EVOLUTION OF THE HUMAN PELVIS

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Received 12 January 1996, 18 February 1997

ABSTRACT: The transition from a quadrupedal pelvis into the bipedal, human design is described here in simple, biomechanical terms. The pelvic cylinder is partly uplifted from the horizontal, coned out in front, and a lumbar curve is added to complete the trunkal erection. The sacrum is drawn back to position body weight above the acetabulum and to provide a gluteal fan; the ilium is shortened to avoid making that fan too large. The sacrum is broadened in order to direct weight transmission more vertically. Intermediate designs in human evolution involved less lumbar curvature, but provided a narrower gluteal fan that would have inhibited walking with the body leaning far back or forward.

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INTRODUCTION

The human pelvic design is illustrated and discussed in almost every work that deals with hominid evolution. It is contrasted with the pelvic design found in quadrupeds in general and apes in particular. However, a comprehensive description of the reasons for our total pelvic design does not appear in any of these works. What we find are mainly discussions of fossil specimens where particular pelvic parts are compared. What we lack in the literature are clear answers to questions like the following:

1. Why is the human ilium so "broad" from front to back?
2. Why do we have a lumbar curve?
3. Why is our ilium vertically so short?
4. Why is our sacrum so broad?
5. Why has our acetabulum moved toward the front of the pelvis?

And, in my opinion, there are inadequate explanations for our deep sciatic notches and short ischia. Le Gros Clark (1959 and 1967) described most of these pelvic traits and discussed their significance in contrast to those of quadrupeds, but he did not propose a biomechanical model that would fully account for their functions and origins. Campbell (1985) also addressed this anatomy in some detail, but again without providing us with anything like a comprehensive model. Many other authors have similarly dealt with technical aspects of this anatomy without combining them in an interrelated pattern. Accurate description with intelligent discussion does not necessarily constitute an explanation.

What appears here is a biomechanical description of the ape-to-human pelvic transition, largely as given in my 1981 book (which went unnoticed), and slightly modified as of its 1990 revision (privately printed as a textbook). This is then followed by a similar description of the actual australopithecine and Neandertal pelvic designs from my unpublished 1990 revision. Functional explanations are offered for all of these designs. All of the information given here, except as otherwise cited, is from these two sources or else is original in this writing.

This presentation is directed toward two readerships--to researchers in human anatomy,

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Evolutionary Theory 11: 255-272 (August, 1997)
The editors thank M. Stoller and another referee for help in evaluating this paper.

and to anthropologists without this kind of specialization. For anatomists this is a model to be further tested and refined, and compared with new discoveries of pertinent fossils. For other anthropologists this is a clear model of pelvic evolution that is otherwise very difficult for them to visualize, let alone explain to students. In order to facilitate the latter goal, I have tried to keep my terminology as close to simple English as possible. This analysis is not a summary of detailed studies, but rather is a theoretical model intended for visual comprehension.

FROM QUADRUPED TO HUMAN

Quadrupeds and humans both stand with their hind limbs vertically oriented. We, however, elevate our torso by 90° to put it in line with these legs instead of at a right angle to them. Given the ball-and-socket joint of the hip, it would seem at first glance there should be no problem simply to rotate the pelvis (and trunk) up from a horizontal to a vertical orientation. This does not work very well because the pelvic muscles that move the femur forward and backward in walking would have their relationships so changed as to become largely ineffective for these actions. Those quadrupeds who do manage bipedal walking maintain some flexion at the hip and they progress less efficiently than they do on all fours. It is one thing to take a few steps on two feet; it is quite something else to put on boots and a backpack, and hike 20 miles.

The propulsive relationships in the hips can be visualized by treating the quadrupedal pelvis as a horizontal cylinder with the vertebral column being incorporated along the top, and with the legs extending down from its sides (Fig. 1). The lower front partof this cylinder is cut away as not essential, and also the upper rear part can be omitted. This, with minor modifica-tions, is the basic design of the quadrupedal pelvic girdle. (See Hooton,1946, for some of this basic concept; what follows is largely original here.)

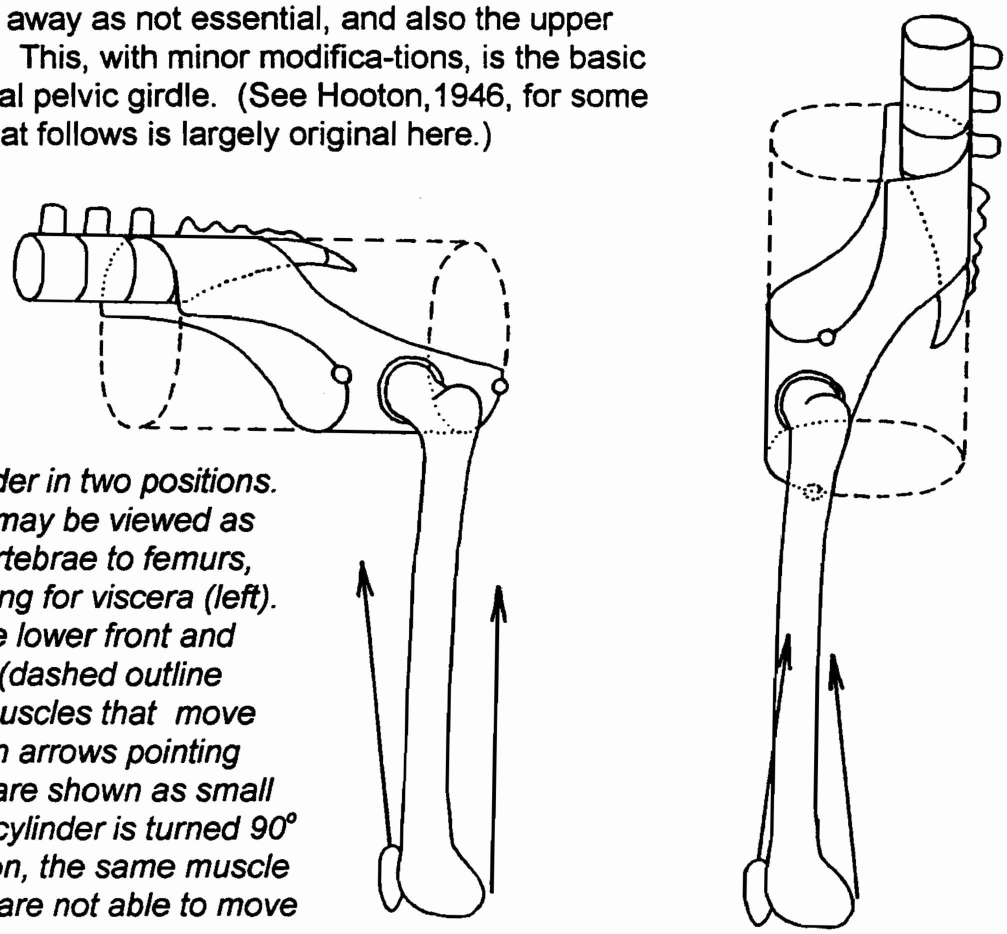


FIGURE. 1. *Pelvic cylinder in two positions. The quadrupedal pelvis may be viewed as a cylinder connecting vertebrae to femurs, leaving the central opening for viscera (left). Unnecessary parts of the lower front and upper rear are removed (dashed outline of full cylinder). Major muscles that move the thigh are marked with arrows pointing toward their origins that are shown as small circles. When the same cylinder is turned 90° to the fully upright position, the same muscle actions (shorter arrows) are not able to move the thigh in normal walking.*

Muscles that draw the femur forward originate on the anterior part of the pelvis (ilium). When the pelvic cylinder is turned completely upright, these origins are moved to positions more nearly above the insertion, and some of those muscles' actions will be compromised. Muscles that draw the femur backward originate from the lower, or rear part of the pelvis (ischium). When the pelvis is tilted up by 90° this origin is now in line with the femur instead of behind it. From this origin these muscles will extend the thigh only from a flexed position, but not when it approaches full extension. From that full extension, any further hyperextension, of course, is now impossible.

A total redesign of the hip and its musculature could correct this situation, but evolution works only with the additive effects of small, quantitative changes. It is also desirable that the pelvis should have a dual locomotor design--it must still be able to function when the human body returns to assume the quadrupedal position. Its function as the birth canal continues to be a limiting factor throughout this evolution.

