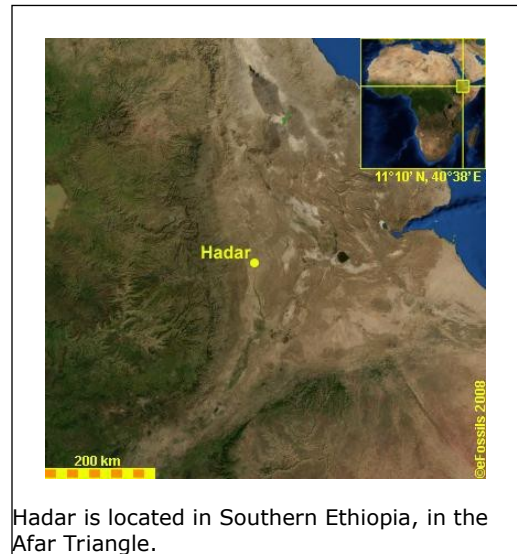




### The discovery of Lucy

On November 24, 1974, Donald Johanson and his student Tom Gray were surveying a site named Hadar in the Afar region of Ethiopia, East Africa (shown right) when they noticed a bone jutting out of the ground. They began work to uncover the bone and found many more bone fragments, which turned out to be a remarkably complete early hominin skeleton (illustrated below). Officially, the skeleton is designated AL 288-1, denoting that it was discovered at (A)far (L)ocality 288. The skeleton was nicknamed "Lucy" after the Beatles' song, "Lucy in the Sky with Diamonds" that was playing while the research crew celebrated the Lucy's discovery. In Amharic, an Ethiopian language, she is affectionately referred to as "Dinqinesh," meaning "wonderful thing."<sup>1</sup>



Hadar is located in Southern Ethiopia, in the Afar Triangle.



An Illustration of Lucy's (AL 288-1) remains, found in 1974. Drawn after Johanson and Edgar 2006.

Lucy was allocated to the species, *Australopithecus afarensis*, meaning "African southern ape from the Afar region." However, Lucy was not the first *A. afarensis* discovery. An articulated knee joint dating to 3.4 million years ago (Ma) was discovered a year earlier in 1973, but it was not properly identified as *A. afarensis* until 1979. Still, Lucy's discovery eclipsed nearly all earlier findings because of the extraordinary completeness of Lucy's skeleton, making her one of the most important paleoanthropological findings of our time. Roughly 40% of Lucy's skeleton is accounted for (hands and feet excluded), including cranial material such as fragments of the cranial vault, face, and jaw. Postcranial material includes parts of the shoulder, spine, and pelvis. Much of the limbs bones are also represented (upper arm and forearm fragments, a carpal and finger bone, a partial tibia and nearly complete femur)<sup>1</sup>.

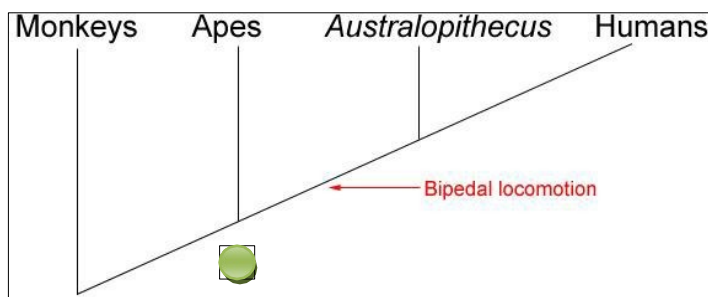
The preservation of so much of Lucy's skeleton has allowed researchers to study a number of aspects of her anatomy, about how she moved in her environment (locomotion), what she ate (diet), and even to hypothesize about how she is related to modern humans.



## Who is Lucy related to?

Lucy's evolutionary relationship to modern humans was one of the first questions asked by scientists after the "Lucy" discovery. The process of determining relatedness among organisms is called systematics. Unfortunately, we can't travel back in time to answer this question. However, in one type of systematics called cladistics, we can understand the evolutionary relationships among organisms by grouping them together based on shared characters (traits) (See the eFossils lesson "Evolution: From the Beginning" for more information). Specifically, cladistics is concerned with features that are novel and unique, termed derived features, to a particular subset of animals within a larger group. For example, among mammals, primates have nails. Since, most other mammals have claws, nails are a derived primate feature. In contrast, characters that everyone in the larger group has are termed primitive characters. For example, primates have hair, but so do all mammals. In this case, hair is a primitive feature that primates share with all mammals. All organisms that share a derived character belong to a clade.

