

Ape to Human 03/05/08

Human Hips: Quadrupedal to Bipedal Locomotion

Follow up in Textbook: pp. 314-315;
346; 380-381

A) Objective:

To identify the features of the human appendicular system that represent re-engineering of the primate quadrupedal stance to accommodate a bipedal posture.

B) Preparation:

Work in your seminar teams. The exercise should be self-sufficient, and the Textbook need not accompany the laboratory. However, follow up in the Textbook is advisable.

C) Introduction:

One of the most distinctive features of humans, compared to most other animals, and even compared to other primates, is the human ability to walk upright, comfortably for prolonged periods on two hindlegs. The condition, *bipedal locomotion*, is a derived state from *quadrupedal locomotion*, four-footed locomotion of ancestors. Many dinosaurs were bipedal, but these retained a long tail balancing the weight of the upper body across the hips. No such tail is present in humans. This means that the mass of the upper body is projected above the hips, a precarious position to balance this weight on only two legs, one leg when in mid stride. Without a large tail, a different engineering solution was required to accommodate the upright posture in humans. Adjustments in the musculoskeletal system from feet to neck were involved. Here, we will concentrate only on the hips.

D) Preparation & Procedures:

Exercise 1: Basic Steps

To appreciate the mechanical problems a bipedal consider the consequences of lifting a quadrupedal animal into a bipedal posture (Figure 1). One of many resulting problems is the development of

unfavorable lines of muscle action between legs and hip. Arrows indicate lines of action of major muscles that move the femur and open circles (o) show their points of origin. When upright, the same muscles cannot move the femur because the shifting origins place their lines of action on the wrong side of the bone. Also, the center of mass of the upper body (solid box) is out of line with the supporting femur, positioned posterior to it tending to tip the body backwards.

As a consequence of these, and other unfavorable mechanical changes, the human hip has been re-engineered to better accommodate a bipedal stance. In Figure 2, the primate (quadruped) and human (bipedal) postures are schematically illustrated. One hypothesis suggests that the transition from quadrupedal to bipedal pelvis occurred in four major steps (Figure 3). First, the quadrupedal pelvic girdle is partly uplifted (a), then coned out in front (b), and a lumbar curve is added (c). To complete the redesign, the sacrum is drawn back to position body mass above the acetabulum, hip socket (d) and the ilium shortened to make the gluteal fan more compact (e).

Exercise 2: Walking Striding Gait

When a human walks or runs, only a single leg momentarily supports the weight of the upper body in mid-stride. This means that the hip on the side of the raised leg, tends to fall, rotating about the acetabulum on the opposite supported side.

How is this accommodated? The large buttocks muscles present in humans are the answer. When in mid-stride, with one leg off the ground and swinging forward, the buttock muscles of the opposite side contract to counter this tendency to fall. The buttock muscles are the *gluteal muscles*, three in number, the gluteus minimus, gluteus medius, and the gluteus maximus. Confirm action of these muscles for yourself. If you are sitting, stand up and leisurely walk across the room holding yourself in good upright posture. Place your hands on your butt (gluteus maximus) and continue striding slowly across the room. Note that contraction of the gluteus maximus occurs opposite to the leg off the ground. Try again. Right?

Now walk and feel, but tip your body slightly forward. This muscle contracts more vigorously. It is not only involved in preventing rotation of the hips, but helps hold this slanted posture.

A similar demonstration is even more convincing using your fingers to detect contractions of the gluteus medius. Find the top of your ilium, the edge just at the sides of your body. Now walk across the room with your finger tips just below this crest of the ilium. You should be able to feel these muscles contract when the opposite leg is off the ground.

Exercise 3: Gluteal Fan

From various postures of walking, running, carrying, leaning, and standing, the gluteal muscles must resist hip tilting. They can meet the various demands by being spread, fan-shaped, out along the ilium of the hips. This gives them the greatest number of angles of action to match these various functional demands. The ilial crest provides the site of origin of these gluteal muscles. In the tall ape hip, the ilium is lengthened. If it were to provide for the origin of these fanned muscles, it would have to be very broad, occupying much space in the body. But shortened, the ilium could be broad enough to offer sites of origin for gluteal muscles and yet give the wide, fan-shaped orientation (Figure 4).