The first step in pelvic redesign to make it human is simply to tilt the cylinder up in front by about 30°, or one-third of the way to the ultimate goal (Fig. 2, left). This estimate is based mostly on the orientation of the pubic symphysis. It can be moved this far without materially affecting the functions of the thigh musculature with their original attachments. The second step is to open out the front part of the cylinder by an additional 20° so that it becomes more of a truncated cone than a cylinder (Fig. 2, center). This estimate is based mostly on the angle between the symphysis and the sacrum. These two steps now bring the upper surface of the cone more than half of the way up toward the vertical position. This is about as far as pelvic modifications can go in this direction, for reasons to be seen below. The third step in erecting the trunk is simply to bend the lower lumbars in a curve to make the last 40° of the total change of direction (Fig. 2, right). (The number of degrees assigned to each of these three angles is somewhat subjective, but I think most anatomists would probably make roughly the same estimates.)

These three directional changes should be thought of as occurring simultaneously, along with the other changes detailed below; they are descriptively separated into a sequence here only to make them easier to visualize. These three changes will, by modest increments in each, change the orientation of the torso from horizontal to vertical. But the resultant pelvic design still does not look very human.

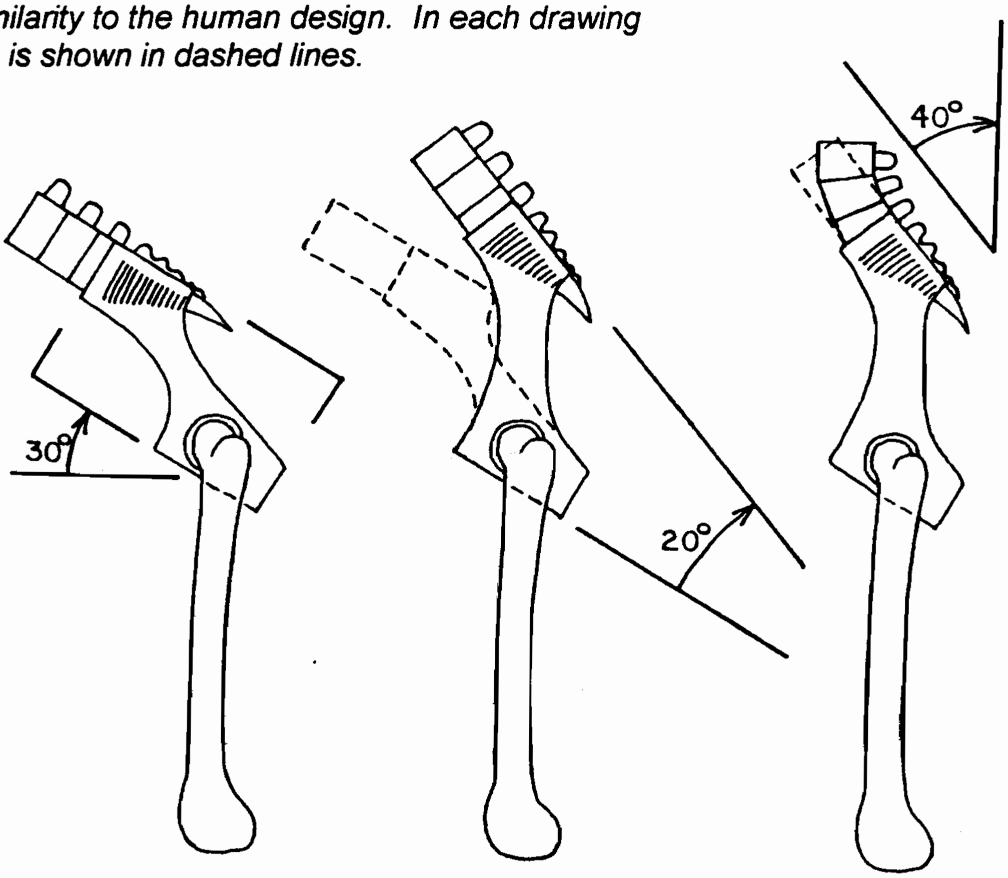
In order to stand or walk erectly, and with minimal effort, the body must have its center of mass (excluding the legs) situated directly above the acetabulum, or hip socket. The middle of the body (centrum) of the third lumbar vertebra is commonly used to represent this body mass. In our erected pelvis and trunk, as pictured thus far, that mass is still well anterior to the line joining the two acetabula. That imbalance is most easily corrected by a posterior movement of the area for sacral attachment until this center of mass is located above the acetabula. This also means that when one leg is lifted from ground contact, its added weight will not move the center of increased body mass either forward or backward. (A similar effect could also have been accomplished by increasing the lumbar curve still further and throwing the shoulders far back, but this curve is already a weak spot in the construction, and increasing it would only make it worse.)

The posterior (dorsal) movement of the sacrum also now puts the sacroiliac joint behind the acetabulum in most postures of standing and walking. This is a relatively minor problem because the weight transmission is only through the most anterior part of that joint. Still, this arrangement tends to cause the entire pelvis to rotate backwards around the acetabulum.

This awkward situation is corrected by muscular action of the iliacus, psoas, rectus femoris, and sartorius to hold the pelvis stable, but is still a less-than-ideal construction. A better pelvic design would certainly be one where the body weight, sacroiliac, and acetabulum are all in the same coronal plane; some earlier hominid pelves (described below) were definitely closer to this ideal design.

Moving the sacral attachment back is accomplished, not by further bending the upper part of the pelvis, but by expanding its anteroposterior dimension (Fig. 3, left). In other words, the sacral part of the ilium is extended dorsally. This moves the sacral attachment posteriorly, while retaining the relatively anterior position of the front of the ilium. The upper part of the pelvis now has acquired a considerable front-to-back "breadth," (or A-P width) as viewed from the side. This is the blade of the ilium that gives the human pelvis much of its basin shape. The function of this basin is not so much to hold the viscera with its internal surface as it is to provide muscle attachments mainly on its outer surface. It is well known that the iliac breadth provides muscular leverage, mainly for abductors and extensors on the femur, but just how these function has been poorly described up to now.

FIGURE. 2. *Basic steps toward the human pelvic design. Left: we begin with the cylindrical quadrupedal pelvis with a short tail, which has been lifted up in front by 30° without changing the usual leg-muscle arrangements. Center: the upper part of the pelvis is then tilted up another 20° by opening out the cylinder into a more cone-shaped structure. Right: finally, the lumbar region curves the last 40° to become vertical. At this stage the pelvis has only a vague similarity to the human design. In each drawing the earlier stage is shown in dashed lines.*



EVOLUTION OF THE HUMAN PELVIS

Bipeds walk by alternately supporting the body weight on one leg at a time. When the body is supported by a single leg, its weight is transmitted through the acetabulum on that side alone. The body's center of mass is located well medial to that support point and will thus tilt toward the unsupported side unless it is held upright by muscular action. This is accomplished by tensing the gluteal muscles, usually medius and minimus, on the supporting side. These are technically known as abductors that can be used to swing the free leg out to the side. Actually, their major function is to serve as body erectors that resist tipping of the torso toward the unsupported side. From this functional point of view, these muscles may be said to originate on the greater trochanter of the femur and run up to insert on the blade of the ilium. Without this gluteal action the body would fold at the hip, or "jack knife," to one side with each step. These muscles must be powerful but, because they merely stabilize and have no need for a long action stroke, they can also be rather short.

The body may assume various orientations while walking, running, carrying, and other activities. These include trunk positions that vary from a vertical orientation--especially leaning far forward but also backward, as in carrying bulky loads. Much of this leaning of the trunk is accomplished by bending the vertebral column itself, but some of it, especially in extreme bodily orientations, includes a leaning of the pelvis itself. It is to this pelvic leaning that my comments are directed.

The gluteal muscles must be able to resist the sideways body tilt from any of these bodily inclinations, and so they must fan out onto an ilium that is "broad" from front to back. When the body leans back the gluteus minimus becomes vertical and takes more of the load with each step; in an actual vertical posture the gluteus medius does the major work; with the body and pelvis leaning far forward the gluteus maximus at the rear becomes vertical and comes into action. (Most of the gluteus maximus attaches in soft tissue farther down the leg, but its function, as described here, still follows the same pattern as the other gluteal muscles.)

