Steven R. Cummings, MD

2. Protocol:
"Defining Points on Vertebrae for Digitization"

Defining Points on Vertebrae for Digitization

Human vertebrae are bilaterally symmetrical, that is, the left and right sides are approximate mirror images of each other; however, they are asymmetrical back to front and top to bottom. Ideally, when the patient has an X-ray of her spine, she will be lying in such a way that these mirror image sides exactly overlap. In reality, this precise overlap is difficult to achieve for a number of reasons: scoliosis (rotation) of the vertebrae side-to-side or around the axis of the spine may be present; the patient may have wide hips which, when uncorrected by a bolster at the waist, cause an unnatural sideways curvature of the spine; or the vertebrae under consideration are distant from the focal point of the X-ray and are imaged at an oblique angle. In the present study, we wish to evaluate the posterior, anterior and middle heights of the body of the vertebrae along with the cross-sectional area and shape. These features must be measured with sufficient accuracy to determine if fractures of vertebrae have occurred. In order to achieve this accuracy, the following protocols have been devised.

Vertebral Anatomy

The body of a vertebra can be likened to a cylinder with slightly kidney-shaped bases (Figure 1). When viewed from the side, the outer compact bone forms a lip at the top and bottom of the cylinder. This lip functions as a surface for the attachment of intervertebral disks and is larger in the lumbar vertebrae, which support more weight than do the upper thoracic vertebrae. There is a narrowed waist in most vertebrae at mid-height. The resulting hourglass shape may be accentuated by the accrual of bony spurs on the upper and/or lower edges of the vertebrae (Figure 2). When vertebrae lose density,

as occurs in osteoporosis, they may be seen with varying degrees of flattening or wedging as they are crushed under the weight of the patient's body (Figure 3). This crushing may give a wrinkled or wavy appearance to the vertical edges. The digitization protocol is meant to account for these irregularities while estimating the vertebral dimensions.

Selection of Points

Six points are determined on the vertebral body to yield the posterior, middle and anterior heights. Points are registered in a clockwise direction beginning with the superior posterior point. The posterior edge is oriented toward the left. From these points any posterior, medial and/or anterior wedging or flattening can be calculated as ratios of these heights. These points need to be determined carefully since a 1 mm difference in height can imply a 5% change in a vertebra of 20 mm height. Although the lumbar and lower thoracic vertebrae are relatively large (3.5-4.5 cm), this variation will make a significant difference in evaluating the smaller, upper thoracic vertebrae which may be only 2.0-2.5 cm in height. The same reasoning applies to determining the width of the vertebrae. On the other hand, the measurements should not be attempted with such excruciating accuracy that the technician is unable to evaluate the spine films in a timely fashion. There are other inherent inaccuracies in the measuring procedures, such as varying focal length and distortion of the vertebrae, as mentioned above, which make extreme (<1%) precision impossible.

The Anterior Points: The upper and lower anterior points are often the easiest to determine (Figures 4A and 5A). Because the ends of the vertebral

body are often slightly broadened or have spurs appended to them, the outermost extent of the body is described by a line along the waist of the vertebra parallel to the vertebral axis. This line is extended upwards and downwards until it intersects the upper and lower edges. These intersections are the upper and lower anterior points (digitizing points 3 and 4).

The Posterior Points: The upper and lower posterior points (digitizing points 1 and 6) (Figures 4B and 5B) are placed, in the lumbar and lower thoracic regions, at the upper and lower extents of the rounded edges of the body and, in the upper thoracic region where these rounded edges are replaced by a bright forked images, in the base of the forks. However, the posterior points are frequently difficult to determine, especially if there is axial rotation of the vertebrae. A convenient clue that indicates the presence of this rotation is the appearance of pairs of bright oval cross-sections of the ribs as they diverge from the thoracic vertebrae, so that two posterior edges can be seen, at least in their upper and lower extremes. In the middle of the vertebral body, the posterior edge is obscure since the two pedicles extend from here to surround the vertebral foramen. In the thoracic region, a bright line will extend vertically along the posterior portion of the body, probably indicating the denser compact bone of the inner curve of the kidney-shaped basal cross-section as viewed from the side. In the lumbar region, this single line may be duplicated in part, probably indicating the denser compact bone of the convex contours. The more posterior of these two lines is fainter,while the other, more brightly defined line indicates a posterior edge superimposed over compact bone of the inner contour. The latter superimposition is more easily identified and should not be mistaken for the posterior edge in the rotated vertebra. Rather, midpoints should be taken between the two upper posterior

corners and the two lower posterior corners to determine the average upper and lower extent. The use of midpoints avoids under- or over-estimating the depth of the posterior edge and hence an under- or over-estimate of the cross-sectional area.

