WALKING THE LINE: EXAMINING AN ILLUSTRATION OF A.L. 288-1 FOR ANATOMICAL ACCURACY AND ITS IMPLICATIONS FOR STUDYING AUSTRALOPITHECINE LOCOMOTION

by
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Abstract

After over 45 years, since Dr. Donald Johanson's famed discovery of "Lucy" (A.L. 288-1), a debate in the scientific community still endures over the nature of her bipedal gait. Did *Australopithecus afarensis* walk upright more as a great ape, with significant hip and knee flexion (the Bent-Hip Bent-Knee [BHBK] walking hypothesis), or was her gait closer to a modern human's?

At the heart of this debate is a single pen-and-ink line drawing, first published in an article by Drs. J. Stern and R. Susman on australopithecine locomotion (Stern and Susman, 1983). Despite the decades of arguments that have followed, this lone two-dimensional fossil reconstruction has never been tested. This project compares the with a contemporary 3D model of A.L. 288-1, and deciding if the Stern and Susman (1983) figure, which has been crucial to BHBK proponents, is indeed anatomically accurate.

To test the drawing's accuracy, casts of A.L. 288-1's innominate and sacrum were scanned using high-resolution computed tomography (UHR CT). This produced a 3D mesh which was compared to the original illustration. In the end, it was not possible to match the drawing to the model. Though it demonstrates nothing about australopithecine gait in itself, it undermines the BHBK hypothesis which is derived from the drawing, since it contains flawed anatomy. The flaws are likely due to the source material provided to the artist, demonstrating the importance of the collaboration between scientists and illustrators, and their ability to understand one another.

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Introduction

Is a single line drawing a substantial enough basis to support nearly half a century's worth of scientific theory? This possibility lies with the pelvis of fossil A.L. 288-1, the famous early hominin commonly known as "Lucy". There is an ongoing debate over the exact nature of bipedalism in *Australopithecus afarensis*. Was its bipedalism characterized by a bent-hip and bent-knee, kinematically similar to a chimpanzee walking bipedally? (Stern and Susman, 1983) Or was the gait of early hominins like our own, that of an obligate terrestrial striding biped? (Lovejoy, 1973) Arguments and theories for both possibilities have been contested for decades yet left unresolved. The evidence at the root of these theories is scant, and as such any conclusions require reexamination and careful consideration of the source, particularly if the evidence must first filter through an artist's interpretation.

1. The Drawing

This project investigates a single line drawing, done with weighted lines using pen and ink, that was first published the 1983 article, "The Locomotor Anatomy of *Australopithecus afarensis"*, by J.T. Stern and R.L. Susman (fig 1). A figure on pg. 292 depicts a posterior view--"looking directly downward onto the surface of the iliac crest"--of the A.L. 288-1 sacrum (A.L. 288-1an) with an approximation of the iliac crest's orientation. The A.L. 288-1 pelvis is compared to the pelvises of a male and female *Homo sapiens* and the pelvis of a female chimpanzee (*Pan troglodytes*). Stern and Susman use this to make the case that A.L. 288-1's ilium (A.L. 288-1ao) lies in a plane that is even more coronal than chimpanzee ilia, implying that the bipedal mechanism is closer to an ape than a human (Stern and Susman, 1983). Not all are convinced,

however, so here the two main theories about australopithecine bipedalism diverge and have yet to be resolved.

Since its publication, the illustration has been problematic. It has been suggested, although never investigated, that the Stern and Susman (1983) line drawing is not anatomically possible, because if the iliac blades are in the position indicated in the drawing, the pubic symphyses would not touch (Sylvester, personal communication). This demonstrates the hazards of relying too heavily on a single piece of evidence that has been interpreted by the hands of an artist, even that artist is a scientific illustrator, who rigorously strives for accuracy. Lucille Betti-Nash, who only recently retired from a prolific 41-year career as Scientific Illustrator at the Stony Brook University Department of Anatomical Sciences, created the original line drawing in question. In personal correspondence, she acknowledged the limitations she faced in the task, namely relying solely on photographs, saying,

> ... I did the weighted line drawings from those [Stern and Susman's] photos to the best of my abilities, most likely even traced the outlines to get as close to accurate as possible. As you can imagine, it was far less information than I would have liked. I am pretty sure that access to the fossils was very limited at the time, and we did not have casts. I wish we had, I hate drawing from photos, but that was all that was available to us. (Betti-Nash, personal communication)

The limitations imposed by illustrating with only photographs for reference are discussed later in this report. It is the goal of this project to evaluate and reinterpret the drawing using more accurate modern methods.

