students to measure long bones accurately. The effects of aging and the influence of lifestyle alterations on skeletal elements are presented along with the prediction of their effects on the living individual. This laboratory is intended to acquaint students with the process of collecting and analyzing data, interpreting scientific results, and assessing the accuracy of their conclusions. Gathering and analyzing their own data sets gives students a better understanding of the scientific method and an increased ability to translate this understanding to other scientific disciplines.

Key Words: Anatomy; human skeleton; osteometric board; laboratory activity.

Many science courses require students to master a body of knowledge in human anatomy. This is often the first course students encounter that requires them to memorize a large amount of detailed information, which makes it challenging to teach as well as to learn. Human anatomy classes generally proceed system by system, and it is advantageous to provide the means to pique student interest in each system. A way to do this for the skeletal system is to show students how their knowledge of bone features can assist in learning about the physical appearance and lives of the owners of those bones. This information can be acquired by applying simple techniques derived from the disciplines of forensic anthropology and pathology. The information students can learn about many osteological specimens includes sex, age, ethnicity, stature, chronic illnesses, and the life habits that alter bones (Bass, 1971; Rorshchind & Martin, 1993). Learning about particular lives through a study of bones can personally connect students to the subject of human skeletal biology.

In doing the exercises described below, students will (1) strengthen their understanding of the scientific method, (2) demonstrate how scientific experimentation works, (3) learn how to assess the standards for accuracy in data collection, (4) understand the importance of scientific research as a way to learn about the world, (5) learn how to collect scientific data individually and cooperatively, (6) learn how to test for and achieve high standards of accuracy, and (7) cooperate in groups to pool data, analyze results, and derive conclusions from their work. The skills learned in these experiences will improve students' analytical abilities, further them in science, and help them in their other studies.

O Methods & Materials

Students work singly or in groups of no more than three or four. Each student is given a set of laboratory instructions, data sheets, and pertinent reference materials. The instructor guides the students through a set of procedures for collecting data individually and in groups, analyzing their results, and reaching conclusions. To complete the exercises described here, at least one 2-hour laboratory period should be allocated. If students are to measure more than one set of specimens, compare and discuss their results, or do additional research, additional laboratory periods may be necessary.

Students should have access to at least one mounted skeleton to allow them to view the typical body posture. Each student or group will require a set of disarticulated bones. At a minimum, bone sets should include a skull and mandible, an upper limb and limb girdle (a clavicle and scapula), a complete vertebral column, and a lower limb with at least a half pelvis. These elements are the typical contents of bone boxes that are available for purchase from anatomical supply companies. If natural bone elements are not available or preferred, high-quality plastic casts, more durable than natural bone, are readily available. Other required equipment that each student or group should have includes a 15-cm (or 6-inch) ruler, a meter (or yard) stick, a tape measure at least 2 m (or 6 feet) in length, a set of data collection sheets (Figure 1), a laboratory notebook, an osteometric board (or a T-square and two corrugated cardboard boxes that can be converted to an osteometric board substitute; Figure 2), and reference materials.

O Construction of an Inexpensive Osteometric Board

Table and portable osteometric boards—expensive pieces of equipment that allow precise skeletal measurements—can be purchased from specialized suppliers. However, a device that will allow measurements of
### Figure 1. Format of a data sheet for recording of measurements and conditions of bones and bone features to determine age, sex, stature and ethnicity of human skeletons.
sufficient quality can be constructed from two stiff cardboard boxes (see Appendix). Briefly, each box should be at least 30 cm (12 inches) in length and any width greater than 15 cm (6 inches), and one must be able to nest snugly inside the other. If the boxes have tops or overlapping flaps, these must be removed. One end should be cut off of each box, and, optionally, one side from each as well). A paper scale in millimeters (or inches) should be taped or glued to the floor of each, so that when one box is slid into the other, the tapes will be aligned. The boxes can then be nested and the vertical ends slid toward one another, with a maximum size range between about 30 and 56 cm (12 and 23 inches). This range is greater than expected for adult human long bones and should allow for accurate measurements. The procedure is to place a bone to be measured in the assembled box with the proximal end against the vertical end and then to slide the vertical end of the second box to abut against the box at the distal end. The lengths of the bone can be accurately measured by adding the dimensions read from the scales on the floor of each of the two boxes. Having two vertical ends against which each bone can be placed ensures that all bones are oriented similarly to ensure repeatability of measurements, eliminating the variation inherent in measurements made with a ruler or measuring tape (Figure 2).

