non-functional)
- 4-5 fingers on forelimbs

General features
Encased in shell-like bony armor made of interlocking osteoderms that formed a continuous shield across the neck, throat, back, head, tail and often the cheeks – the most impressive of all dinosaurian armor; armor patterns and styles varied between species, genera, families, so ankylosaurs are easy to identify from scrappy material.

Bodies beneath the armor were flat and broad, housing large guts.
All had triangular-shaped teeth (like stegosaurs) for plucking and slicing plant material, Strong cheeks, some evidence of chewing (oral processors)
Rarely over 5 m long, with exceptions, e.g. Ankylosaurus (9 m long)
Probably weighed 3-4 tons
Fore limbs relatively short (like stegosaurs), with hindlimbs 2x the length of forelimbs

NODOSAURIDAE derived characters

- Narrow skulls
- Skull osteoderms large, few, and symmetrical
- Unique scute patterns around eyes
- More rigid armor and tails than ankylosaurids
- Spines in shoulder/neck region
- Ischium bent downward
- No tail clubs or 'horns' on skull
- 4 toes on fore limb

Key Genera:
- *Hylaeosaurus* (4 m), *Polacanthus, Sauropelta* (7m), *Panoplosaurus* (6m), *Edmontonia* (6m)
ANKYLOSAURIDAE derived characters
Very wide skulls covered with small, asymmetrical osteoderms
Eyes extremely posterior
‘horns’ at back of skull
Last three caudal vertebrae + osteoderms fused to make tail club (largest weighed 66 lbs.)
Tails bore relative light armor, for maximum flexibility
Secondary palate
3 toes on fore limb
Key Genera:
  Ankylosaurus (to 9m), Euplocephalus (to 7m), Pinacosaurus (5m)

B. When did ankylosaurs evolve?
Nodosaurids: mid-Jurassic to Late Cretaceous
Ankylosaurids: early to Late Cretaceous
Late Cretaceous marks time of greatest diversity and abundance for the clade

C. Where did ankylosaurs live?
Nodosaurids: North America, Europe, Australia, South America, Antarctica
Ankylosaurids: North America, Asia

D. Ankylosaur Lifestyles

1. HABITAT
In North America, unusual numbers of ankylosaur remains are found in shallow marine sediments, suggesting that they lived in coastal region; many are also found upside-down, suggesting a bloan’ float scenario for their pre-burial transport

Asian ankylosaurs are commonly found in sediments that represent semi-arid, inland environments (one mass accumulation in China contains 12 Pinacosaurus)

2. MOVEMENT
Amongst the slowest moving dinosaurs for their body weight
Walking speed 3-6 mpg (equivalent to a slow to fast human walk)
Several trackways (e.g. from Canada) allow velocity estimates and show that ankylos walked full erect (no squatting)

3. FOOD AND EATING
Ankylos were browsers, like stegosaurs (probably restricted to vegetation 2 m high or lower)
Had beak in front of heads for slicing plants; nodosaurs had narrow beaks and were probably selective feeders; ankylosaurs had broader beaks and were probably generalists
All had long, flexible tongues, as evidenced by large hyoid bones
All had weak teeth, like stegosaurs
Jaws were large and strong, so ankylos were probably better able to gather and maybe process food than stegosaurs
Ankylosaurs used gut fermentation to digest their food; evidence = very broad hips and massive rear guts
Gastroliths found with a few specimens

4. THERMOREGULATION
Bulk meant no need to warm up, but perhaps needed mechanisms to cool down
Large surface:volume ratio
Turbinates to exchange heat and recapture water?