This important function of the gluteus maximus may easily be confirmed by the reader with a simple demonstration on his/her own body. Place the hands on the buttocks and walk upright for a few normal steps to ascertain that little or no gluteus maximus action occurs. Now walk a few more steps while leaning far forward and feel the powerful, alternating contractions of this muscle. This forward lean will involve some bending of the spine, but much of it results from tilting the pelvis forward. The fact of pelvic tilt can easily be palpated by the experimenter; it is also observable on another person, especially if they are unclothed.

It should be pointed out that prolonged travel in either of these leaning positions is not necessary to require such differential use of the various gluteal muscles. Taking even a single step without the proper muscular support of the pelvis against tilting would likely result in the individual falling down. (The reader may note that I refer to side-to-side pelvic movements as "tilt," and front-to-back orientations as "lean.")

The anteroposterior expansion of the ilium was gained by extending back the sacral attachment to increase its breadth. This produces the gluteal surface and iliac fossa, which in turn provide the gluteal muscles with the wide range of directions in which they can pull, depending on pelvic orientation. If the human ilium had the great height of the apes' ilium it would have to be much "broader" than it is from front to back. With considerable vertical shortening of the ilium (Fig. 3, center), the same range of gluteal muscle fanning can be accommodated on a more modestly sized ilium (Fig. 3, right). The short action stroke of the gluteal muscles permits this reduced space. Washburn (1950) dealt with the shape and orientation of the ilium, but gave no reason for its shortening. Campbell (1985) ascribed this shortening to a supposed advantage in lowering the body's center of gravity. Bringing the flexible part of the lumbar region down closer to the acetabulum level should make it easier to hold the pelvis upright, but the same advantage would be gained by shortening any or all parts of body above the pelvis. Bringing the sacroiliac down and closer to the acetabulum does not serve to help stabilize the trunk, as some have claimed, because that stability involves controlling the orientation of the entire body above the acetabular level.

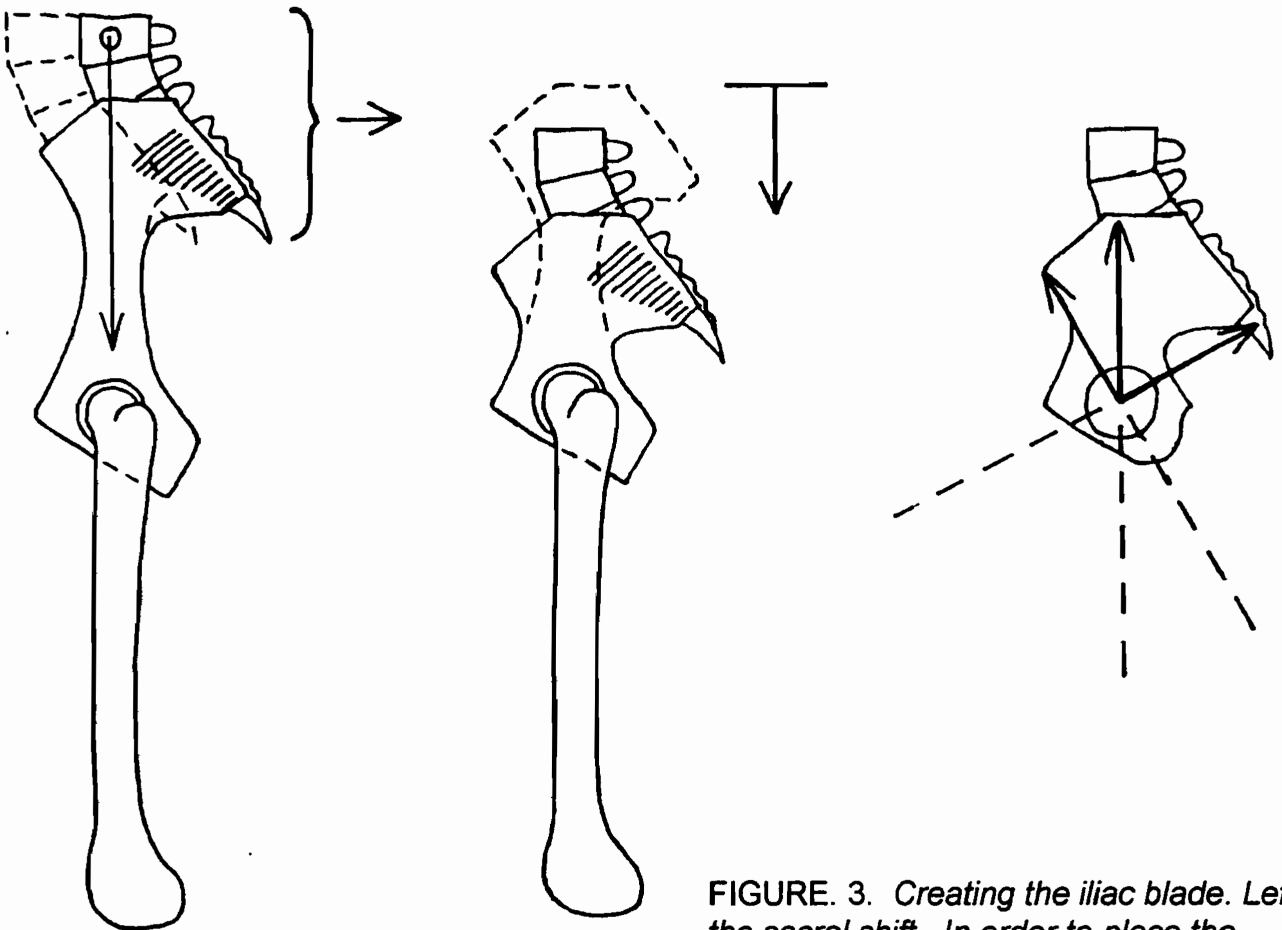


FIGURE. 3. *Creating the iliac blade. Left: the sacral shift. In order to place the sacroiliac articulation above and slightly behind the hip sockets, the sacral region is extended posteriorly. This is an addition of new bone rather than simply a bending back of the existing structure; the front of the ilium must retain its anterior position for muscle action. Middle: Shortening the pelvis. The entire ilium is drawn down closer to the hip socket. This facilitates balancing of the body, and allows an effectively greater spread of the gluteal muscles of the hip. This is now a basically hominid pelvic design. Right: Gluteal muscles. There is a 90° spread for attachment of the gluteal muscles (front to back: minimus, medius, maximus) that hold up the body from the supporting leg with each step. If the pelvis had remained tall, the same spread could be obtained only by "widening" the ilium much more, from front to back.*

The somewhat broad ilia of apes, especially in the gorilla, are directed laterally (nearly in the coronal plane), and provide muscular attachment for other motions. They do not have the dorsal extension of the sacrum as in humans.

The vertical drawing down of the ilium brings the sacral attachment closer to the level of the acetabulum. This, combined with the posterior displacement of the sacrum, produces the deep indentation between them called the sciatic notch (Campbell 1985). Lowering the sacrum also tends to reduce the size of the pelvic outlet. The sacrum must retain its forward leaning orientation--the lowest part being to the posterior--in order to minimize this constriction for obstetrical reasons. Thus the sacrum is committed to a considerable lean forward from the vertical, and a 40° lumbar curve must occur in order to turn the rest of the spine to a fully upright orientation.

The human sacrum is notably broad as compared with those of apes. Le Gros Clark (1967) attributed this to providing more area to attach powerful back muscles to maintain the vertical position of the spinal column. While this function is there, these muscles could as easily have encroached upon the iliac crest to find attachment without widening the sacrum itself. In fact, much of the musculature supporting the back does arise from the top of the ilium (quadratus lumborum). It should also be noted that the major breadth of the sacrum is in its anterior portion where it makes contact with the ilium (and where it is closest to the coronal plane of the acetabula). Only about 40% of the chimpanzee sacrum width is of the wings (alae) extending beyond the body; in humans the wings make up more like 53% of the total width. The greater weight support on the sacrum in bipeds increases the area of lumbar contact, but the human sacrum has expanded disproportionately beyond that. Some other explanation must be sought.

The increased sacral breadth results indirectly from the shortening of the ilium, which brings the sacral attachment down and much closer to the level of the acetabulum. The lines of weight transmission (in bipedal standing and jumping), from the upper sacroiliac edges to the femur heads, diverge outward and thus tend to force the pelvis apart at its lowermost point--at the pubic symphysis (Fig. 4).