Exercise 4: Birth Canal

One irregular trend within hominids was for the enlargement of the brain. In turn, this meant that the birth canal within the hips had to accommodate the relatively larger head of the infant during parturition. But, this eventually produced a problem. As the birth canal evolved even wider, the surrounding hips holding the acetabula moved farther apart. As a consequence, the mechanical advantage of swinging the legs was compromised. This can be illustrated in the hips of an early hominid, *Australopithecus africanus* (“Lucy”) and modern *Homo sapiens*, Figure 5.

During a striding gait, one leg is momentarily off the ground. Consequently, the weight of the upper body is supported on the head of the opposite femur, which acts like a fulcrum (Figure 5a). Contraction of the gluteal muscles lateral to this femur tends to counteract this through its lever arm to the fulcrum. In *A. africanus*, the lever arm through which the gluteal muscle acts is relatively long, thereby improving its mechanical advantage in accommodating the weight of the body. However, in modern humans, the head of the femur is short, producing a short lever arm through which the gluteal muscles act (Figure 5b).

E) Synthesis:

- 1) What is the functional significance of large gluteal muscles in humans?
- 2) What is the functional significance of a wide, but shortened ilium in humans?

Acknowledgments. Most ideas above are based on the research of Dr. G. Krantz (personal communication, and in *Evolutionary Theory*, 1981).

References

Krantz, G. S. 1981. The process of human evolution. Schenkman Publishing Co. Cambridge, Massachusetts.

Lovejoy, C. Owen. 1988. *Scientific American* (November). -125.