Figure 2. (A) A portable osteometric board available from commercial sources and a long bone placed in the correct position for measurement. (B) An inexpensive version, modified nested boxes with scales glued to the floors. Students can construct the device as an additional class exercise. (C) Students use the device to make measurements that can be replicated reliably.

O Experimental Procedures

1. Determining the age of a skeleton

Individuals under the age of 20 years. Ages of humans of 20 or fewer years can be determined because the ends of the epiphyses have not fused to the diaphyses. The bone elements of different joints join at different times, and an assessment of the degree of fusion and the list of joints can assist in determination of age in a young individual (Figures 1 [I, A] and 3). Age in children can be estimated from the timing of the eruption of the teeth (Schour & Massler, 1944; Figure 1 [I, B]). Tooth eruption patterns correlated with age are available from many published sources (e.g., Bass, 1971). Each student group should have a copy of this chart as a reference.

Individuals over the age of 20 years. Once the epiphyses have fused, the individual is considered an adult. Adult ages can be estimated by several methods, including the degree and location of cranial suture closure (Todd & Lyon, 1924, 1925a, b, c; Meindl & Lovejoy, 1985; Figures 1 [I, C] and 4), the degree of erosion of the pubic symphysis (Figures 1 [I, D] and 5), and the amount of osteophytic lipping of the vertebral bodies (Rothschild & Martin, 1993; Figures 1 [I, E] and 6). General signs of aging of the skeleton include bone thinning, increased porosity, and greater evidence of bone remodeling (Figures 1 [I, F] and 7).

2. Determining the sex of a skeleton

At present, adult skeletons can be distinguished more reliably than those of children. The appearance of secondary sexual characteristics makes this possible. Table 1 summarizes the appearance of characters that can permit sex determination in human crania.

Estimating sex from the cranium. The skull is the most diagnostic part of the skeleton, and many characters are important (Figures 1 [II, A] and 8). In general, the features of male skulls are more robust, larger, more angular and prominent than those of female skulls (Bass, 1971). These include: the inion process, the mastoid process, the frontal ridges, the dentition (Miles, 1958), the dental arch, the shape of the chin, the shape of the angular process, the zygomatic arch, the cranial sutures, and the overall thickness of the cranial bones (Bass, 1971). Some of these characters are subjective and there is a different range of variation for each, so students will need to judge the reliability of each character and its usefulness in determining sex. Students should examine the skulls and mandibles for each of the 10 features described here and decide how many indicate that an individual is male or female. The more consistent the characters are, the more confidence they can have in their estimate. The level of confidence should be indicated in the result of the sex determination exercise (Ubelaker, 1989).

Estimating sex from the pelvis. Next to the cranium, the pelvis is the easiest bone to use in determining the sex of an individual (Figures 1 [II, B] and 9), and students should assess characters from both skeletal regions. The descriptions of pelvic characters are more variable than those of skull characters. They include (1) a narrow pelvis (even if the bones are more robust in males), (2) a narrow sacrosciatic notch in males (~30°), (3) a narrow subpubic angle, (4) absent or shallow pre-auricular sulcus (deep groove in females), (5) flat auricular area of the ilium (area of articulation with the sacrum), (6) larger symphyseal face in males, (7) flat medial portion of the ischiopubic ramus in males, (8) larger acetabulum in males, (9) shorter pubis in males, and (10) no ventral arc on the pubis (Stewart, 1968; Krogman & Iscan, 1986). As with the 10 cranial characters, students should examine each pelvic character and see how many indicate
in height between taller females and shorter males. Therefore, it is more probable that the tallest specimens are male and the shortest female. There are also many other means of estimating sex from different bones, and students could be required to identify several of these characters.

3. Determining the stature of a skeleton

It is possible to estimate the stature of a skeleton by using several methods and many different individual bones or combinations of bones, even when a complete skeleton is not available. In keeping with the theme of collecting and comparing different data sets, it is suggested that students use two methods and compare their results.