The Midpoints: The middle height of a vertebra is the distance between the upper and lower midpoints (digitizing points 2 and 5) (Figures 4C and 5C). These are each arrived at in two steps. First, a horizontal line is fixed between the upper or lower anterior and posterior points and its midpoint is found. Second, a line parallel to the axis of the vertebra is extended from this midpoint to the upper and lower curves of the oval formed by whichever base is under consideration. The midpoint of this latter line is found and is considered the midpoint of that base. The midpoints are derived in this two-step fashion to give a more accurate outline of the vertebra rather than simply provide the absolute cross-sectional area. The reason for this is that wedging and crushing occur not only along the anterior-posterior axis but are also seen laterally as triangular indentations which can give the vertebra a swayback appearance (Figure 3). The oval of each endplate must be carefully assessed since it may contain hairline fractures which can be mistaken for an edge, the lip for disk attachment may be thickened and mistakenly included (a dense granular appearance), or lateral spurs may be appended (a diffuse granular appearance) and should not be included either.

Numbering the Vertebra

The spinal column consists of seven cervical vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, the sacrum (five fused segments) and coccyx (four segments) (Figure 6). We analyze 13 vertebrae, L4 through T4, although

most of the spinal films have the sacrum, L5-L1, and T12-T2 captured on film. By convention, L5 is the first vertebra above the sacrum; it is usually within the shadow of the iliac crest (part of the pelvic girdle). T12 usually has the lowest set of ribs attached, but this varies. Some individuals have no short ribs or have short ribs that emerge from T11. Thus, it is easiest and most accurate to count upwards from L5 to T4.

The entire vertebral column is recorded on two X-ray films, so matching of the equivalent vertebrae from film to film is necessary. This is accomplished by comparing landmarks on the vertebrae such as spurs, curvature of vertebral bodies, angles between vertebrae and intervertebral inclusions. Vertebrae are numbered with a china marker and these markings are retained for matching of vertebrae with later sets of films for the same patient. Generally, L4-L1 are read off the first film and T12-T4 from the second; however, sometimes a vertebra will be more clearly imaged or less distorted on the other film and may be read from it. To indicate this change in procedure, put a slash through the number of the vertebra which has <u>not</u> been read. It is important to emphasize that T12 should not be necessarily defined as the lowest vertebra with a rib since the rib may be missing or too poorly imaged to be identified.

<u>Marking Points</u>

Although a rough collection of data can be achieved by using a freehand style of digitization, it is more accurate to mark points directly on the films with a colored china marker. Often the lumbar vertebrae exceed the scope of the digitizer in both horizontal and vertical extent. Anterior and posterior points can be established first, with the midpoints located with greater certainty afterwards. Midpoints can be conveniently and accurately located using

the crosshairs of the digitizer for the smaller thoracic vertebrae. A particularly useful approach is to mark all the posterior points as they travel up the spinal column and then to come back down the spine for the anterior points. This technique takes advantage of the fact that the vertebral bodies are usually aligned with each other and follow the thoracic and lumbar curves. There are cases, especially in X-rays of older subjects, in which there can be a pronounced stepping of the vertebrae, sometimes by a centimeter or more. The intent of this technique is not to define the points, but rather to assist with choices made in equivocal areas, such as occur with simultaneous extreme lateral and axial rotations, with superimposition of the scapulae or ribs, or with individuals with pulmonary disease. It is important to emphasize that the technician should not extrapolate an otherwise unreadable point. The occurrance of vertebral irregularities is unpredictable. Never invent data. Use the systematic procedures outlined here, not imagination, to select points.

Directions for Using the Digitizer

Turning on the VAX and Digitizer. Depress the upper half of the toggle switch on the back left side of the VAX monitor. In a few moments the white cursor arrow will become clear. Depress the toggle switch on the surge suppressor (on the floor beneath the desk) so that the red light appears. Click the left button on the VAX mouse to open a menu, select CREATE NEW VT220 WINDOW, and click the left button of the mouse while the cursor arrow is on the menu selection. A log-in window will appear.