One can visualize this structure as putting some weight on a two legged stool, which is made of three parts built like the sacrum (seat) and two ilia (legs). The legs of this stool diverge downward, and will obviously spread even more if the weight is increased. One may also imagine a string connecting the bottoms of those legs (like the pubes) that resists that spread. If the legs are standing near to vertical, there will be little force tending to spread the legs and to strain that string; but the more the legs diverge, the stronger is the force to spread them farther. (Exactly the same problem occurs with a peaked roof on a building--its weight forces the lower edges of the roof apart, and this is resisted by adding internal cross beams or outside buttresses.)

The sacroiliac joint is fairly strong, but there is always a force tending to separate most of that joint surface, and compressing it at a point near its upper rim (along with a continuing strain to separate the two pubic bones). Ligament connections resist that spread, as does the connection between the pubes below. If the sacroiliac joint were even stronger, say fused, then the body weight would effectively be transmitted straight down on the femur heads. Since this degree of rigidity is not the case, and some spreading force exists, various mechanisms are employed to resist it.

The effective line of weight transmission can be described as running from the top of the sacroiliac to the center of the femur head. In bipedal standing, divergence between these two lines greatly increases with the shortening of the ilium. Apparently a divergence of about 30° is mechanically acceptable in the quadrupedal pelvis (Fig. 4, left). With the lowered sacroiliac position, the lines of weight transmission would diverge more like 45° (Fig. 4, center), and the lateral force tending to split the symphysis would be correspondingly increased. Either the acetabula must move closer together or the sacrum must broaden. Restrictions of birth-canal size limit the former, so the hominid sacrum becomes broader, and the weight transmission lines continue to spread by only 30° (Fig. 4, right). Selecting 30° as the acceptable divergence was simply because that was the angle I found on both ape and hominid pelves.

Essentially the same explanation for the great sacral breadth in *Australopithecus africanus* was given by Leutenegger (1977) as part of a paper dealing with the whole sacral anatomy. By implication, this would apply to the recent human sacrum as well. (This reference was kindly passed on to me by a reader of an earlier version of this paper.)

A further pelvic modification occurs in our shortening of the posterior projection of the ischium. This shortening means that the extensors of the thigh will have a shorter lever to work from and they will pull with less force. It also means that the thigh can be moved through a long arc with less effort being expended (as in a striding gait). In contrast, the longer ischium of the ape provides more power in extending the thigh from a flexed position, which is especially useful in climbing (Le Gros Clark 1967). Hominids can still somewhat increase the effective length of the ischium simply by leaning forward. In Fig. 3 (right), one may visualize the trunk as being tipped forward substantially; this tips the pelvis somewhat and turns the existing ischial projection to extend back more horizontally. A common hikers' trick is to lean forward for brief periods while walking up long inclines, thus maximizing the leverage of the hamstrings.

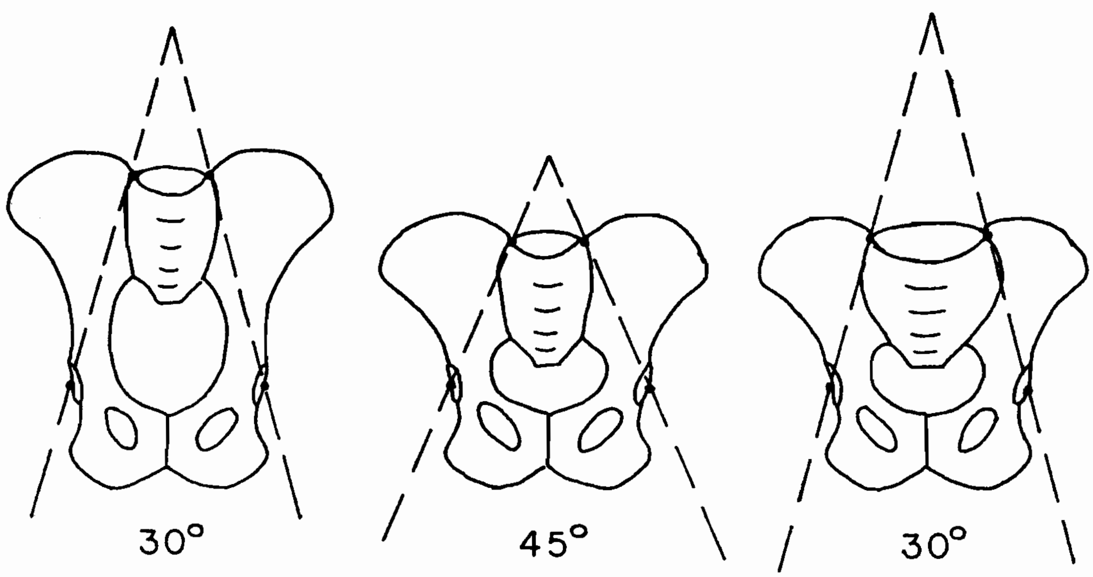


FIGURE. 4. *Sacrum broadening. When the pelvis is made shorter, the line of weight transmission from the sacroiliac joint to the femur head would automatically come to point more out to the sides instead of down (center), and this would tend to force the lower pelvis apart at the pubic symphysis. Broadening the sacral attachment (right) keeps the line of weight transmission at about the same acceptable angle. (The lines of weight transmission, from sacrum to femur head, are projected back to a meeting point in order to measure the angle between them.)*

THE FOSSIL RECORD

The description of pelvic changes to this point has shown how we can move from the quadrupedal design directly to that of modern humans. The fossil record, however, appears to interpose at least two rather different pelvic design stages between apes and humans--those of the australopithecines and of the Neandertals. These are not simply anatomical intermediates between the ape and human designs, but they show some unique traits. The reconstructions presented here are necessarily somewhat hypothetical, but they are largely based on the best fossil evidence currently available.

Australopithecines

The australopithecine pelvis has been reconstructed from two fairly good specimens, "Lucy" and Sts-14, as well as many smaller parts of other individuals. They display a suite of characteristics (somewhat different from the modern human design), which appears to follow from three functional contrasts--smaller neonates, a lesser ability to walk while leaning much forward or back, and considerable arboreal activity. (The observed differences between Lucy and Sts-14 result mainly from damage to both of them and from their different, and somewhat uncertain, reconstructions; functionally they appear to be very similar.)

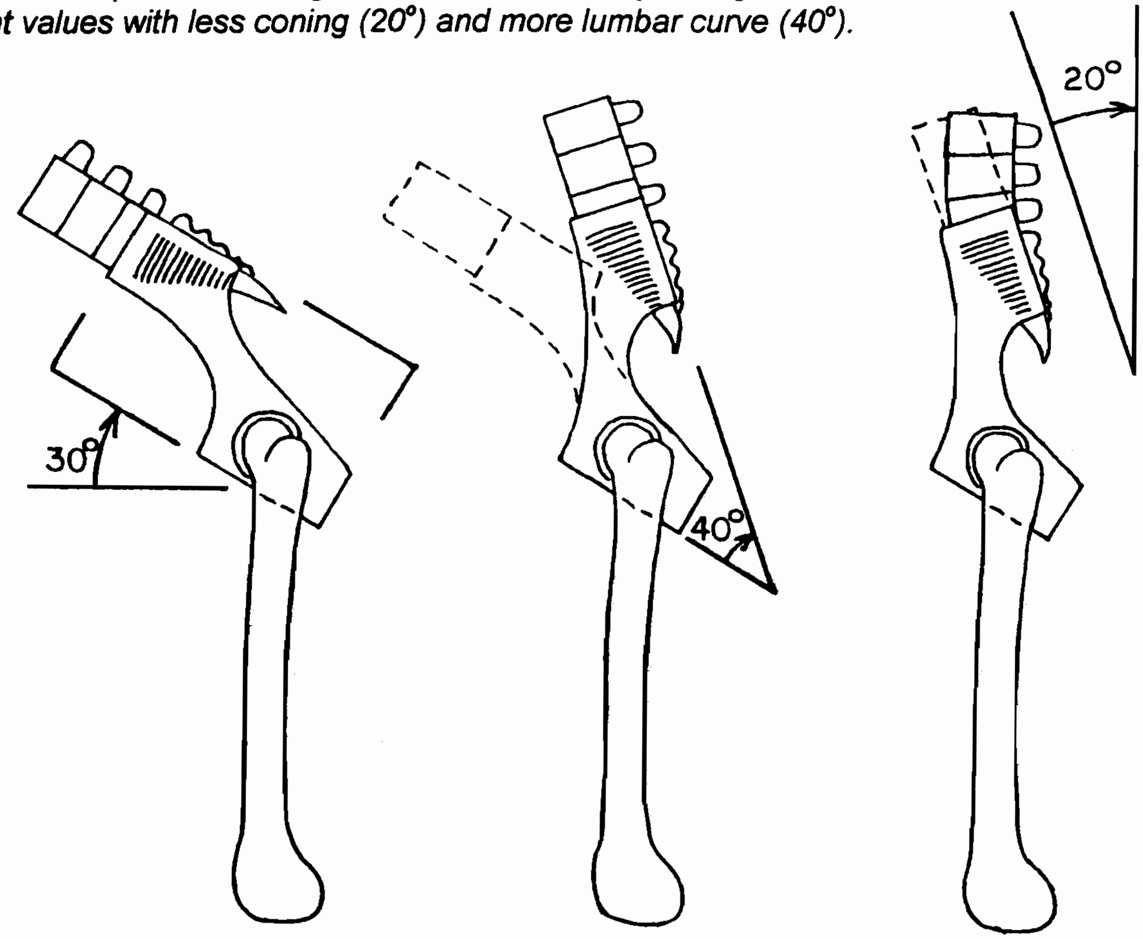
The blade of the ilium has a "breadth" approaching that seen in modern pelves, but this is oriented much more out to the side (coronally) instead of forward (sagittally). The side view of the pelvis shows rather little of our front-to-back extension or "breadth." In front view the iliac blades spread widely over the relatively small base. (By "base" I mean all of the pelvis below the blade of the ilium.) Hip sockets are placed well to the sides, not toward the front as in the modern pelvis. The ischium projects rather more than ours (though there is some controversy on this point).