Two methods that require measuring a minimum number of bones were devised by Fully and Pineau (1960). These formulas are as follows:

1. Stature = 2.09 \times (\text{femur length} + \text{sum of body heights of 5 lumbar vertebrae} + 42.67; and
2. Stature = 2.32 \times (\text{tibia length} + \text{sum of the body heights of 5 lumbar vertebrae}) + 48.63. The measurements (cm) shown here can be made using an osteometric board or the measuring device illustrated in Figure 1 (III). The metric system is normally used in scientific measurement, but if required these results can be converted to feet and inches by multiplying centimeters by 10 and dividing the product by 307.

4. Estimating ethnicity

The cranium reveals most of the characters that allow determination of the ethnic affinities of an individual (Figures 1 [IV, A] and 8). Human crania are traditionally divided into three groups: Asian, African, and Caucasoid. Cranial characters include (1) wide nasal apertures (African), (2) narrow

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**Figure 3.** Anterior view of a young adult human skeleton, showing the epiphyses of the long bones and the times at which they fuse.
Figure 4. Chart showing the pattern of ectocranial suture closure as a means of estimating age from the human cranium (after Meindl & Lovejoy, 1985).

Figure 5. The changes that occur with aging of the pubic symphysis (after Brooks & Suchey, 1990).

Figure 6. Examples of osteophytic lipping of the bodies of the lumbar vertebrae. (A) Anterolateral view of the lumbar region of a normal, healthy adult human vertebral column. (B) Lateral and (C) posterior views of a lumbar vertebra with moderate development of osteophytic lipping. (D–E) Extensive osteophytes, anterior views. (F) Magnified view of the large osteophyte on lip of E.

Figure 7. Examples of bones showing age-related and other pathological changes, including (A and B) parietal thinning (C and D) thinning of the scapular body (E and F) translucency of the iliac region of the pelvis (G and H) translucency of the acetabulum. Specimens A, D, F, and H were photographed under typical lighting; specimens B, C, E, and G were backlit for photography.
Table 1. The characters of skull and mandible that reveal sex in humans.

<table>
<thead>
<tr>
<th>Character</th>
<th>Condition</th>
<th>Sex determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inion process</td>
<td>Large and prominent</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Small and smooth</td>
<td>Female</td>
</tr>
<tr>
<td>Mastoid process</td>
<td>Large, rugose, and robust</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Small, gracile, and smooth</td>
<td>Female</td>
</tr>
<tr>
<td>Frontal ridges</td>
<td>Large, prominent, and rough</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Smooth and flat</td>
<td>Female</td>
</tr>
<tr>
<td>Dentition</td>
<td>Large, squared, and angular</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Small and rounded</td>
<td>Female</td>
</tr>
<tr>
<td>Dental arch</td>
<td>V shaped</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>U shaped</td>
<td>Female</td>
</tr>
<tr>
<td>Chin shape</td>
<td>Squared and prominent anteriorly</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Rounded or V shaped, gracile</td>
<td>Female</td>
</tr>
</tbody>
</table>

Figure 8. The human skull in (A) anterior view and (B) lateral view, illustrating features used to determine sex and ethnicity.
5. Pathological observations

Students should examine each skeletal element for defects. The most common clue to a problem in a bone is increased porosity in a given region, so this is the sign students should look for initially. Porosity may indicate changes in bones that result from aging, illness, or trauma. These categories of abnormalities can be distinguished on the basis of either regional bone loss or deposition of additional bone, as in osteophytic lipping of vertebral centra, especially in the lumbar region of skeletons of older individuals (Figures 1 [V] and 6). Healed fractures and other skeletal traumas leave areas that are either thinner or thicker than the undamaged bone (Figure 7). When a bone has been subjected to trauma, the injured region is often surrounded by areas of thinner bone that result from regional resorption and porosity of the bone surface. These effects indicate hypervascularity surrounding the area of necrosis caused by the injury (Rothschild & Martin, 1993).

Other bones that may indicate ethnicity include (1) the sternum, which may show an opening that is frequently mistaken for a healed entry wound from a bullet in the lower aspect of the manubrium (African) (Figures 1 [IV, B] and 10); (2) the femur, which shows an anteriorly oriented bowing (African); (3) greater bone density than typical (African); (4) femoral shaft bowed anteriorly (Asian); and (5) considerable torsion at the femoral neck (Asian). Other characters may also indicate ethnicity, but they are less common or conclusive (Figure 10).