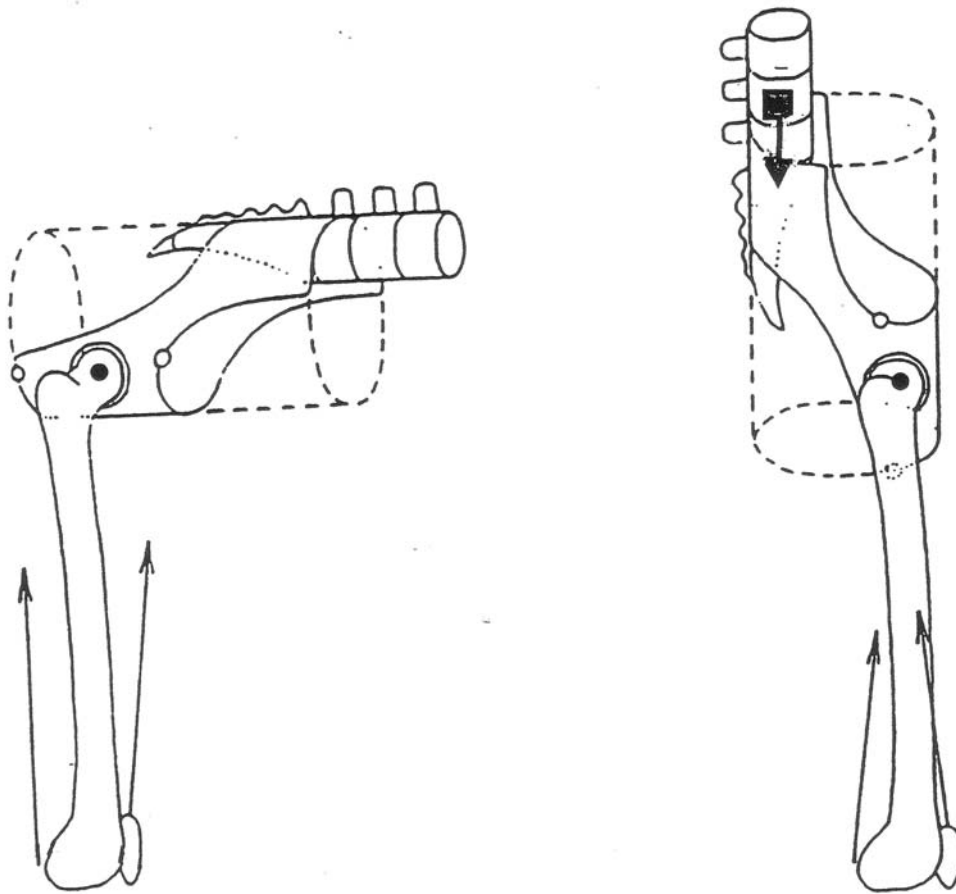


Figure 1. Quadruped to Biped. The pelvis, basically a cylinder connecting the sacrum to the femurs, is shown, leaving the central opening to viscera. The line of action of major muscles (arrows) that move the femur are indicated, together with their points of origin on the pelvis (open circles). Lifting a quadrupedal (left) to an upright stance (right) produces unfavorable lines of action of these muscles. Further, the center of mass (solid square) is rotated to a position well behind the acetabulum (solid circle) where the femur rotates on the hip, tending the body to lean backwards.

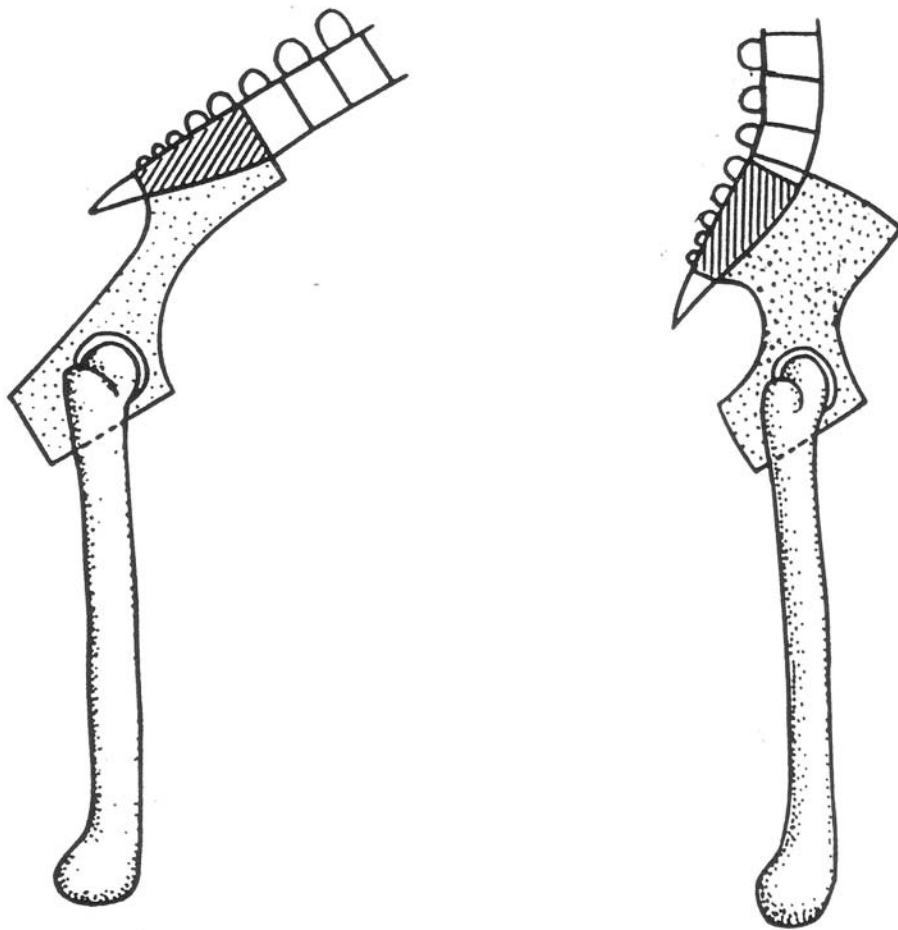
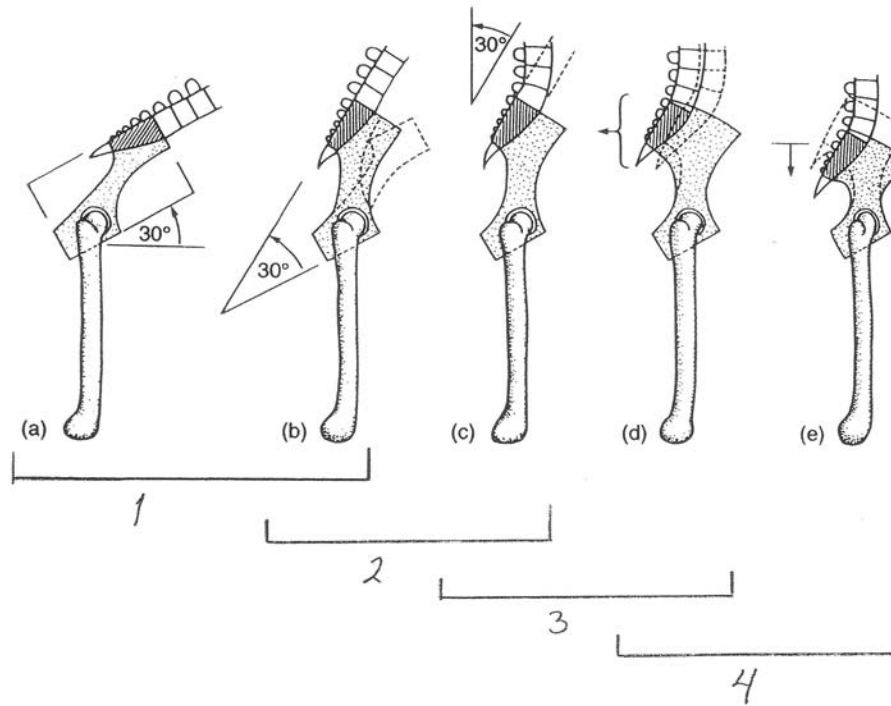