Humans and their fossil relatives all belong to a clade we refer to as hominins. This clade is defined, in part, by the shared ability to walk bipedally. Bipedalism refers to locomotion (how an animal moves or travels) on two legs. You move bipedally whenever you walk, jog, run, or skip. However, most other animals, including chimpanzees, use quadrupedalism, meaning to walk on four legs. Thus, although chimpanzees are our closest living relatives, they are not part of the hominin clade. Bipedal walking is unique to hominins, and is considered a novel acquisition since their divergence from the common ancestor that hominins share with the African great apes.



A cladogram depicting relationships between major primate groups

classifications (i.e., family, genus, species). The diagonal line (or line running horizontally) represents the ancestral species. The point where the vertical and horizontal lines meet is called a node, and represents a speciation event. Let's walk through an example together. As mentioned, the "hominin" clade is defined by the ability to walk bipedally. Therefore, bipedal locomotion must have evolved after the divergence of hominins from living apes. That point is illustrated by placing "bipedal locomotion" after the node (large dot) where hominins and apes diverge.

The diagram shown left is called a cladogram (think: diagram of clades). A cladogram can contain living and/or extinct species, and tells about the relative timing of speciation events, or when species diverged from a common ancestor. By extension, cladograms also tell us about the relative antiquity (i.e., old age) of these ancestors. In the cladogram, each vertical line represents a general group of primates based on their taxonomic



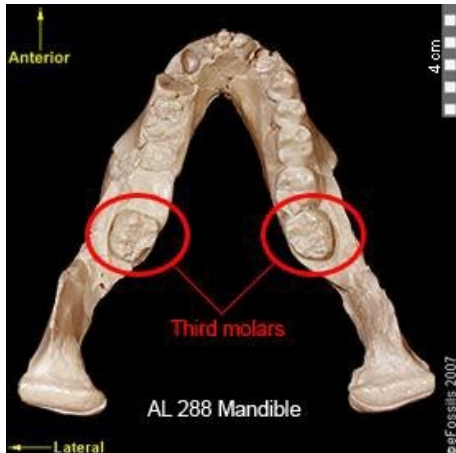
## WHO IS LUCY?

### A. An Introduction to Lucy

Through analyses of Lucy's skeletal morphology (see below), we are able to conclude that she walked bipedally. Therefore, we can conclude that Lucy is a hominin. Lucy belongs to the species *A. afarensis* that existed from 3.7 and 2.8 Ma<sup>2</sup>. There are many other extinct hominin species, but only one living hominin species: us, or *Homo sapiens*.



**How old is Lucy?**



Superior view of Lucy's mandible. Fully erupted 3<sup>rd</sup> molars are circled in red. The state of wisdom tooth eruption can help establish age.

Lucy has two ages: one that refers to how old she was when she died, her biological age, and the other that refers to how long ago she lived, her geological age.

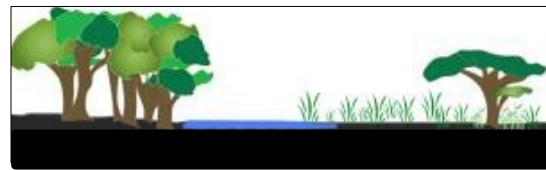
Lucy was an adult when she died. Scientists are able to determine this age because Lucy had fully erupted wisdom teeth (or third molars) and her bones appear fully fused. Bones form in separate pieces and fuse (connect) together at different times in life, just as teeth erupt at different ages as an animal grows. By the age of 35, most humans have fully erupted third molars and completely fused bones.

Lucy's geologic age dates to 3.2 Ma<sup>3</sup>. After Lucy died, her bones settled into dirt and rocks, called sediments. She then was buried by many more layers of sediments. The weight of all these sediments crushed

some of her bones. After a long time, the calcium in her bone was replaced with minerals from the surrounding soils. This process is called mineralization. It turns the bone into rock which help preserve it for a long time. Scientists can determine when Lucy lived by testing chemicals, called Potassium-Argon and Argon-Argon, in layers of volcanic ash above and below the rock layer where Lucy was found. Lucy was found in sandstone sediments associated with a paleo-stream. In this context, it is possible that a stream carried Lucy's body some distance away from where she died<sup>4</sup>.

**Where did Lucy live?**

Lucy probably lived in a mixed environment from dense wooded areas to open grassland areas, characterized by both wet and dry conditions. Thus, Lucy was probably able to tolerate the living conditions of a broad range of habitats. There is no evidence that Lucy or other members of her species preferred one habitat over another<sup>5</sup>.