Reconstructions of the A.L. 288-1 fossil have been done, but fossil reconstructions should be viewed as scientific hypotheses; i.e., subject to revision given novel data and techniques. A.L. 288-1 reconstructions carried out until now have been produced based on what researchers thought “looked right” (Lovejoy, 1979; Stern and

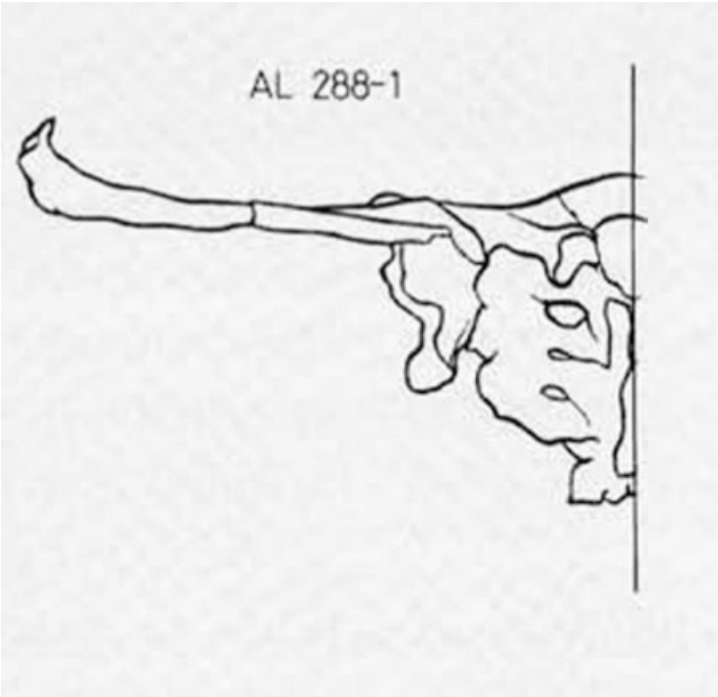


Figure 1: Detail of the drawing in question, made by Scientific Illustrator Luci Betti-Nash, first published in Stern and Susman (1983, pg. 292).

Susman, 1983; Sylvester, personal communication). There is a new generation of phylogenetically informed reconstructions that reference extant primate morphology, which is becoming the normal. Known variation in primate pelvic dimensions could provide data to inform pelvic shape and produce a variety of fossil reconstructions. Specifically, pelvic inlet/outlet shape is of critical importance in determining the overall shape of the pelvis and the orientation of the iliac blades, as well as any plastic deformation resultant of the fossilization process (Sylvester, personal communication). But before moving on to these new methodologies, the Stern and Susman interpretation must be examined to determine if it is even anatomically feasible. Science, as art, begs to be revisited.

2. Objectives

It was the goal of this project to evaluate, for the first time, the accuracy of the Stern and Susman (1983) line drawing by comparing it to a 3D model of the A.L. 288-1 os coxa and sacrum, generated by new computed tomography (CT) scanning. An assessment was made to determine whether the elements depicted in the illustration match those of the fossil, making an anatomically viable structure, whose pubic symphyses connect. Analysis was done with the software **Amira** and **ZBrush**. (In

response, and for the sake of comparison, the new model served as reference for a new line drawing.) The aim was not to visualize the pelvis as it may have been in life, correcting for the plastic deformation that comes with fossilization. Instead, the purpose was to depict the fossil as it exists today, compare it to the line drawing from 1983, and determine whether it is accurate enough to form any conclusions about the bipedal locomotion of *A. afarensis*.

The Center for Functional Anatomy and Evolution (FAE) at the Johns Hopkins University School of Medicine provided casts of the original A.L. 288-1 fossil, which were used to make digital surface model. It should be noted that, for these casts, the auricular region of the pelvis was reconstructed by Dr. C. Owen Lovejoy (1979). The auricular surface region of the os coxa used in this project has therefore been reconstructed to adjust for postmortem damage (Sylvester, personal communication). High-resolution photographs of the casts were taken from all angles, providing orthographic views that would assist in digital sculpting. For high-resolution surface models, the Canon Aquilion Precision scanner at Johns Hopkins (one of only two in the United States) was utilized to scan the A.L. 288-1 os coxa and sacrum cast. This scanner can get voxel sizes down to 0.125mm—a level of precision that cannot be obtained with other conventional medical scanners (Canon, 2019).

Once the scans were collected, they were segmented via Zbrush, providing well-defined 3D models of the A.L. 288-1 casts. **STL** files produced from the scan were all that was needed for segmentation, as they could be read by ZBrush--the chosen 3D visualization software. ZBrush is a powerful program used to digitally sculpt 3D meshes, and it is used for everything from medical illustration to cartoon entertainment. It was chosen for this project because of 1) the ease with which it can perform the set task of comparing an image with a model, and 2) the illustrator's familiarity with the program.

3. Significance of the Study

No attempt has been made to build a digital 3D reconstruction of Stern and Susman's (1983) line drawing for more comprehensive examination. Theories on hominin locomotion require a more robust model than an ink drawing. 3D models are more valuable for debates of this nature, and surface models and CT scans of the fossils expedite their creation while preserving accuracy. This project is a testament to the importance of accurate scientific visualization, and how the profession of science illustration can influence the science itself. The end result will be informative to researchers of paleoanthropology, primatology, biological anthropology, osteology, evolutionary biology, and biomechanists, as well as scientific illustrators or anyone curious about our ancient hominid origins.

There are many further advantages to collecting this information. With this new 3D model of Lucy's pelvis, future projects relating to gait, arborealism, and muscular placement on the bone can be undertaken. For the illustrator, the new CT scan and 3D mesh will make a solid foundation for a contemporary, realistic model of the A.L. 288-1 pelvic girdle. The digital sculpture could produce a 3D printed model, for anyone who wants the physical evidence in their own hands. Should other researchers want to take it further, they will then have the opportunity to animate the pelvis and legs, all with muscle attachments, forming portrayals of how *A. afarensis* walked. This will lead to further biomechanical analyses.