To understand these differences we should begin with an ape pelvis and reconstruct the most probable steps to change this into the australopithecine design. These are not exactly the same as in the ape-to-human transition as described above. The pelvic cylinder is tilted up by the same 30° as in humans (Fig. 5, left); it is coned open by a full 40°, not just 20° as in humans (Fig. 5, center); and a lumbar curve makes up the last 20°, not 40° as with ours (Fig. 5, right).

A fully human lumbar curve was presumed by Robinson (1972:104) for the Sts-14 pelvis based on the wedge-shaped lumbar vertebrae. In humans the lumbar centra are taller in front than behind, thus introducing some curvature, but at least half of our lumbar curve results from the similarly wedge-shaped intervertebral discs. There is no reason to presume there was such a vulnerable disc shape in these early hominids. If we presuppose a structurally sounder disc design of constant thickness, the australopithecine lumbar curve would be only half of ours.

In the australopithecines only a small rearward shift of the sacrum is needed to line up the body weight because of the greater coning effect that moved the sacrum so high and far back (Fig. 6, left). This also leaves the sacroiliac joint virtually in the coronal plane of body weight and femur support, so there is no force tending to rotate the pelvis backward. The ilium is lowered by the appropriate amount (Fig. 6, center), much as indicated for the human design. The sacrum is widened, as required by that lowered ilium, and this increase is mainly in the wings rather than the centrum part. The Lucy sacrum is even superhuman in having about 60% of its width in the wings alone. This produces the basic australopithecine pelvis.

FIGURE. 5. *Uprighting the australopithecine pelvis. These three steps are similar to those described for the human pelvis, as shown in Fig. 2, but with some different angles. The entire pelvic cylinder is tilted up 30° (left), then coned out by 40° more (center), and finally the lumbar curve makes up the last 20° (right). This actually represents the origin of the hominid pelvis--our angles were more recently changed to the present values with less coning (20°) and more lumbar curve (40°).*



Even so, the acetabula are still well inside (medial to) this iliac flare. The greater coning effect involves tilting up the sacrum higher than ours, but it also includes a flaring out of the iliac blades far to the sides. This flare, combined with the small birth canal, leaves the hip sockets positioned well medial to most of the ilium. Accordingly, the acetabula can be positioned quite laterally rather than being shifted around toward the front as in humans.

I am making the assumption here that the coning effect equally involves both the sagittal and bilateral spreads of all boney parts. Thus if both the symphysis and sacrum increase their divergence anteriorly, the iliac blades will also spread laterally; since these ilia constitute only the dorsal half of the original cylinder, opening this cone means they become more coronally oriented. Likewise, if the symphysis and sacrum decrease their divergence, the iliac blades will move to a more sagittal orientation. There is no obvious anatomical reason why this correlation should exist as a simple coning phenomenon, but the observed and reconstructed pelvic designs all seem to fit that pattern.

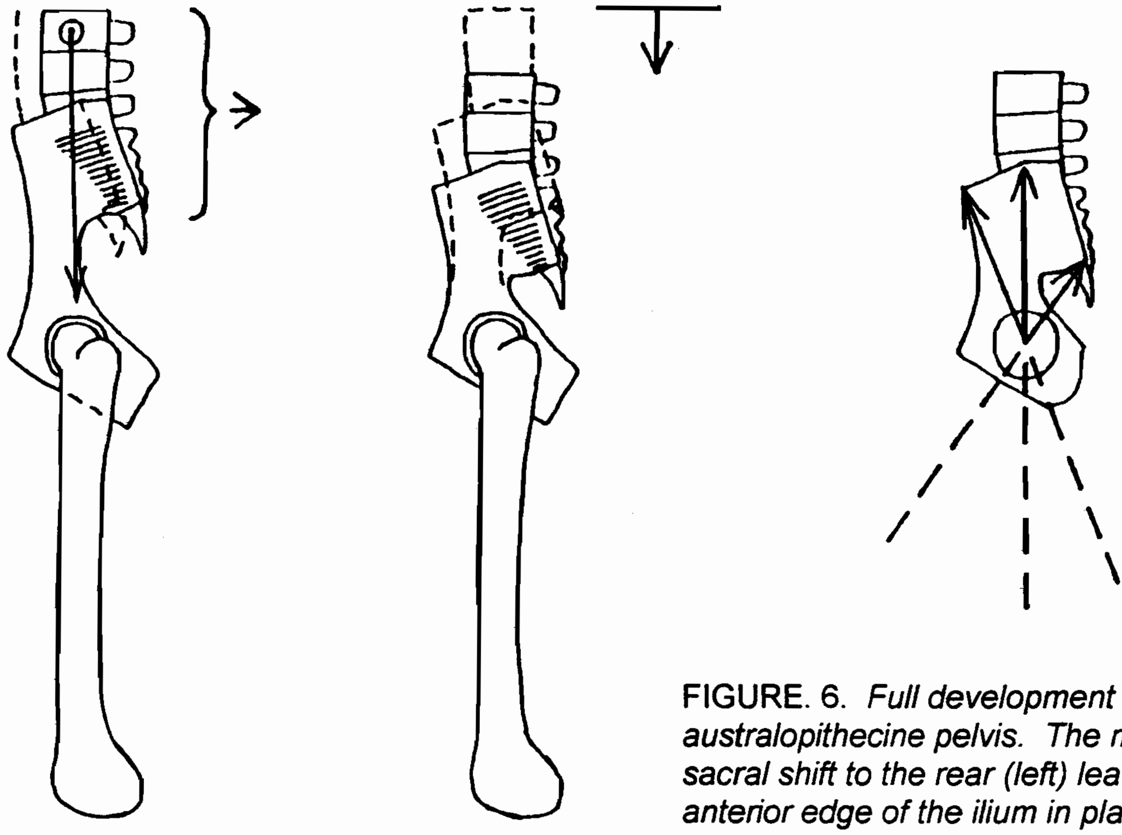


FIGURE. 6. *Full development of the australopithecine pelvis. The modest sacral shift to the rear (left) leaves the anterior edge of the ilium in place and adds bone to move the sacrum back to a position above the acetabulum, as was illustrated for humans in Fig. 3. The ilium is drawn down closer to the socket (center) for a shorter pull of the gluteal muscles. The resulting range of the gluteal action fans out through 55° (right).*

The gluteal muscles function most efficiently in a vertical direction, as viewed from the front, where they pull at a right angle to the lever line from trochanter to femur head. This fact permits the australopithecine femur shaft to be set out unusually far from the acetabulum to line up with these muscles and the iliac crest. This in turn requires a slightly longer femur neck to reach from its shaft to the socket, as noted by Lovejoy in 1973. Lovejoy went on to point out that the longer neck provides a longer lever for the gluteal muscles, so they don't have to pull down very hard on the pelvis. This then means the femur head, which supports the body weight as well as gluteal muscle pressure, is somewhat less strained than ours and can be smaller (Fig. 7).