**What did Lucy eat?**

Lucy probably ate a mix of foods, including ripe fruits, nuts, and tubers from both the forest and savanna. Incisor teeth are typically used to prepare the food for mastication (think about biting off a piece of an apple), and molar teeth are used to masticate, or chew, the food into a small pulp that can be swallowed. Compared to chimpanzees, Lucy had relatively smaller incisor teeth, but larger molar teeth, suggesting that she did little to dentally prepare her food, and spent more time intensively chewing or breaking down the food<sup>6</sup>.



Additionally, the enamel or hard outer shell of the tooth, and the body of the mandible itself, were relatively thicker in Lucy than chimpanzees, affording greater strength for the mastication of tough or hard-object foods. Foods that require a lot of chewing include nuts, seeds, and underground storage organs (root vegetables). However, *A. afarensis* incisors also show patterns of wear consistent with stripping leaves, and the canines show patterns of wear consistent with puncturing or crushing foods<sup>7</sup>. Thus, Lucy probably also ate ripe fruits when they were seasonally available.

#### What did Lucy look like?

Lucy was a small-bodied female that probably stood about 3'6" (107cm)<sup>8</sup> tall and weighed roughly 60 pounds (27.3 kg)<sup>9</sup>. Scientists can tell that Lucy is female because the anatomy of her pelvis generally resembles that of female modern humans. In addition, Lucy's body size overall, as well as those of other female *A. afarensis*, is smaller than the body sizes of male *A. afarensis* specimens. A difference in body size between males and females of the same species is called sexual dimorphism, meaning two ("di") forms ("morph") between sexes.

Lucy's face was chimpanzee-like. Below her eyes, her face projected forward beyond the plane of the eyes, a character trait known as prognathism. Features that Lucy shares with chimpanzees are called retained primitive features, meaning that these features were present in the ape-like species from which Lucy's species evolved, and that Lucy's species, *A. afarensis*, kept these features even after the species diverged from that last common ancestor.



Recreation of a male, female, and infant *A. afarensis*.

#### How big was Lucy's brain?



Lateral views of 3 crania, from left to right: extant chimpanzee, *A. afarensis* (not Lucy), and modern human. All to scale.

Fossil remains of Lucy's braincase are fragmentary, limiting the reconstruction of her brain size. However, brain size estimates from other members of her species suggest that Lucy's brain was probably about the size of a modern chimpanzee's (range between 387 – 550 cc; average

446 cc)<sup>10</sup>. Although it might appear as though these australopiths had small brains, it must also be remembered that they were smaller-bodied than living humans. In fact, when her brain size compared relative to her body size, her brain would actually be considered larger than expected for a living ape of that body size<sup>11</sup>. Importantly, Lucy's relatively small brain size (compared to humans) in combination with her bipedal adaptations of the lower limb, reveal that bipedalism evolved before large brains.

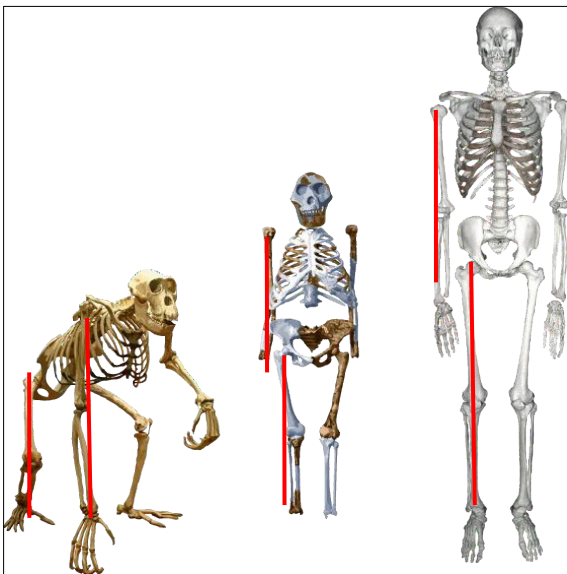


### How did Lucy move?

Lucy was clearly bipedal, although she may have continued to locomote through trees (i.e., arboreal locomotion) with some ease. Scientists can deduce this information from her skeleton, which is a combination of derived human-like features and retained primitive chimpanzee-like features. Each section below discusses aspects of Lucy's anatomy that help us determine her mode of locomotion.