4. Measure of Success

Successful completion of this project will yield a reliable and accurate 3D model of what exists of the A.L. 288-1 pelvic girdle. The model can then be compared to the Stern and Susman (1983) line drawing. This will either support or disprove rumors that the Stern and Susman (1983) reconstruction is not anatomically possible. If it is found to

be anatomically viable, researchers will have the means to evaluate the biomechanical ramifications of this nearly forty-year-old reconstruction. This, in turn, will provide opportunity for further research. Ultimately, we will have a more informed community and public as a result of this model. With more accurate muscle reconstructions achievable, further avenues of biomechanical analysis can be pursued.

Materials and Methods

1. Acquiring and Processing Data

The most crucial component to this project is an accurate 3D model of the A.L. 288-1 fossil against which we can compare the drawing in question. As of this writing, the original A.L. 288-1 fossil is in the possession of the National Museum of Ethiopia. Unfortunately, access to the fossil is impossible, along with any kind of computed tomography (CT) data taken of the original specimen. (The University of Texas at Austin obtained the first high-resolution CT scans of A.L. 288-1 (University of Texas, 2009), but this data was unavailable. The model was instead based on casts of the fossil, in the possession of the Center for Functional Anatomy and Evolution (FAE) at the Johns Hopkins University School of Medicine.

1.1 Photographing Reference

Many photographs were taken of the casts of the A.L. 288-1 sacrum (A.L. 288-1an) and left os coxa (A.L. 288-1ao). Pictures were taken with a Nikon D3300 with a zoom lens set at 50 mm, being aware of potential parallax issues (Ippolito and Isham 2003, 331). While these photos are useful for seeing relative proportions and texture (which could be projected directly onto a digital model in ZBrush), there is undeniably lens distortion affecting the casts' true dimensions. In this way, the photos are an unreliable source of empirical information because they were taken without a metric scale to indicate measurements or camera perspective. Such a scale is almost always used in these situations (Ippolito and Isham 2003, 331). Generating a model of accurate measurements relied on 3D scanning.

1.2 Initial Scanning in FAE

A NextEngine 3D surface scanner was available from FAE, along with its native application software, and it generated 3D imaging of the sacrum and os coxa casts. The results, however, were deemed insufficient. Though they described enough information to find the general placement of casts in relation to one another, the objective was not to reconstruct the fossil, but to match the articulated casts with the line drawing appearing in Stern and Susman (1983). Lower resolution scans capture less subtlety and curvature and are visually at odds with line drawings, in which a particular edge may be represented by a precise and smooth pen stroke. Higher resolution meshes were needed for smoother edges and greater accuracy, bringing the model closer to the real biological specimen, increasing our chances of finding a match between drawing and model.

1.3 Ultra-High-Resolution CT Scanning

In 2019, the Johns Hopkins Department of Medicine - Division of Cardiology expanded the possibilities of visualizing disease by being among the first to install the Canon Medical Aquilion Precision Computed Tomography (CT) system, a new ultra-high-resolution scanner with twice the resolution of current conventional medical CT systems (Canon, 2019). The A.L. 288-1 casts were scanned using the Aquilion system to obtain higher resolution 3D meshes of the sacrum and os coxa. The results were delivered as **STL** files, which, when opened, produced the most accurate digital 3D visualization of the A.L. 288-1 pelvis that could be obtained, outside of scanning the original fossil itself.

1.4 Preparing the Model

The high-quality scans of casts were foundational to this investigation. The drawing in question is a line drawing, where a single line must be placed accurately and

convey as much information as possible. To keep the model accurate, allowing for a fair comparison to the drawing, the mesh imported into ZBrush was left untouched, except for repositioning. This ensured no accidental morphing, sculpting, or rounding would happen to any bit of geometry that could be crucial to the line drawing.

ZBrush is a polygonal-based 3D sculpting application utilized by many digital artists and illustrators in all fields, and it has myriad simple ways to smooth out and sculpt model meshes in highly realistic and aesthetically appealing ways. (This has its place for work that can be done on the model to generate assets for projects like 3D prints and animations, but those are for another project at a later time.) To give this drawing its best possible chance of lining up with the model, though, the model was left in its rawest form, eschewing the softer modeling options (which could easily distort the geometry in subtle but results-changing ways) to preserve outside edges as close to the original as possible. Leaving the edges exactly where they were, as they were, should have provided a close match to the drawing.

1.5 Visualizing STL Files

With accurate 3D meshes in hand, it was next necessary to have them imported to and interpreted by visualization software. ZBrush can open STL files on its own, with the **Zplugin**, **3D Print Hub** (**Z plugin** > **3D Print Hub** > **Import STL**). ZBrush imports an accurate 3D mesh that can be drawn on the canvas and edited. At this point, ZBrush considers the 3D model a **tool**. By going to **Subtool > Export**, the fossil's mesh can be saved as an **OBJ**, a more universal format that can be utilized by many programs.