Logging In. Enter your user name at the prompt, press RETURN, and enter your password and RETURN. At the $ prompt, enter DGMENU and press RETURN to open the digitizer menu options. Type in DG as your menu selection. Enter the name of the study name or subdirectory name you wish your data to be entered into. Please do not attempt to use other menu options since irredeemable damage can be done to the database.

Recording Data for a Patient. Enter the patient name, usually the 5 digit code which corresponds to the X-ray file, and press RETURN. The cursor will appear after the prompt ENTER POINT NUMBER 1. (See Figure 7 for the arrangement of digitizer buttons.) This is referred to as the entry point and two options are available here: entering data points for that vertebra (using CONT button) or skipping to the next vertebra (using the ABORT button). The ABORT button will not skip T4, however; dummy points must be entered, and ABORT pressed to void the data and begin the next patient (see 3 below). Use the CONT button to register the 6 points. Points are registered in a clockwise direction with the superior posterior point chosen as #1. The postierior edge

of the vertebral column is placed on the left regardless of whether the film is marked left or right.

When six points have been entered for a vertebra, the cursor will appear after the prompt DO YOU WISH TO ACCEPT THESE VALUES? This the editing point and several options are available:

1. CONT button accepts values for points and then begins the next vertebra. If you have just finished entering data for T4 (the last point), a new patient will be started. A prompt will appear for each vertebral point to help you keep track of your place.

2. EDIT button causes the prompt ENTER YOUR CHOICE to appear so that you may edit any of the fields. You may belatedly correct the patient name or change the vertebra number upwards or downwards. If you change the number to a lower vertebra, you must re-enter the data for any vertebra above it.

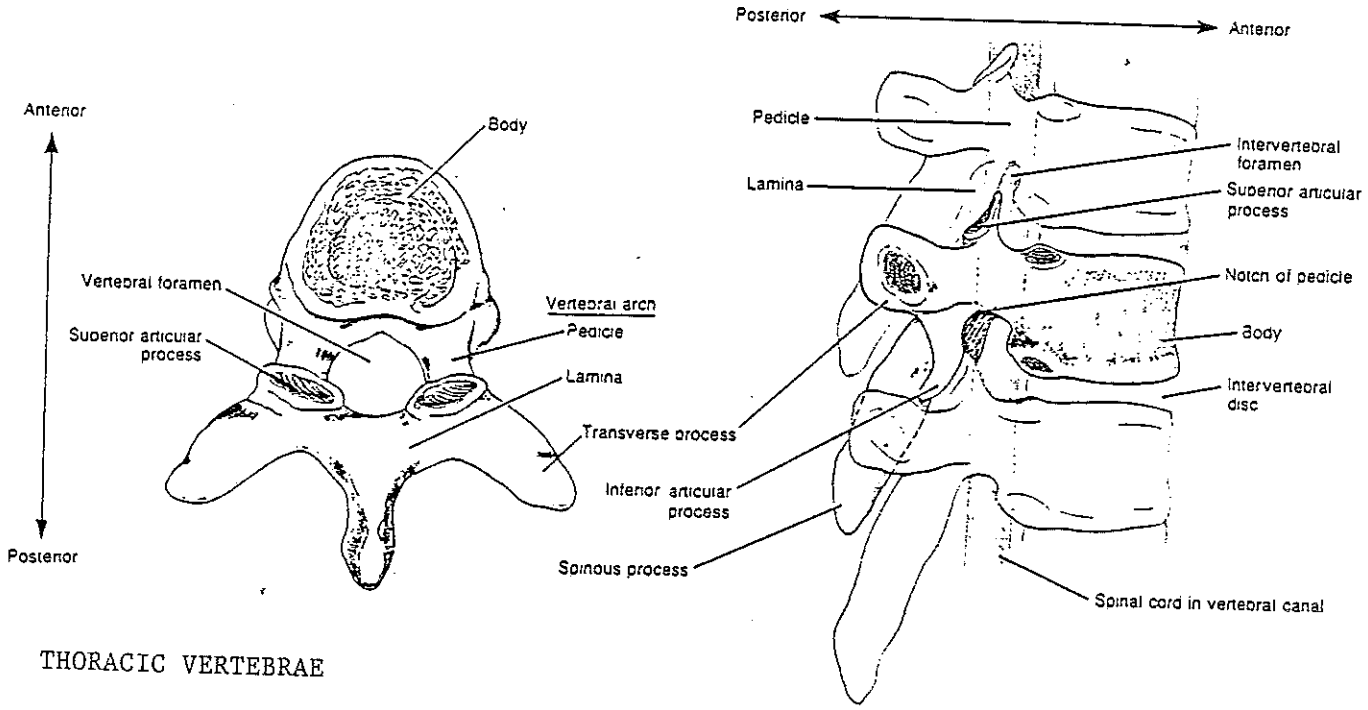
3. ABORT button will truncate the current data set and start a new patient when employed at any vertebra and will not record that vertebra's data. This is the only way in which you can skip T4.