**Limb proportions:** An animal's limb proportions can provide clues as to what mode of locomotion an animal utilizes on a regular basis. A ratio of limb proportions is calculated by dividing the forelimb length (humerus length + radius length) by the length of the hindlimb (femur length + tibia length). This ratio is called an intermembral index ("inter" means

"between", "membral" means "limb"). Look at the picture (left) and examine the length of the red lines that highlight the forelimbs relative to the hindlimbs.



Humans have an intermembral index between 68-70<sup>11</sup>, meaning that their hindlimbs are longer than their forelimbs. A low intermembral index in humans reflects the fact that they rely exclusively on their hindlimbs for propulsion during bipedal walking. Chimpanzees have an intermembral index of 106<sup>12</sup>, meaning that their forelimbs are longer than their hindlimbs. A high intermembral index in chimpanzees reflects the fact that they

rely heavily on their forelimbs for climbing and arm-hanging/swinging activities. Lucy's intermembral index is 88<sup>11</sup>. Thus, Lucy appears to have an intermediate measurement between modern humans and chimpanzees. Measurements of the individual bones in the index show that Lucy's intermediate body proportions are a result of a shortened humerus. Since the evolutionary trend in hominins is toward relatively longer hindlimbs than forelimbs, as in modern humans, Lucy's skeleton shows that arm length reduced before thigh elongation<sup>2</sup>. Functionally, Lucy probably relied on her hindlimbs for moving bipedally and on her forelimbs for climbing.

**Scapula:** Some of Lucy's primitive features, such as the orientation of her shoulder, suggest that she might have spent some time in the trees (arboreal). The scapula (shoulder blade) articulates with the humerus (upper arm bone) at the scapula's glenoid fossa, a small circular or oval depression located on the scapular head. A cranially (up, toward the head) oriented glenoid fossa enhances an animal's ability to climb or use forelimb-dominated activities where the arms are held above the head. Like chimpanzees, and unlike humans, the *A. afarensis* glenoid fossa faced cranially, suggesting Lucy probably used above-head arm postures, consistent with the idea that she may have climbed trees<sup>11,13</sup>.

## > WHO IS LUCY? C. Lucy and Bipedalism

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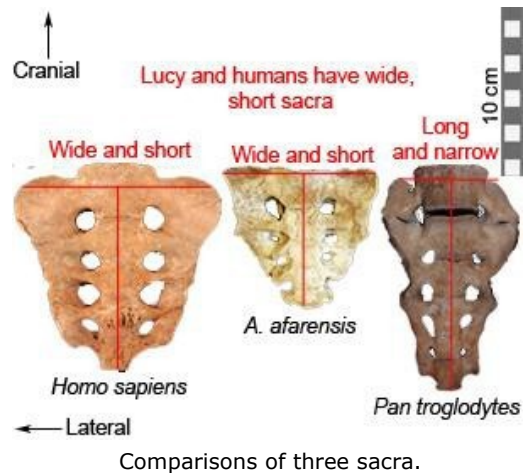


y (pelvis and hindlimbs) indicates that when Lucy was on the ground bipedally. For example, Lucy's innominate blades (pelvic bones), are short, broad, and curved forward, so that the iliac crest of the body. In contrast, the chimpanzee innominate blade is where the iliac crest lies flat across the back. This difference in the shape affects the way some of the gluteal muscles attached to the greater trochanter) and action at the hip joint. In chimpanzees, a muscle to the hip. This action helps move the limbs front-to-back during walking. In humans, and in Lucy, the curved iliac blade moves these muscles to pull the leg to the side at the hip. This action

maintain the body's support and prevent collapsing toward the side that is unsupported by a leg during bipedal walking. That Lucy's pelvic blades appear closer to the human condition indicates she walked bipedally.

gluteal muscle originates dorsally from the pelvis and inserts on the greater trochanter. Note that the sacrum is wide at the top (proximally) and short in length, although not to the extent observed in humans<sup>13</sup>. In contrast, the chimpanzee sacrum is long and narrow. You can see these differences in the picture to the right. A proximally wide sacrum positions the sacroiliac joint (where the sacrum articulates with the innominate) over the hip joints (where the femoral head articulates with the innominate). By aligning these joints, stress on the pelvis during bipedal walking is alleviated.