1.6 Reorienting the Mesh

Before attempting to fit the sacrum and the os coxa together, it was necessary to reorient the meshes so that each would be sitting in 3D space in the same way. The os

coxa and sacrum meshes were reoriented independently, each in its own file, before both were merged onto one canvas.

When the STL files of the A.L. 288-1 casts were opened in ZBrush, they appeared as mirror images of their true selves. To correct the mirroring, the meshes were reflected across the X-axis **(Subtool > Deformation > Mirror [with "x" highlighted])**. The STLs also arrived oriented at random angles, with "center points" nowhere near the center of the object. This was corrected using the **MoveTranspose** tool.

When using the MoveTranspose tool, it is helpful to turn on **Gizmo 3D** (located on the **top shelf**, to the right of the **Rotate** button). Moving the controls of the gizmo will move the object, but if the option key is held down, the gizmo itself can be adjusted to reorient it with the mesh. With **Gizmo 3D** unlocked in this way, it was manually moved into the approximate center of the mesh. Checking multiple views ensured it was placed appropriately in all three dimensions. Then, when clicking and dragging outside the object to rotate the view, the object pivoted about its center, making it much easier to handle.

After establishing the correct center point, the second task was to orient each mesh into perfect orthogonal views, shown in Figure X. With both models having the same sense of front, back, etc., future work will be more efficient. Establishing the views in ZBrush requires the MoveTranspose tool, as well as a navigational aide known as **CamView (Preferences > CamView > Click CamView button).** Activating CamView displays an object (in this case a cube) in a corner of the canvas with the front, back, sides, top, and bottom labeled. Clicking and dragging on the canvas outside the model rotates the modeler's view, and the CamView cube rotates along with it, to show from what angle the model is currently viewed.

To orient the models, the view was snapped to an orthogonal position, which was indicated by the CamView cube. (Snapping is done by holding Shift while clicking and

dragging on the canvas outside of the model.) This would undoubtedly leave the model positioned at an odd angle. It was corrected by using the MoveTranspose tool to rotate the model into the appropriate position, corresponding to the CamView object. For example, to get the dorsal view of the sacrum, the view was snapped until the CamView cube read "BACK". (The angle at which the modeler sees the sacrum could be anything at this point.) The MoveTranspose tool was activated (to move the *model* rather than the *view*) with the Gizmo 3D displayed. The circle controls on the gizmo rotated the model into the correct position—sacral plateau at the top, median sacral crest down the center. This same procedure was repeated for other orthogonal views until the entire mesh sat in 3D space correctly.

The final step was to ensure that, while the mesh was correctly oriented in 3D space, it was also centered. This was quickly adjusted and verified by activating the **Floor** (in the **right shelf**), which displays the center point at which X, Y, and Z axes intersect. With the grid displayed on the canvas for reference, the MoveTranspose tool was used once again. Pulling on the gizmo's axis arrows maneuvered the model to the center of its world. All of this was done to the os coxa separately, and both models were exported as OBJ files.

1.7 Articulating and Aligning

After having correctly oriented the os coxa and sacrum models in 3D space, they were then brought together into one file, both pieces articulated together as they would be in the fossil. The single resulting model served as the basis for comparison to the Stern and Susman (1983) line drawing.

1.7.1 ZBrush Method

Articulating the sacrum to the os coxa in ZBrush was a largely intuitive process, depending mostly on the modeler's hand-eye coordination to fit the fossils together by sight. The connection is made at a sacroiliac joint. To connect the sacroiliac joint, the auricular surfaces of both models set the best frame of reference. To make these manipulations more efficient, the center point of each model was moved (with Gizmo 3D as in the procedure described above) to the center and outside edge of its auricular surface. From there it was a matter of moving, rotating, and nudging until the borders of the auricular surfaces lined up, and close examination of the topologies of both surfaces suggested they would interlock. Visual references were kept within sight, of both human pelvises and pelvises of our fellow great apes (White et al. 2012, 220-239). Spot checks around the model ensured there were no areas of overlapping geometry--for example, occasionally rotating to a dorsal or superior view helped assess whether the anterior iliac crest was clipping through the sacrum's articulating process.

This workflow produced good results, but it was an inexact method. No measurements or quantities were involved when doing it this way, and it instead depended on a similar kind of intuition that would be used in trying to fit the actual A.L. 288-1 units together. A key component, however, is lost when doing this kind of work digitally: there is no tactile response to feel the moment when all the ridges and grooves slip into place, and the fossils lock together.

When the os coxa and sacrum were connected, each bone was manipulated as a separate **SubTool**. Now that the placement was satisfactory, it was decided to also merge both bones into one model, which would be easier to manipulate while comparing to the line drawing. In the SubTool list, a duplicate was made of each model. (If something should go wrong when the two were merged, there would still be copies of undisturbed data.) To merge, the copy of the sacrum SubTool was moved to the top of

the list, with the copy of the os coxa directly underneath. With the top SubTool selected, the **Merge Down** button was pressed, and both models were finally together in one space; however, because both models may still need to move independently in a future project, they were split into separate **Polygroups (Polygroups > click Auto Groups button).**

The resulting model at this point appeared well-constructed, and it was certainly accurate enough to compare with the Stern and Susman (1983) line drawing. For the sake of thoroughness and accuracy, however, the sacrum and os coxa OBJs were taken to the FAE laboratory and fit together in a more precise way.