4. RESTART will void data entered for the current vertebra and allow new data to be entered for that vertebra.

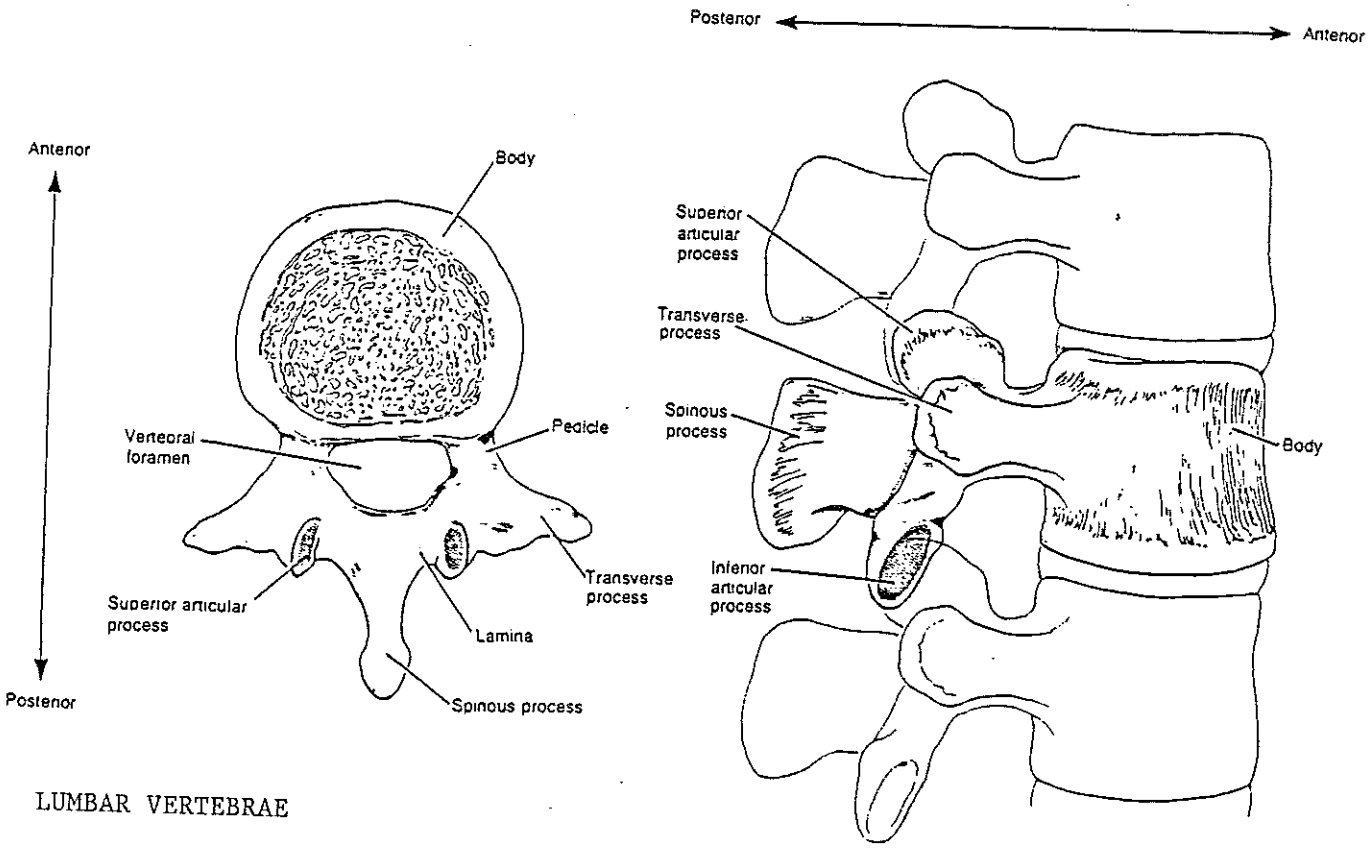
5. The fifth button is non-functional and produces no effects when pressed.