Conclusions

We anticipate that students will find these exercises an impetus toward learning the names of the anatomical characters that they use for estimating age, sex, stature, ethnicity, and diagnoses of pathologies. We also anticipate that the emphasis on variability in all areas of the human skeleton will highlight the uniqueness of each individual and encourage students to relate skeletal anatomy to their own bodies. These exercises teach students how to generate and manipulate scientific data and evaluate the quality and reliability of their results. This should enable students to recognize...
patterns and relate the investigation of pattern to other anatomical systems and biological processes. The experience will test students’ skills under new conditions and help them add new information and means of acquiring data to their previous understanding of anatomy.

Acknowledgments

We thank E. Becker for permission to photograph bones from the teaching collection of the Department of Biology, Elgin Community College, Elgin, Illinois, and Barb Ball, Department of Biological Sciences Graphics Laboratory, Northern Illinois University, DeKalb, for her assistance with the graphics. This work was supported in part by the Department of Biological Sciences, Northern Illinois University.

References


Appendix. Osteometric Board Construction (see Figure 11).

Tool & Equipment List

Needed:
- Measuring device (yardstick, meter stick, steel tape)
- Cutting device (snap-blade, utility knife, single-edged razor)
- Marking device (pencil, pen, fine permanent marker)
- Pasting material (glue, paste, spray glue)

Useful/helpful:
- Squaring device (drafting square, framing square, T square, anything metal or plastic with known square [90°] corners)
- Long metal or hard plastic straight edge to use as a cutting guide (can be measurer)
- Crimping tool (scraper, spatula, dough scraper; not a sharp edge)
- Clamping device (binder clips, clothes pins, small spring clamps, locking pliers)
- Cutting sheet (any flat expendable material to protect your desk or tabletop)

Figure 11. Osteometric board construction diagram.
Appendix. (Cont'd)

Directions

This is a flexible design that can be used as is or easily scaled up or down. Our version is 24 inches long by 6 inches wide and can be used on objects up to about 40 inches in length. The needed materials are easy to get and free or inexpensive, being mostly cardboard. Some of the tools may be costly but they should be easy to find. The only critical factor in the design is that the slide and the spacers must be of the same thickness and, preferably, the same material. A diagram is provided (Figure 11) for cutting all parts from a single 18-inch by 30-inch sheet of corrugated cardboard (e.g., from a computer or TV box), but smaller pieces can be used as long you pay attention to the critical factor above. The pieces that must be cut are as follows:

- One base, 6 × 24 inches (fixed)
- One slide, 3 × 24 inches (moves, so corrugation should run lengthwise)
- Two spacers, 1.5 × 24 inches, of same material as slide (fixed)
- Two top rails, 2 × 24 inches (fixed)
- One front end plate, 4 × 6 inches (moves)
- One sliding end-plate brace, 3 × 7 inches (folds and moves)
- One large piece of material to use as a cutting mat

Also needed are some tools and fastening items (listed above). You will need a cutting tool, such as a snap-blade knife, single-edge razor, or scalpel (scissors do not work well) to cut the pieces to size. You will need a measuring tool longer than 24 inches (a yard or meter stick, preferably a metal one, works well) and a marking device such as a pen or pencil. In addition, you will need some fastening material such as glue or paste (white glue and cooked paste work well). Because several square corners are required, try to obtain a framing or drafting square. Some pieces need folding, so a stiff spatula or scraper will be useful for crimping the corrugation along the fold lines to make folding easier and more exact. Whenever possible, measure from a commercially cut edge, which will usually be more accurate than hand-cut edges. Similarly, using your measurer (again, preferably metal) as a cutting guide will make your cuts more accurate. The quality of the end product will be only as good as the quality of the work put into it.

Having gathered the materials, start laying out/drawing all the measurements and shapes on the cardboard (Figure 11). Consult diagrams and sketches as needed, especially with regard to the end plates and braces. Although they can be added later, it may be best to mark all the fold and secondary cut lines on the end plates and braces before removing them from the basic material. Once you have all laid out, begin cutting out the pieces. Use the measurer or straight edge to ensure no movement, remove the clips, clamps, or weights that does not meet in the center.