1.7.2 Amira Method

With the use of the computers available in the FAE department, and the OBJ models previously built, the sacrum and os coxa were fit together in a more precise, mathematical, computational way. By using Amira software to visualize this 3D data, there was the opportunity to connect the auricular processes with their topological data, rather than by sight.

All the geometry of the models was hidden, except for the surface geometry of each auricular process. After bringing the two near one another, the **Align Surface** command is executed. Amira studies the topology of one surface, and the topology of the other, and finds the most closely related vertices. In bringing these vertices together, the models were oriented to make to minimize the sum of the squared distances between paired vertices. The models were exported as STL files for later.

As a final check, the whole unit was reflected across the midline, creating a symmetrical mirror image of the left os coxa to stand in place of the right os coxa. (This simple but effective method of reflecting is often used, such as in the Berge and Goularas reconstruction of the Sts 14 pelvis [Berge and Goularas, 2009]). If the reflection showed

that the pubic bones did not meet in the middle as they should, then the model was not anatomically viable. The pubic symphysis, however, formed at the midline as it should be, further indicating that the connection between os coxa and sacrum was correct.

After achieving the most accurate fit, with data from the most accurate scan, the model of the A.L. 288-1 pelvis was completed. Satisfied that the model was accurate and trustworthy, it became the standard to which we compared the Stern and Susman (1983) line drawing.

2. Comparing

Now equipped with an accurate model, the main objective was tested: Will a model of the pelvis align with the ink drawing in Stern and Susman (1983), or does the drawing in fact depict an anatomical impossibility? An initial attempt at this comparison was done while still within the Amira software, just after the model was completely assembled. It was later taken back into ZBrush, which had better views and more possibilities for making the comparison.

2.1 Amira

In Amira, it is possible to display a **JPG** of the line drawing against which the pelvis model was repositioned, trying to find a view in which the contours of the model matched the lines of the drawing. It was decided that, since the sacrum had the greatest number of recognizable details to use as landmarks, the sacrum would serve as the basis for alignment. The Stern and Susman drawing has only “the surface of the iliac crest drawn” (Stern and Susman 1983, 292), so the ilium of the model provided little help in finding a matching orientation. Much trouble was had with the angle formed by the sacrum and iliac crest. The angle seemed shallower in the drawing than what could be done with the model (fig 3), and this was never resolved. After countless attempts to get

the features of the model in line with the details in the drawing, not one matching view was found. Further investigation was done in ZBrush, with the suspicion that not even the sacrum on its own could be positioned to match the sacrum in the drawing.

2.2 ZBrush

Making the comparison in ZBrush was an opportunity to utilize the software's **Spotlight** feature (fig 6). **(Texture > Import > Import JPG of drawing > Click icon with JPG previewed > Add to Spotlight.)** Using the control dial, the opacity of the image was reduced to make the model more visible. Pressing the **Z** key on the keyboard allowed the user to toggle between control of the model and control of the Spotlight image. To reduce the number of variables at play in making the comparison, the Spotlight was left undisturbed, except for the few occasions that required adjustments to the image opacity. The model was maneuvered by adjusting the view as usual (clicking and dragging on the canvas outside the model) and by zooming in and out to increase or decrease the perceived size. The actual position and scale of the model were never altered.

With the drawing fixed in place as a reference, and a model capable of being repositioned in any way, comparisons were made in a series of attempts to match only the model of the sacrum to the sacrum in the drawing. Was it possible to even line up a single object with itself? Again, the sacrum was chosen for this experiment because the ink drawing held more identifying details than the ilium. Useful landmarks included the sacral canal, the posterior sacral foramina, a distinct pointed angle on the lateral edge midway between the ala and the sacral apex, and the left superior articulating process and facet.

The left superior articulating facet was chosen as a primary point of reference. Its distinct shape was easy to find on the model, with no mistaking it for any other

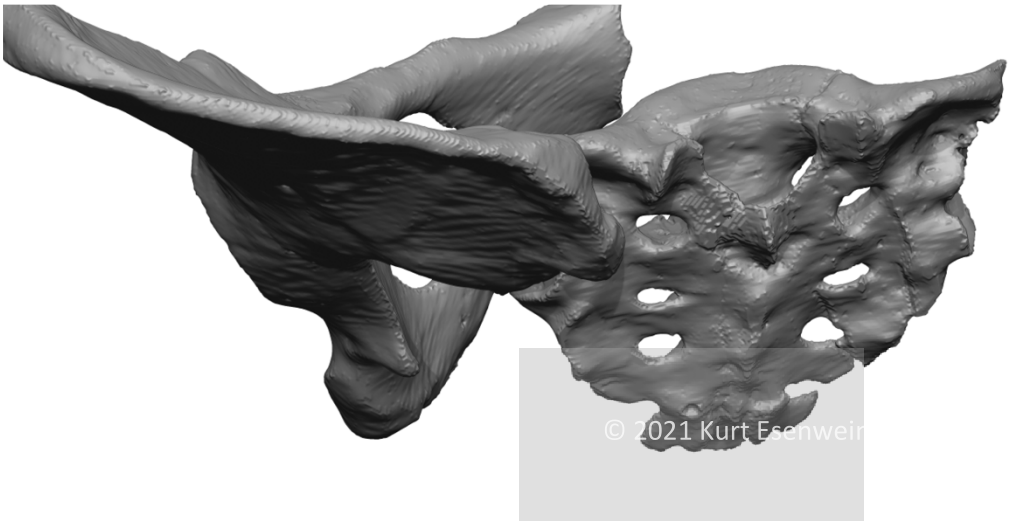
anatomical feature. The sacrum's center of rotation was moved to the articulating facet in the same manner as in previous steps. The sacrum was then moved so that the exposed surface area of the articulating facet completely and accurately filled the outline of the facet within the drawing. When these features matched, there was no other major position that would "fill in" the articulating facet in the same way; however, because of the thickness of the drawing's outline, there was still room to rotate and resize the model and still have the articulating facets match acceptably. These many small rotations and zooms searched for more matches with other landmarks, hoping to find multiple landmark matches while keeping the articulating facet match in place. There was limited success.