Figure 2. Ape to Human Pelvis. The ape pelvis, and orientation, are indicated at the left; human pelvis at the right. Considerable redesign of the hips has occurred.

Human Engineering



Human bipedal posture. Compared with quadrupedal primates (a), human upright posture is engineered by changes in the slant of the pelvic girdle (b), increased curvature in the lower back (c), broadening (d), and then shortening of the hips (e).

Based on the research of G. Krantz.

Figure 3. Human bipedal posture.

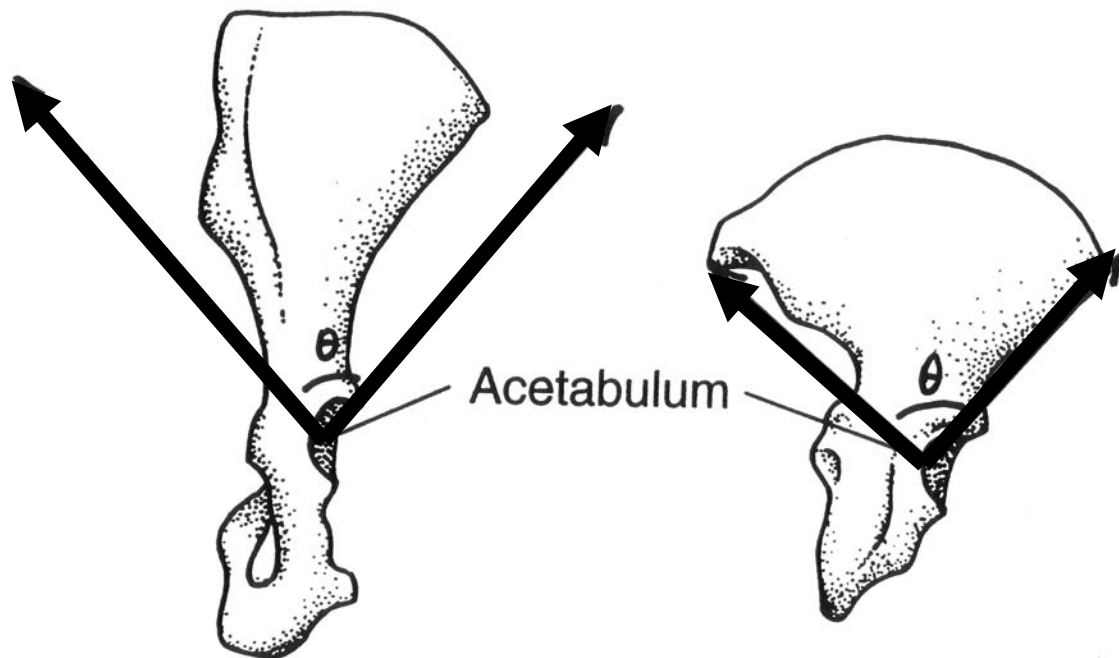


Figure 4. Gluteal Fan. Chimp (left) and human (right) hips are drawn to similar scales, but note the tall ilium of the chimp. The gluteal muscles act to prevent hip tilting during striding gait as well as during other activities. To do so, their lines of action are broadly spread through an angle (θ) equal in both hips. To accommodate this same spread, the tall chimp ilium would have to be very wide. The human hip accommodates this by shortening of the ilium, yet it maintains the angle of fanning of the gluteal muscles.