It has long been noted that australopithecine femurs have rather long necks and small heads, as compared with modern specimens; this follows automatically from their pelvic design. It should be noted that the reconstruction of Lucy's pelvis indicates an almost human width of inlet (Tague and Lovejoy 1986). My own study of the fossil suggests this may not be the case, and the Sts-14 pelvis does not indicate anything like this breadth.

In side view, the australopithecine pelvis appears to have little breadth from front to back in its upper part. This allows for less spread of the fan of gluteal muscles than in ourselves. Using the center of the acetabulum to represent the attachment point on the femur, my measurements indicate their gluteals could spread only about 55°, amounting to 20° in front of vertical and 35° behind (Fig. 8, left). This contrasts with the 90° gluteal fan in humans--35°

in front of vertical and 55° behind (Fig. 8, right). This means that the australopithecine would have difficulty balancing his/her walking body if the pelvis leans back to near 20° or forward to near 35°. This allows for comfortable walking, and running with a modest forward inclination. But carrying bulky loads in the arms or on the back, as well as various other bodily gyrations, would appear to be more problematical.

Marzke et al. (1988) noted the presence of a gluteus maximus attachment area on the australopithecine ilium from Makapans (according to Dart), and they both presumed that it would have functioned as in modern humans. This does not necessarily follow because the total pelvic design, as interpreted here, limits what that muscle can do. On the other hand, Stern (1972) found that this muscle attachment is not clearly seen on the Sts-14 pelvis and, if present, it was not of modern human development. (On Lucy's ilium the muscle's existence cannot be determined one way or the other.)

Finally, there appears to be some contrast in the projection of the ischium, where the australopithecine design is reported to be more ape-like than ours (Fig. 8). Robinson (1972) noted that in the tiny Sts-14 specimen the ischium projected relatively little more than it does in the human pelvis, whereas the larger specimens showed rather more projection of that part.

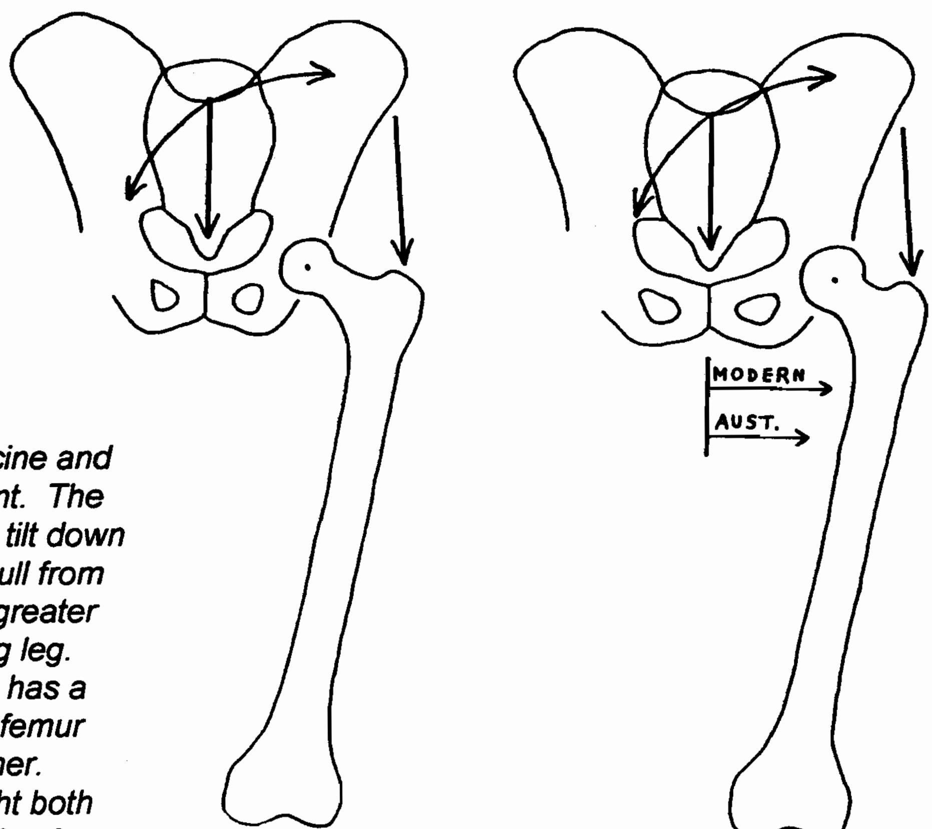


FIGURE. 7. *Australopithecine and human pelves from the front. The unsupported side does not tilt down because gluteal muscles pull from the pelvic brim toward the greater trochanter of the supporting leg. The australopithecine (left) has a smaller pelvic inlet, and its femur heads are set closer together. Muscle pull and body weight both press down on the supporting femur head that is located about mid-way between these forces. In the modern design (right), with a larger birth canal, the femur heads are set farther apart, and the necks of the femurs are correspondingly shorter. Gluteal muscle pull must greatly increase because the power arm of this lever is now shorter. This means that the muscles bring more pressure down on the femur heads, and they must become larger to spread this potentially damaging pressure over a greater surface area.*

This does not necessarily mean that there was a difference in function between the two types, but more likely it is just the allometric result of two different sizes. The small australopithecine clearly shows more ischial projection than would a human pelvis of equally small size, and thus it actually is probably of the same design as is seen in the larger specimens.

Muscles that extend the thigh originate on the ischial tuberosities and run down toward the knee. A longer ischium allows greater power of extension; the shorter ischium of the human pelvis gives rather more speed and efficiency to this muscle action. More powerful extensors certainly would be useful if those hominids repeatedly squatted down to the ground and stood up again. Such powerful extensors would also fit with a much more arboreal way of life where the legs were often used in tree climbing as with the apes. Since all recent foraging humans frequently squat and rise quite well without this extra projection, it appears more likely that it functioned in arborealism.