3. Drawing

One final step was to provide an alternative to the line drawing in Stern and Susman (1983). To do this, the model was positioned in ZBrush to mimic that of the original drawing. It was then rendered out with the **Best Possible Render (BPR)** function, to get a cleaner outline and reduce some of the aliasing and "stair stepping" that was so prevalent on the original unpolished model in preview mode. The render was saved as a JPG **(Document > Export)** and then loaded into **Adobe Photoshop**. From here, the image was directly traced on a new layer, using an inking brush and making the marks by hand. The original drawing still served as a reference for which features to accentuate and which to subdue, with the major difference being that the new drawing outlines the entire os coxa, rather than only the top of the iliac crest.

Results

This is the first time that the illustration of A.L. 288-1–first published in Stern and Susman (1983), depicting the alignment of the iliac blade—has been tested against an accurate, up-to-date 3D model of the *Australopithecus afarensis* pelvis. Multiple stages were necessary to achieve this comparison between the line drawing and the 3D model. The first stage resulted in a 3D mesh, made from CT data taken by a high-resolution CT scanner, using casts of the A.L. 288-1 pelvis. After the second stage, these meshes were reoriented to sit properly in three-dimensional space and brought together with an accurate fit, resulting in a 3D model of A.L. 2881's left innominate properly attached to the sacrum. Third, an image of the 1983 line drawing was superimposed over the model, and the model was reoriented time and again to try to match the drawing, but it was impossible. This resulted in the key insight of this project: the pen and ink line drawing that appeared in Stern and Susman's 1983 article on australopithecine locomotion is anatomically flawed and cannot be used to conclude the nature of bipedalism in *A. afarensis*. In response, the fourth and final stage resulted in a revised line drawing, executed digitally and referenced from an accurate 3D model of A.L. 288-1. Figure 2-5 show the final products of each stage of the workflow.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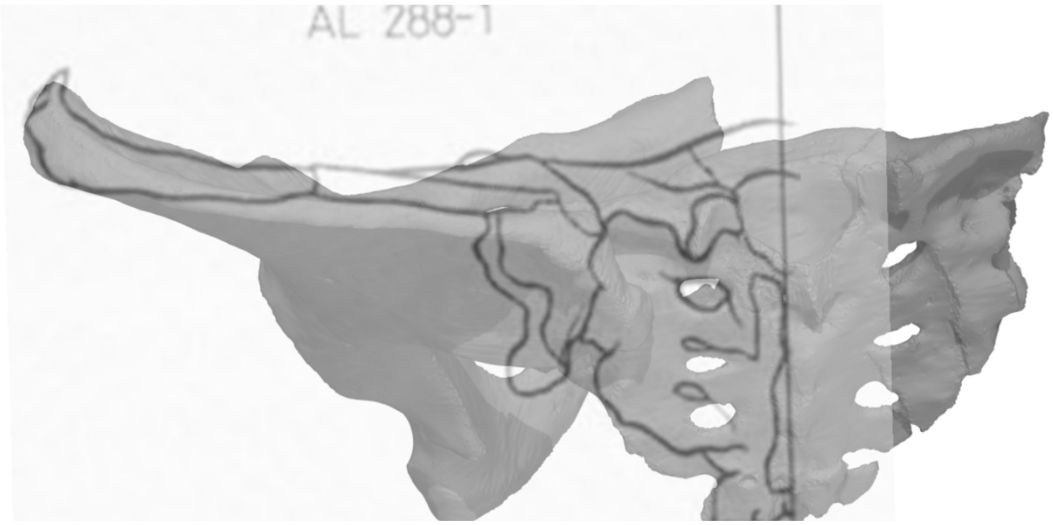
AL 288-1

Figure 4: Weighted lines are traced over the model in photoshop to make an alter line drawing, this time in "true perspective," using ZBrush's Universal Camera. © . Kurt Esenwein.

Figure 5: Side-by-side comparison of 3D mesh (left), Esenwein illustration (center), and Betti-Nash illustration (right) from Stern and Susman (1983). © 2021 Kurt Esenwein.