Check the glue, last piece first. If all has dried enough to ensure no movement, remove the clips, clamps, or weights and apply a layer of adhesive to the top of the spacers. Again, complete coverage but not too thick: thickness encourages slippage. Place the top rails down over the spacers, aligning the outside edge of the three layers. The rails hang over the interior slot by a half inch. Clip, clamp, or weight as you did before. While the adhesive is setting, you can move on to making the sliding end plate.

This part consists of two pieces, the plate (4 × 6 inches) and the brace (3 × 7 inches). The plate is simply a flat sheet, which you must mark so that you can center it on the brace. This brace is shaped much like the front end plate but is smaller and must be attached to the slide and the sliding end plate. This is done in a way that allows this plate to move over the top rails as the slide moves through the slot under them. You can leave this as a box-like piece or angle the sides as shown. Mark the cut and fold lines if you haven't already. Cut and remove the 2 × 1 inch piece from the bottom edge. Then crimp along the fold lines and fold, flaps up and wings over the top rails as the slide moves through the slot under them. You can leave this as a box-like piece or angle the sides as shown. Mark the cut and fold lines if you haven't already. Cut and remove the 2 × 1 inch piece from the bottom edge. Then crimp along the fold lines and fold, flaps up and wings to the center. This time, the flaps should come together to make a bottom to the semi-box. You should have four sides, so to speak. Place the slide (3 × 24 inches) in the slot and push it completely in. Place the brace in the slot but on the slide with the closed end facing front and the open end at the back edge of the slide. Mark the position of the front of the brace on the slide. Place the sliding plate on the rails and against the front of the brace. Center it on the brace and then mark the brace where the plate contacts the slide. Remove the plate and brace. Apply adhesive to the bottom of the folded flaps and return it to its position on the slide, which is still in

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the slot. Be careful to fasten it to the sides of the slot. Clamp or clip until it sets up.

While the brace is setting up, position the front end plate on top of the rails with the open end in and the flat front lined up with the end of the base, spacer and rail set. Mark, fasten, and clip/clamp to the base unit. Allow it to set up before disturbing. Once it sets, you can go back and finish the sliding end plate. The reason for the wait is that the sliding end plate will need to be trimmed slightly so that it can move all the way forward and fit tight against the front end plate. As soon as it has set, place the sliding plate up against the open end of the fixed plate structure and mark or measure it so that you can cut off enough material that it can fit inside and slide up against the front plate. Trim the sliding plate and refit to be sure it will fit smoothly. Now simply push the slide and brace forward into the front support. Apply adhesive to the front side of the brace, position the slide plate inside the support, and clip/clamp the slide to the brace. When all has set and dried, the construction is done. Next, you will need to add a scale of measurement to the device. You can use either the metric scale or the American inch scale, as long as the application process is followed.

We are simply going to transfer values from a master scale or ruler to the board, but this needs to be done carefully. Our master needs a zero edge, no run up. The marking tool should be fine and should leave a nonspreading mark (pencil, good ink pen, etc.). An alternative is to use a paper tape-measure that can be glued in place or a plastic one with adhesive already applied. Start with the face of the front plate as the zero point. You will be putting the unit marks on the top rail, not on the slide. Mark carefully toward the sliding end position using the smallest unit you can. As you near the end of the base, watch carefully because you need to stop on a whole unit such as 20 or 21 inches (or in metrics). Having done this much, you can get a value for anything that fits between the two plates. To extend the capacity, we need to turn things around and work from the face of the sliding plate and mark on the slide. There are two ways to do this. The first is to start from zero again at the front of the slide plate and mark down the slide to, say, 20. Now, as the slide extends past the base, note the number of units past the point on the slide and add it to the base for a total length; 21 on the base + 6 and 3/8 on the slide = 27 and 3/8 units. The other alternative, which works very nicely with the tape technique, is to be really careful with the end point on the rail, getting a good square cut, and then simply lay down the tape in reverse on the slide. Thus, the end point on the rail becomes the starting point on the slide. If the rail units end at 21 and the slide extends beyond the base, so that 21 on the base is opposite 31 and a half on the slide, the object is 31 and a half units long. Either system should allow you to get reasonable measurements on objects up to 40-44 inches. Beyond that, there will be stability problems unless you scale everything up.