5. DEFENSIVE BEHAVIOR
Passive defense - Hunkering down
Some armor also had vascular grooves – maybe thermoregulator or maybe to allow ankylosaurs to blush to warn off attackers

6. OFFENSIVE BEHAVIOR
Shoulder spines (nodosaurids) could ward off potential attackers or wielded (shoulders very strongly muscles)
Tail clubs (ankylosaurids): fore part flexible, rear parts rigid
May have included intra-specific combat between males

7. BRAINS
Encephalization quotients low like stegosaurs

8. HISTORY
_Hylaesaurus_ the first-discovered ankylosaur (and the third-discovered dinosaur); at first only front-end of skeleton known
First discovered in the US in late 1880s
Discovered in Mongolia in the 1920s (by American Museum of Natural History expedition)

II. HERBIVORY IN VERTEBRATE ANIMALS
Animals can't break down _cellulose & lignin_, structural components of plants.

Two ways to be an herbivore
Small and picky. Avoid cellulose-rich plant parts, eat nutrient-rich plant parts (fruits & nuts).
  Only enough high nutrient food to support small animals.
  Shift from small carnivore/insectivore to herbivore feeding on high nutrient plant parts.
  EX: Dikdiks, fruit bats. Some get gut floras, get larger and eat poorer food (Apes)

Big and indiscriminate. Eat everything that you can. Pack your gut with microbes to ferment low quality food. Must be large to fit massive gut.
  Shift from large carnivore/omnivore to big, fermenting, herbivore
  EX: Rhinos and hippos. Some specialize teeth and guts, can get small (small antelopes).

What did dinosaurs do?
III. HOW DO YOU WEIGH A DINOSAUR?
Scale replica approach (water displacement) is very subjective.

There is a regular relationship between the weight of an animal and the cross-sectional area of its legs. This relationship has been developed for modern animals, using animals that range in size from shrews to elephants.

In general: **Mass** is proportional to **Leg area**\(^{2.75}\)
The specific relationship differs for bipedal and quadrupedal animals.

**Typical weights derived using this method in metric tons (=1000 kilograms):**
- Big Theropods (e.g., Allosaurus, Tyrannosaurus): 2 - 7 tons
- Sauropods (e.g., Diplodocus, Apatosaurus, etc.): 6 - 50 tons, biggest ~180 tons
- Ornithopods (e.g., Iguanodon): ~5 tons
- Stegosaurus: 2 - 3 tons
- Big Ceratopsians (e.g., Triceratops): 4 - 6 tons

**Why does this relationship exist? Why is getting larger "stressful"?**
As animals get big, their weight increases dramatically.
Imagine 4 animals, all with the same shape, but of different sizes.
The animals have cubic bodies, and 4 rectangular legs (only 1 leg is drawn).
**Animal A** has a side of length 1, and a leg width/length of 0.1 (pick whatever units you want).

![Diagram showing animals A to D with 1x, 2x, 4x, and 10x scales]

Animal weight is determined by the volume of the body. Animal volume increases as length raised to the power of 3. Although animal **D** is only 10x bigger than animal **A** in linear dimensions, it weighs 1000x more.

\[
\begin{align*}
A & : 1^3 = 1 \\
B & : 2^3 = 8 \\
C & : 4^3 = 64 \\
D & : 10^3 = 1000
\end{align*}
\]

**Stress**, the pressure on the legs, increases with volume.
**Stress** = (Mass x gravity)/unit area = (Volume x density x gravity)/unit area
Strength is the stress required to break an object (such as a leg). Strength depends on cross-sectional area of the objects resisting stress. In other words, the total strength of your legs is proportional to their combined cross-sectional area (best calculated at their narrowest point). The increase in leg strength with size for our box animals is easily calculated.

Strength = Combined Cross sectional area of 4 legs

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<th>A</th>
<th>B</th>
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<tbody>
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<td>4(0.1²)=0.04</td>
<td>4(0.2²)=0.16</td>
<td>4(0.4²)=0.64</td>
<td>4(1.0²)=4</td>
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Stress increases much faster than Strength if shape is constant.

Ratio of Strength (length²) to Stress (length³)

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If size increases without a change in shape, stress on legs will quickly outpace strength.

Suppose legs of animal A are 10x stronger than needed to support its weight. For animal D, strength/stress ratio is 10x lower than in animal A. The legs of D would snap under gravity.

How to get large without breaking

- Live in water. Originally proposed for sauropods. WRONG.
- Don't maintain shape. Increase cross-sectional area of legs disproportionately.
- Keep your legs straight. Most breaks occur during bending, not vertical loading.
- Big living animals like elephants don't bend their legs much when walking.