Asset Referral Information

Access to the files resulting from this thesis can be viewed by contacting the author at kesenwe1@jhmi.edu. The author may also be reached through the Department of Art as Applied to Medicine via the website www.hopkinsmedicine.org/medart.

Discussion

The goal of this project was to test a scientific illustration for anatomical accuracy, as this illustration has figured into theories about A.L. 288-1's bipedal gait for decades, yet has never been tested. By comparing this drawing to a 3D model of the fossil, it was found impossible to recreate the view depicted in the drawing with the actual specimen. This section discusses what was involved in the testing and a possible reason for the result, along with limitations encountered.

1. Limitations

The COVID-19 pandemic of 2020 disrupted several aspects of this project. Physical interaction was restricted, communication was possible but inefficient, and consequently the workflow was far from ideal. But beyond the limits in conducting this test, there are also limitations to the work itself. Scientists collaborate with scientific illustrators to communicate ideas effectively, but scientific illustrators rely on accurate reference material, which is all too easy to compromise.

1.1 Physical Isolation

Work on this project was greatly abbreviated due to the COVID-19 pandemic of 2020. Much will surely be written about this year, but for this project, the primary hinderance was a lack of accessibility. While it was still possible to scan and view the casts, it was not feasible to view the casts in-person more than the two times the illustrator *needed* to visit the Center for Functional Anatomy and Evolution. The hazards of being in physical proximity to other people in an enclosed space were too great a risk for the yield, particularly when working adjacent to a major hospital. As a result, the

illustrator behind this project relied heavily on the CT scans of the A.L. 288-1 casts, rather than having the objects themselves for reference.

1.2 Photographic Distortion

One could argue that attempting a fossil reconstruction in this distanced way presents hazards similar to those faced by Luci Betti-Nash in creating the original illustration. In the Introduction, Betti-Nash expressed her frustration with relying on photographs to create it. *The Guild Handbook of Scientific Illustration* recommends that reconstructions of a specimen be made with the use of a camera lucida and tracing paper (Hodges and Rawlins 2003, 2). In this project, the illustrator was largely bound to the segmented 3D mesh, just as Betti-Nash was bound to photographs (Betti-Nash, personal communication). The main difference in this project is that ZBrush purportedly displays models in "true perspective" (Pixologic 2021), that is, the models are seen as they truly exist, without artificial distortions.

Artists with an obligation to recreate objects accurately can have a complicated relationship with photos. On one hand, photos are highly convenient, and they capture the subject as it is, preserving a wealth of details to be used for later reference. One the other hand, photographs do not capture the complete truth about an object's form, since camera lens distortion skews the proportions and shape of an object. Shorter, wider lenses make the subject "bulge" toward the center, while long lenses keep the subject flat and truer to form. This is as true today as it was in 1983. As we are conditioned to viewing photos, we do not notice the distortion when looking at them. When that same distortion is precisely duplicated in a drawing, however, it gives the viewer a false impression of proportions. It is easy to assume the subject of a drawing is in true perspective, when it may in fact be warped by a camera lens. This is the reason the photos taken of the casts at the start of this project are useful for their recordings of

surface textures, but they should be used as the basis for a reconstruction, because a direct tracing from these photos would result in a wildly distorted final product.

2. Potential Projects

The results of this project can be easily reproduced, provided the model can be obtained. Otherwise, the workflow detailed in the Materials and Methods section provides enough information for anyone with access to the software to test the drawing themselves. It is, after all, difficult to prove a negative. There is still a small possibility that the drawing and model do align in an unexpected way, but the matching view was missed.

If the drawing were tested further, the model could be viewed and manipulated using a variety of simulated camera lens distortions. Since the Stern and Susman (1983) drawing was dependent on photographs, it is possible the lens distortion could be replicated to produce a match. This, however, looks doubtful, since a change in focal length would cause the image to bulge in the center, which is unlikely to remedy the discrepancies seen in Figure 3. Nonetheless, ZBrush can simulate distortions by activating **Perspective Distortion** (in the right shelf) and opening the **Draw** menu, activating the camera, then adjusting the focal length. Though ZBrush has this capability if the user wants to stay in the same program, it is recommended that lens distortions be tried in programs like **Maya** or **Cinema 4D**, which are better suited to rendering.

Comparing the model to the illustration is hardly the limit of this project, though. Part of the appeal to this project was its straightforward nature, which was an asset in a time of uncertain working conditions, but also one that opens many possibilities for future work. For one, this new digital model can be polished to a proper finish, with the realistic materials that bring the bones back to life. Meshes in ZBrush are easily exported

to 3D printers, so a physical copy of the model could be made and studied as a tangible object.

The fossils could be reconstructed with an intent to correct the plastic distortion inherent in fossilization. In a subsequent article by Stern, Susman, and Jungers (1984) on australopithecine locomotion, the same illustration in question is reproduced, but the authors note:

> There is damage to the fossil and the orientation that is depicted was not claimed to be other than approximate. [...]. Our portrayal of iliac orientation in the fossil has been strongly criticized as failing to compensate adequately for damage to the specimens. (Susman et al. 1984, 132)

As noted in the Introduction, the casts used in this project have had the auricular surfaces reconstructed (Lovejoy, 1979). This may be significant if the reference photographs provided by Stern and Susman (1983) were of the original fossils themselves, absent of any reconstruction; however, since it appears the broken or missing fragments of the fossil all had connecting edges, leaving little room for "artistic license", the reconstruction apparent in the 3D model is likely true to form (Sylvester, personal communication).