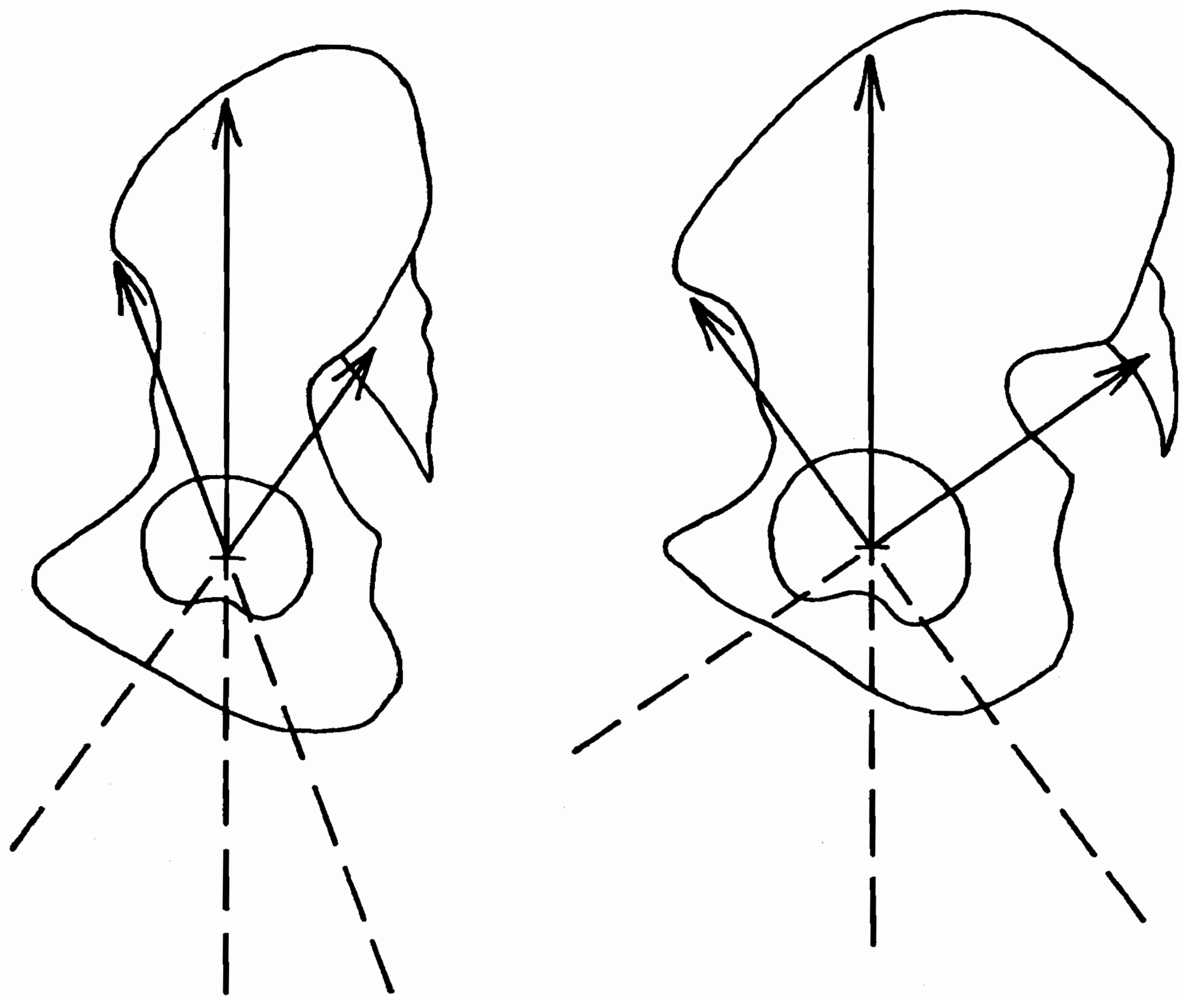


FIGURE. 8. *Australopithecine and human pelves from the side. The fully restored australopithecine pelvis (left) has a gluteal spread of 55°, which allows bipedal walking support with the trunk leaning as far as 20° back or 35° forward. The human pelvis (right) has a much broader gluteal spread of 90°, so it supports a backward lean of 35° and a forward lean of 55°.*

Neandertals

The Neandertal pelvis is built rather differently from that of modern humans, a fact that was long hinted at but only recently understood. We now have a complete innominate and sacrum from the Kebara site in Palestine (Rak and Arensburg 1987), which has ended some speculation about the Neandertals having extra-large birth canals to handle a gestation of 11 to 12 months (Trinkaus 1984). The anterior part of the pelvic basin (the superior pubic ramus) is unusually long. Yet the pelvic inlet, or birth canal, is the same size as ours because the back parts make a relatively smaller contribution to that basin. The australopithecine pelvis, where the pubic ramus also constitutes an unusually large proportion of the circumference, offers a clear parallel. In both cases the acetabulum opens more directly to the side, which seems logical, rather than opening somewhat anteriorly as in modern humans. In many respects the Neandertal pelvis is just an expanded version of the australopithecine design, adapted to a larger birth canal.

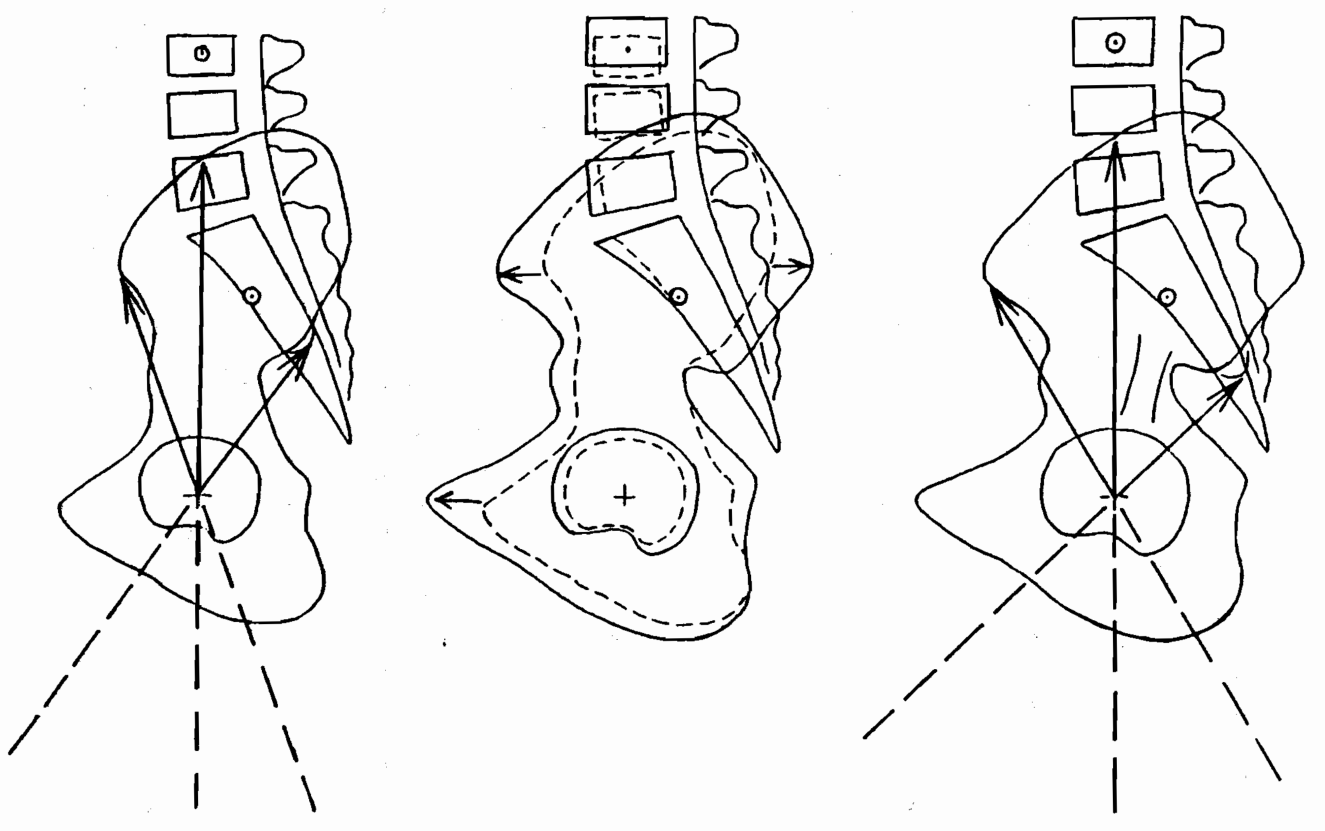


FIGURE. 9. *Australopithecine to Neandertal pelvic designs. The australopithecine ilium (left) has a gluteal fan of 55°, so they could walk while leaning the torso back as far as 20° or forward by 35° and supporting the swing side with vertical pull on the gluteal muscles. The Neandertal enlargement (right) is nearly uniform, but with a disproportionate increase from front to back. This larger pelvis would allow supported walking at 30° back and 45° forward leaning. (The two are superimposed in the center picture, with the australopithecine in dashed lines, showing how the Neandertal expansion is relatively greater in horizontal directions.)*

Australopithecines and Neandertals also have iliac blades that spread to the sides more than ours do, with correspondingly less anteroposterior spread. By my reconstruction, in the side view the Neandertal pelvis offers a gluteal spread of just 75° (Fig. 9, right), ours is 90°; and the australopithecines had only 55° (Fig. 9, left). Neandertals would have been capable of fully human locomotion, but any loads would be better carried directly on the shoulders, with rather less leaning of the pelvis than in modern people. Neandertal acetabula are also necessarily rather farther apart than they are in the modern pelvis because they both have the same size and shape of birth canal. These more widely spaced hip joints increase the problem of body tilt with each step, thus requiring excessive strength of gluteal muscle action on the supporting leg.

The characteristics seen in the Neandertal pelvic design should, to a large degree, apply to the pelves of all forms of *Homo erectus*. In contrast, the change to the modern condition centers largely on increasing the front-to-back spread for gluteal muscle attachments. This allows us to engage in walking with the body (and pelvis) leaning farther forward and/or back.

The early *H. erectus* pelvis from Nariokotome fits the Neandertal pattern reasonably well. The claim for a human type of lumbar curve (Walker and Leakey 1993) is not demonstrated by the human degree of lumbar wedging. Just as with the australopithecine specimens, intervertebral discs of constant thickness are the more reasonable presumption, thus giving this early *H. erectus* only half the lumbar curvature as in ourselves.