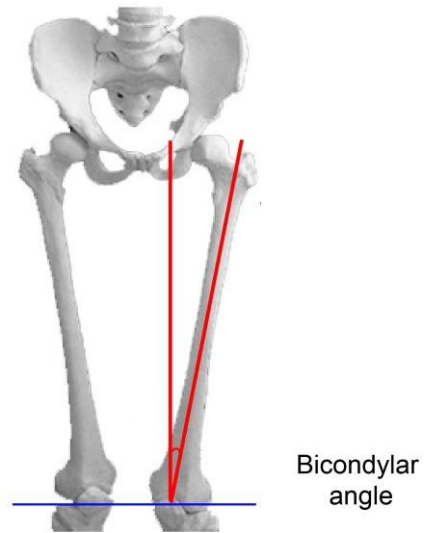
The size of the joint surfaces is related to the amount of weight transmitted through the pelvis during locomotion. A larger joint surface is better able to dissipate weight than a smaller joint surface. Lucy's sacrum also has somewhat expanded joint surfaces compared to chimpanzee. However, again, they do not approximate the human condition completely. Humans have large sacral joint surfaces, even compared to gorillas! Human sacral joint surfaces are so large because their sacrum must withstand the entire weight of the upper body during bipedal posture and locomotion. In contrast, chimpanzees and gorillas have smaller joint surfaces because some of their body weight is transferred to the forelimbs during quadrupedal posture and locomotion. Overall, Lucy's sacrum trends toward the human condition, indicating that she employed bipedal posture and locomotion.



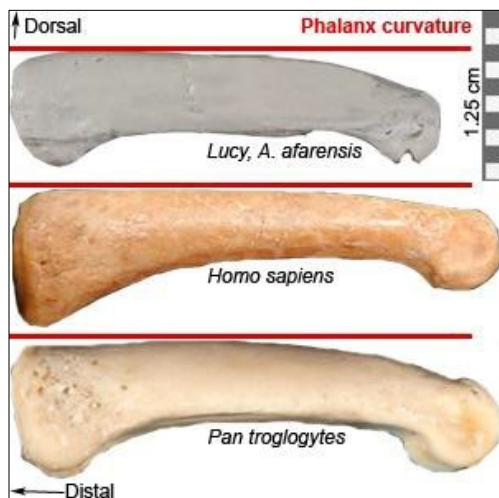
Comparisons of three sacra.



**Femur:** Lucy's femur, or thigh bone, provides some of the best evidence for bipedal locomotion. In humans (shown on the left) the shaft of the femur slants downward and medially toward the body's midline so that the knees are held close together, forming an angle from the knee to the hip joint. This angle is called the bicondylar angle. In this way, the foot is closer to the body's center of gravity during single-foot support, relieving stress on the knee joints and ensuring balance during bipedal locomotion. Quadrupedal locomotion lacks a single support phase. Thus, in quadrupedal animals, the shaft of the femur is straight so that the knees are separated and the legs are positioned directly underneath the hip joints. By contrast, the morphology of the human knee is called a valgus knee, meaning "knock-kneed". Lucy's femur also exhibited a bicondylar angle similar to that seen in modern humans, and thus Lucy also had a valgus knee.



Human pelvis and femur articulation showing the femur's bicondylar angle between the pelvis and the tibia.



**Foot:** Certain bones in the *A. afarensis* foot are long and curved like those of chimpanzees<sup>11</sup>. Curved toes (phalanges) enhance a chimpanzee's ability to grasp a tree trunk or branch while climbing. Since humans don't regularly climb trees, humans have short, straight toes instead, to help propel themselves while walking. Although the transformation to bipedalism was underway, Lucy probably continued to climb trees to escape predators, reach for fruit, and use the tree tops as a safe place for sleeping.

Comparisons of a phalanx curvature from Lucy, a modern human, and a modern chimpanzee.



In 2007, Lucy kicked off her world tour at the Houston Museum of Natural Science, where she went on public display outside Ethiopia for the first time since her discovery. An estimated 210,000 people viewed the exhibit before she moved on to museums in Seattle and New York. Discussions continue on future exhibit opportunities.

2014 marks the 40<sup>th</sup> anniversary of Lucy's discovery, and she continues to excite and stimulate new thinking about human origins. To date, she remains one of the oldest, most complete *A. afarensis* specimens ever found. Lucy opened doors into our understanding of early bipedal morphology that subsequent fossils have built upon. The mosaic state of her anatomy suggested, for the first time, that early hominins engaged in both bipedalism and some arboreal locomotion, while still retaining a relatively small brain size. Even now, Lucy is often referred to during bipedalism debates, including the type of bipedalism *A. afarensis* and other early hominins might have utilized. The growth of high resolution X-ray scanning techniques may make it possible to look inside Lucy's fossilized skeleton, and analyze the structure of her bones (i.e. trabecular bone). Once again, Lucy may be key to answering these, and other long held questions.



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