There are also opportunities to continue work beyond the fossil itself, such as muscle reconstructions and animations. (An example of this kind of work can be found in the reconstruction of *Homunculus patagonicus* done by Kellyn Sanders [2020], also for FAE.) The possibilities reach far from this humble beginning, so long as there remains a symbiosis between artistic creation and scientific rigor.

3. Collaborations Between Scientists and Artists

While science strives to reveal how the natural world works in objective, empirical terms, a scientific artist has methods to communicate these ideas to a broader

audience. Aesthetics and craftsmanship combine with cognitive theory and a degree of scientific literacy to produce didactic presentations that will engage an audience, as well as inform it.

Despite the current prevalence of photography and video, drawing and sculpting are still highly valuable skills in scientific fields, especially in times when a subject that requires description is incredibly rare, perplexingly complicated, or even invisibly microscopic. Illustrations, unlike photographs, can simplify a complex concept and pare it down to just the elements that are necessary to convey the pertinent information. Prof. Maureen O'Leary, of the Department of Anatomical Sciences at Stony Brook University, phrases it this way:

> I think the most important thing is figuring out together what to put in and what to leave out of a figure [...]. A photograph shows everything and it can be a blizzard of detail, really too much, and it will not focus the eye. The artist-scientist collaboration is about simplifying the detail to show what is important and how to show it clearly. (Dunaief, 2021)

This, again, shows the trouble with relying on only photographs as source material, without a physical specimen to reference. The detail captured in a photo is very useful, but it also obfuscates the specimen as a whole. Without an intimate knowledge of the subject, it is easy for an artist to misinterpret its features using only photos. For example, it may be more difficult to judge depth and how elements relate to one another in 3-dimensional space. Edges may blend together, making two separate surfaces appear as one. Information that could be seen within shadows in life is usually lost to a uniform darkness in photos. And then there is, of course, the troublesome lens distortion. Small pitfalls like these can have great repercussions. For scientific illustrators, as for scientists, there is an absolute need for accuracy, at the risk of spreading misinformation (Campbell et al. 2021, 14). When scientists and artists communicate with each other

clearly, each with a basic working knowledge of the other's vocation, these perils can be mitigated.

Just as the sciences have their jargons that takes years to master, visual communication is also a language in itself. Collaborations are more fruitful when each party understands what the other is saying. Consider the words of David Krause, another scientist who collaborated with Betti-Nash, in describing his relationship with the illustrator. Because of Betti-Nash, he says, "There is no doubt in my mind that [she] made me a better scientist and there is also no doubt that my science is better" (Dunaief, 2021). Science and art are both important modes of experiencing, understanding, and ultimately explaining the natural order of things.

For this project, the flawed anatomy in the A.L. 288-1 illustration provides no further insight into the manner of bipedal locomotion employed by *A. afarensis* one way or another, only that the figure is inaccurate, and so ideas about gait that were derived from the drawing need reconsideration. An imperfect process like creating line drawings from traced photographs has potential flaws that make the final product worthy of reevaluation, especially after so many decades, and in light of newer methods. That is why this test was conducted.

Conclusion

Conjectures about the upright gait of *Australopithecus afarensis* remain a contentious issue, with adherents of the Bent-Hip Bent-Knee hypothesis suggesting the gait was more like a great ape's, and those suggesting the gait was more like that of a modern human. Any such opinions need to be revisited, however, if they are derived from a previously untested 1983 illustration of A.L. 288-1's pelvis, since it was found to be anatomically inaccurate. By using an ultra-high-resolution CT scanner to generate a 3D model from casts of A.L. 288-1's innominate and sacrum, the illustration was tested against the digital specimen, where it was found impossible to position the 3D model in a way that matches the drawing. A likely culprit for the inaccuracy is the source material from which the illustration was created—using photographs of the fossil rather than direct observation. This displays the importance of clear communication between scientist and scientific artist, as well as a working understanding of each other's methods. In scientific illustration, accuracy is essential, but the illustrator faces limitations. This is why scientific art, like scientific theory, is subject to reevaluation and reform in light of new and better data.

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Vita

Kurt Esenwein was born in northeastern Ohio, and spent much of his youth between Youngstown, OH and Pittsburgh, PA. He began studying Renaissance art history at the University of Pittsburgh. Following an extensive medical leave, he decided he would rather make art than merely study it. He came across the field of medical illustration by chance while taking a course on traditional animation. In 2016, Kurt moved to Ames, Iowa, where he earned a Bachelor of Arts in Biological/Pre-Medical Illustration, was inducted into Phi Beta Kappa, and graduated *summa cum laude* from Iowa State University.

Currently he is a graduate student at the Department of Art as Applied to Medicine at the Johns Hopkins School of Medicine. He lives in Baltimore, Maryland with his partner, Andrea, and her chihuahua mix, the brilliant Penny Lane.