The modern iliac breadth is not actually increased, but the iliac blade is turned from the Neandertal's rather flared-out direction (toward the coronal plane) to a more anterior orientation (nearer the sagittal plane), as shown in Fig. 10. Reducing the ilium's lateral flare should be matched by moving the acetabula closer to the body's midplane as well. The hip joint should remain well medial to the iliac rim for the gluteal muscles to pull in the most efficient direction, and this rim is now moved medially. Because the breadth of the pelvic opening must be maintained, the acetabula cannot move directly medially toward each other. Instead they are moved around the pelvic rim to a more anterior location, which serves to bring them closer together. Thus the pre-acetabular part of the rim (pubis) is shortened, and the post-acetabular part (lower ilium) is lengthened, leaving the birth canal virtually unaltered.

Shifting the acetabula forward brings them farther ahead of the sacroiliac joint than they were before, but only by about 2 cm. Because the body weight is centered in the lumbar column, those lumbars must then move forward to stay above the acetabula. This change is accomplished by rotating the back of the ilium forward by 20°, thus turning the front of the sacrum down to point more nearly horizontally. The lumbars must now curve through an arc of 40° (twice as much as before) and they thereby achieve the required anterior displacement to become located directly above the anteriorly shifted acetabula. (See Fig. 10.) In his old description of the La Chapelle skeleton, Marcellin Boule said that its lumbar curve was much less than ours, and he has since been criticized for making that statement. He was right. The increase in the lumbar curve at this recent date may have much to do with this being such a weak point in human anatomy. If our 40° lumbar curve were more than four million years old, one would have thought it might be better designed by now.

The anterior move of the acetabulum also increases the tendency for a backward rotation of the entire pelvis, which was a minimal problem in earlier pelvic designs. With the body weight being transferred from the anterior part of the sacroiliac, down and forward to the acetabulum, the force tending to rotate the pelvis more rearward is clearly greater. This is now resisted by increased action of the rectus femoris, sartorius, iliacus, and psoas muscles. This necessarily constant muscular effort is another distinct drawback in the modern pelvic design.

The forward lean of the sacrum is part of the reduction of the cone-shaped opening of the pelvis from the previous 40° down to just 20°. If one thinks of this reduction as affecting the lateral spread of the pelvis, as well as its anterior opening, then this becomes mechanically equated with the turn of the iliac blades to a more sagittal orientation. Thus a single design change describes most of the pelvic alterations, as with a field gene. Only the anterior move of the acetabulum and the increased lumbar curvature are separate, but functionally related, phenomena.

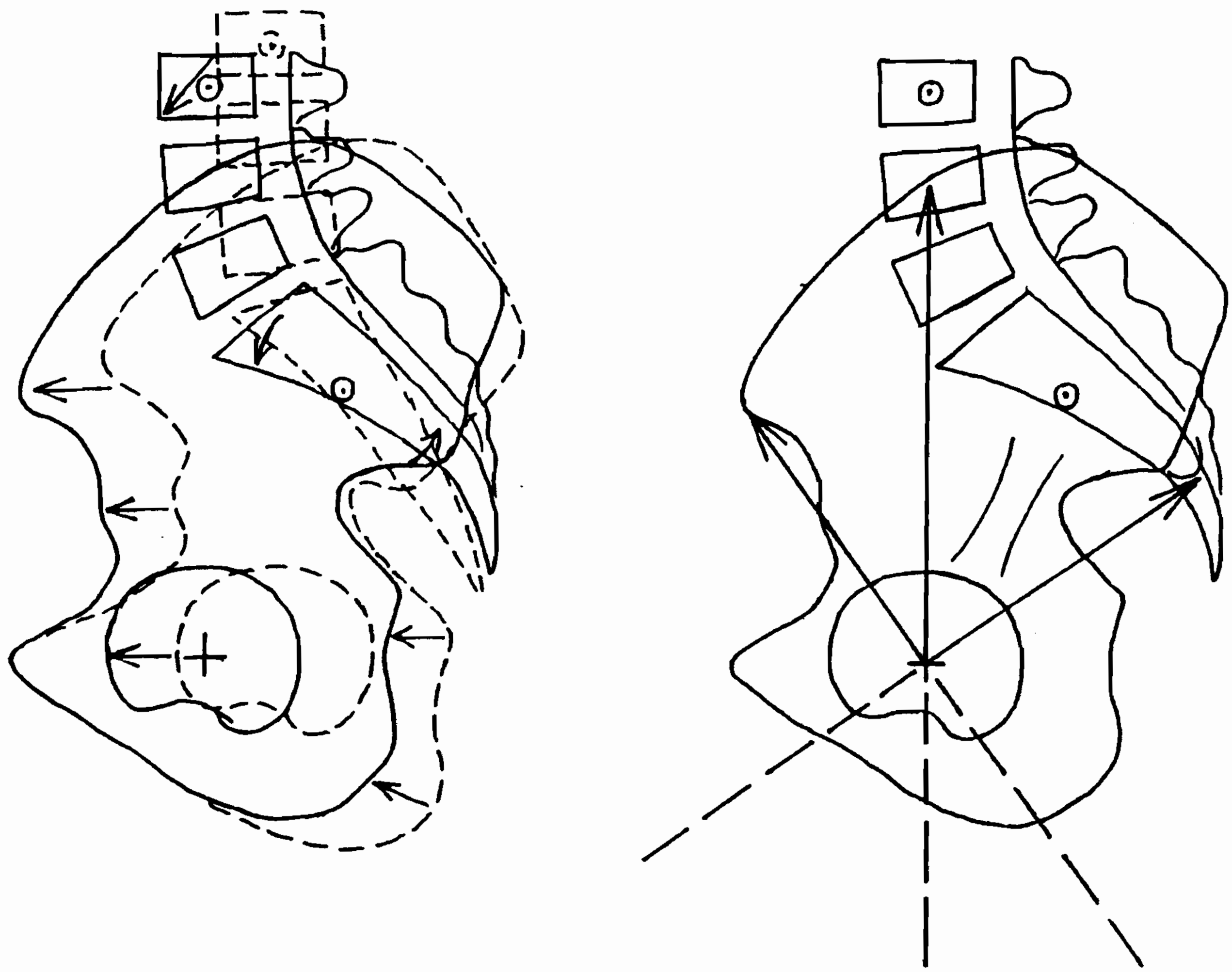


FIGURE. 10. *Neandertal to modern pelvic designs. On the left, the two are superimposed with the Neandertal shown in dashed lines; the pubic symphysis and sacral point of rotation are both held at constant locations. Our modern iliac blade is turned more into the sagittal plane (front-to-back), and thus it becomes much "broader" for a wider gluteal fan. The ilium is also tilted forward by 20°, hinging near midsacrum, which adds to this broadening. The sacrum tips down in front, so the lumbar curve increases from 20° to 40°, and this action moves the lumbars somewhat forward. The acetabula must then be moved correspondingly forward to stay under the body's relocated center of gravity. With the acetabula so moved, the ischial projection also shifts ahead correspondingly. On the right, the modern pelvis is shown by itself, illustrating the full range of potential postures and the gluteal fan.*

With the human pelvis in its normal position, the iliac pillar (a thickened ridge) rises vertically from the acetabulum to the iliac crest. In this position, the pillar provides maximum strength to resist the downward pull of gluteal muscles in ordinary walking. If the earlier design was with an ilium that had less anterior protection, then its vertical pillar would be slightly closer to the front of the iliac blade. That anterior location of the pillar, known to occur in several examples of the *Homo erectus* pelvis, is just what should be expected.

CULTURAL FACTORS

The modern pelvis is not designed for the most powerful movements of a physically active life. Rather, it serves to better support fairly normal walking, but in a wide variety of different postures. Load carrying would be a major task for people who shift their camps in regular annual cycles, especially if they have bulky possessions. Just this kind of moving activity is proposed for the first modern people in Europe (Stoffer 1989). Even where little property is involved, there are still youngsters and very old people who walk poorly or must be carried.

In a society where people communicate efficiently and are aware of their complex cultural way of life, they will put a high value on their children who will continue that culture. The same society will also value the knowledge of old people who have a unique contact with the past. Pelvic alterations that might enable large people to walk more effectively, even if weak and/or crippled, would be favored in a sapient society. Carrying such individuals, and young ones, as well as their physical possessions should also affect pelvic design in much the same manner.

It should also be pointed out that virtually all forms of primitive dancing involve leaning the body forward and back while progressing with alternating footsteps. Such movements are often imitations of other animals. The *Homo sapiens* pelvic design is essential for most of these movements; the *H. erectus* pelvis would present a considerable limiting factor. It would seem reasonable to include dance, along with speech and art, among the innovations that began with modern man.

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