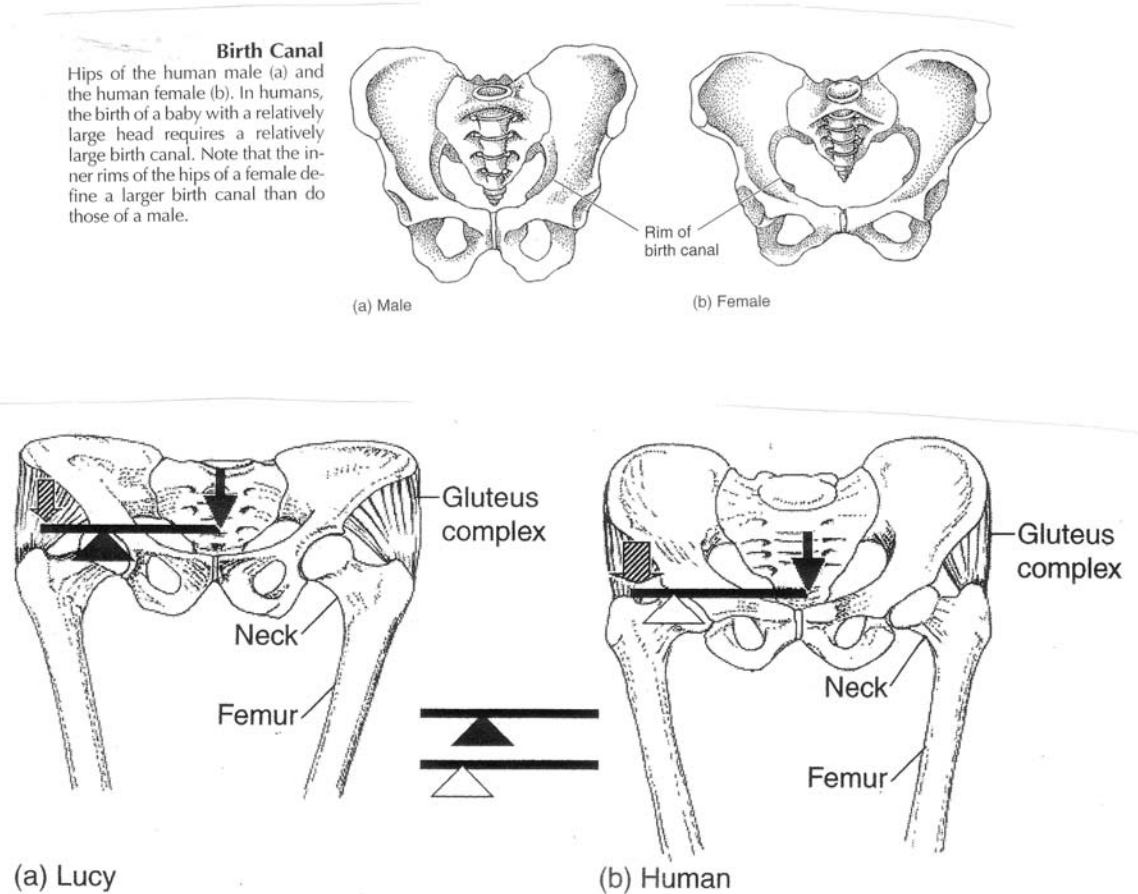


Figure 5. Gluteal muscle lever arms. *Australopithecus africanus* (left) and *Homo sapiens* (right). During a striding gait, the weight of the upper body (solid vertical arrow) tends to rotate the hip about the fulcrum formed with the head of the opposite femur (solid triangle). The gluteal muscles resist this through their lever arm. This gluteal lever arm in *A. africanus* is longer, providing a mechanical advantage over the shorter lever arm of humans. This results from a compromise. The wider birth canal of humans is accommodated by a shorter femoral neck, but the result is a less favorable mechanical advantage.

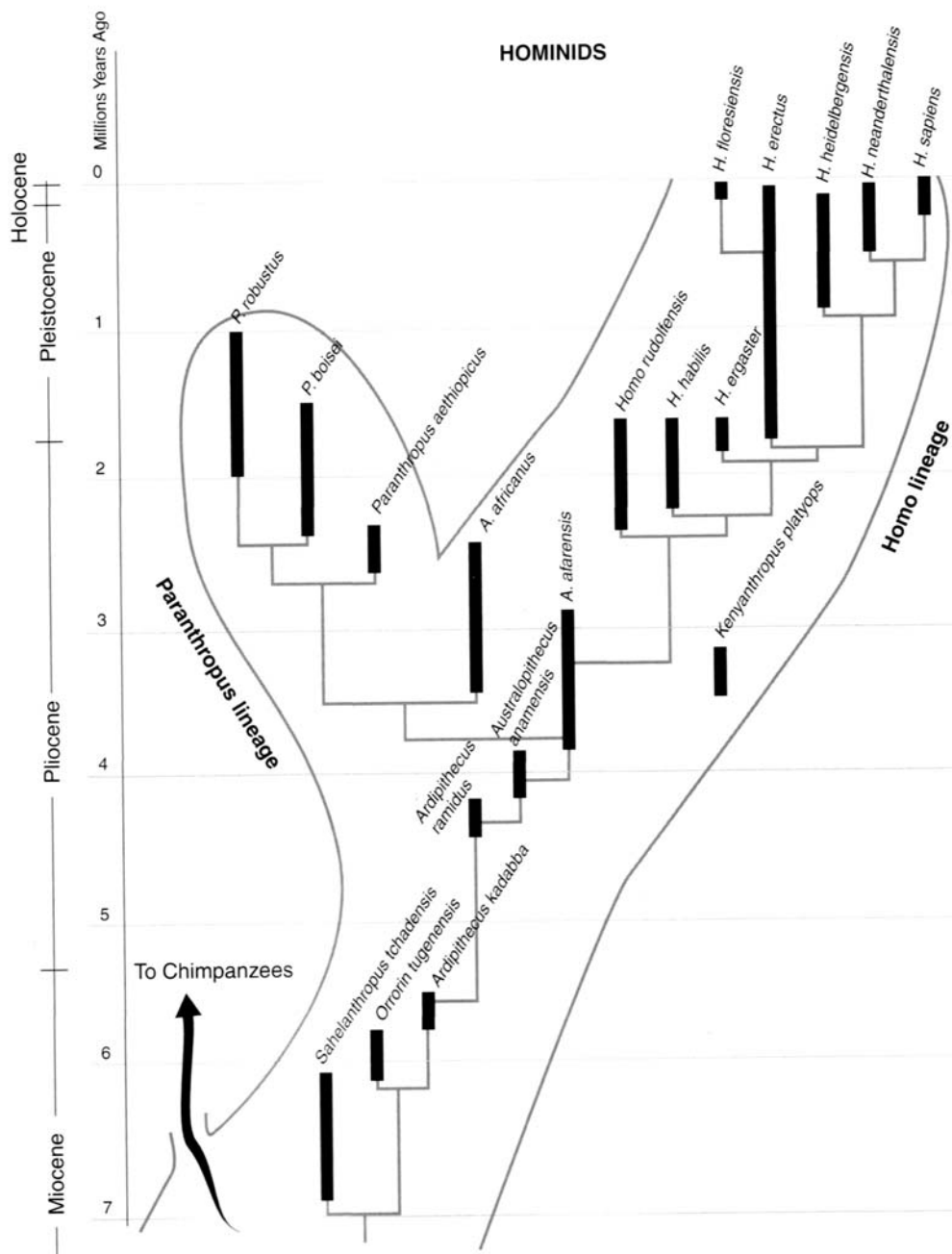


Figure 6 Hominid Relationships Hominids generally evolved in two directions—in a “paranthropus” line that became extinct about 1 million years ago, and in the “homo” line that continues down to modern *Homo sapiens*.

Captions

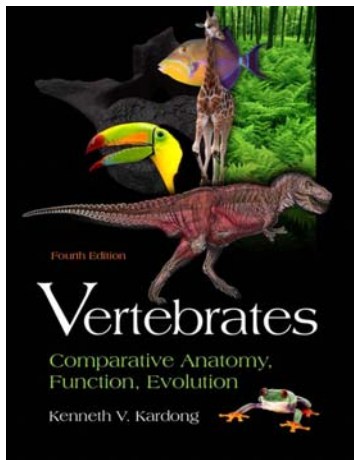
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Instructor's Manual

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Purpose: Analysis of Vertebrate Architecture

Background:

The purpose of this exercise is to present students with a problem in vertebrate architecture. The human hips are substantially remodeled from those of primate ancestors. The reasons are related to the evolution of our upright posture, bipedal locomotion, from the quadrupedal locomotion of primate ancestors. Producing bipedal posture entails much more than just standing an ancestor upright. Doing so creates a set of functional problems that were solved by re-engineering of the hips. This exercise takes students through these problems and draws their attention to the solutions engendered in the human hip.

Related Issues:

In addition to the hip, the human bipedal stance required re-engineering of other parts of the human musculoskeletal system. (See pp. 314-315; 346). Some dinosaurs, birds, and other vertebrates are bipedal, but the engineering solutions are different. For example, in bipedal dinosaurs, a large and massive tail provides a counter weight to the thorax, balancing the upper body across the acetabulum. In humans, no such solution involving a massive tail evolved.

Approach: Active participation of the students in the exercises will lead them through this analysis. The “grab your butt” part should help them make friends, especially if they work in groups. Measuring the lever arms of *Australopithecus africanus* versus *Homo sapiens* will drive home the point, especially if similar lever arm analysis has been done in earlier labs.

Materials: The lab should be stand alone as presented. However, you may wish to bring in hips of humans for comparison to other vertebrates. Human hips, in plastic, are available from most biological supply houses.

Synthesis:

What is the functional significance of large gluteal muscles in humans?

The gluteal muscles generally run from the crest of the ilium to the trochanter of the femur, thereby exerting control over pelvis displacements. Specifically, during striding gait gluteal muscles (especially the maximus), opposite to the side where the limb is lifted, contract to prevent the pelvis from dropping when the leg leaves the ground. Further, when we tip our thorax forward above the hips gluteal muscles contract to hold our posture by controlling pelvis rotation.

What is the functional significance of a wide, but shortened ilium in humans?

When facilitating this question, be sure students address both features of the human ilium—broad and shortened.

The ilium is **broad** to provide the gluteal fan many lines of action to permit many ranges of rotation of the pelvis on the head of the femur. The broad ilium also offers a wide base of support at the hips for stabilizing the thorax above. The ilium is **shortened** (relative to other primates) to bring the base of the vertebral column (sacrum) closer to its eventual support on the head of the femur. Further, if the ilium were not shortened but offered the same broad platform of attachment for the gluteal fan, it would become a huge and likely encumbering bony fan in the pelvis.