Exiting the Digitizer Menu. When the last vertebra of the last patient has been accepted, the prompt will request PATIENT NAME again. Enter EXIT here and the computer will return you to the digitizer menu. Type in EX as your selection and you will be returned to the main menu. You may log out at this point (type LO and press RETURN) or continue with other work on the VAX. Turn off the digitizer light box using the toggle on the surge suppressor to conserve the fluorescent lights.

Figure 1



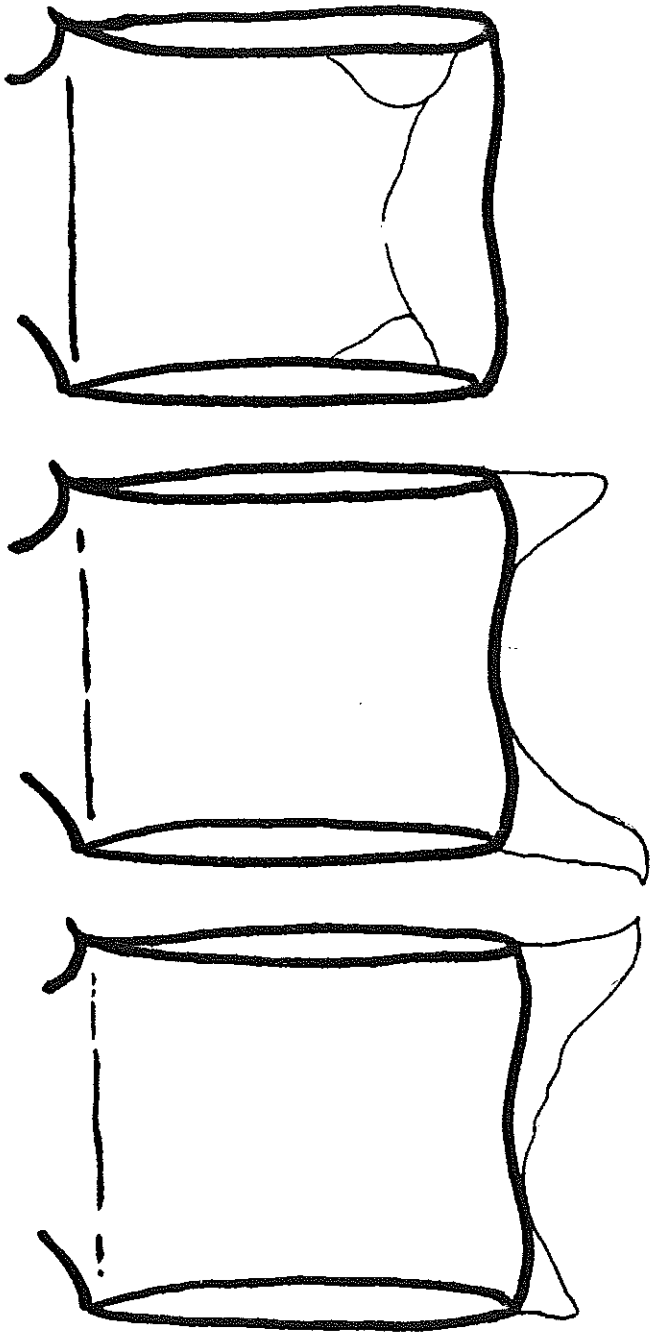
THORACIC VERTEBRAE



LUMBAR VERTEBRAE

Figure 2

TYPES OF SPURS COMMONLY SEEN



laterally occurring spurs

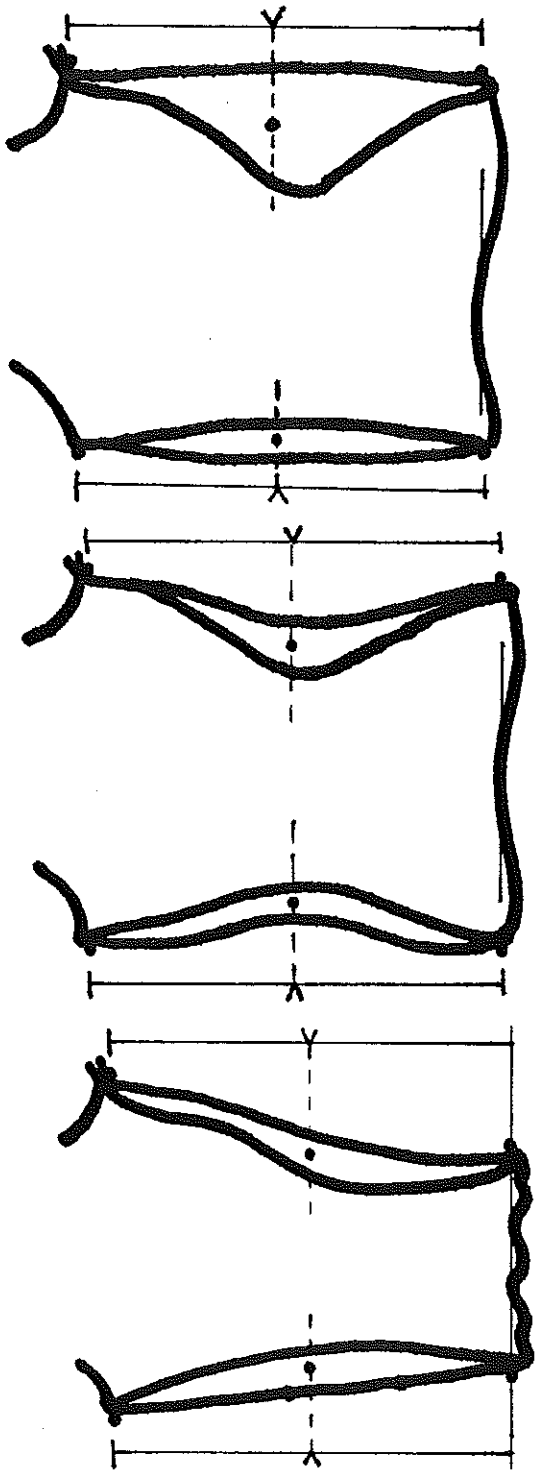
mild spurring w/ line of body still clear.

paired spurs between adjacent vertebrae

spurring which partially obscures anterior edge.

Figure 3

NON-ROTATED VERTEBRAL WEDGES



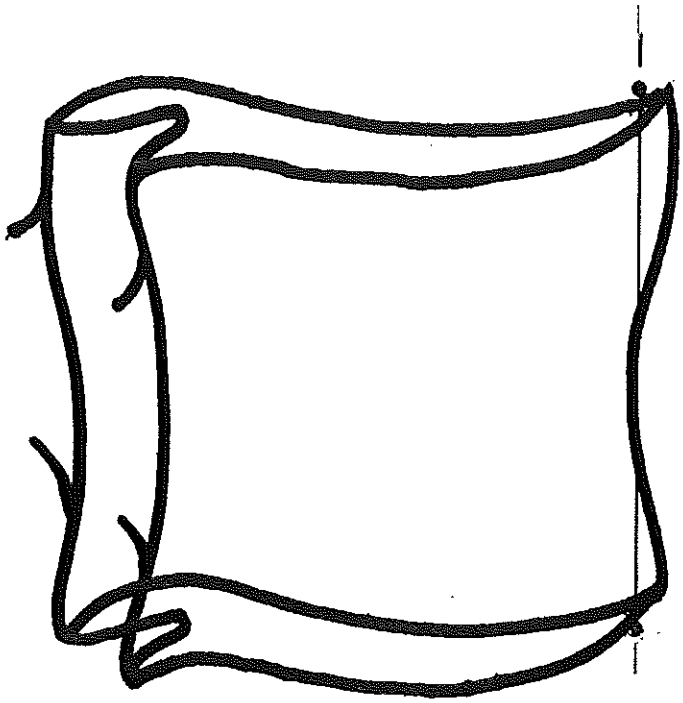
lateral collapse, may occur on upper or lower edge.

typical "swayback"

typical wedged vertebra w/ wrinkled anterior edge.

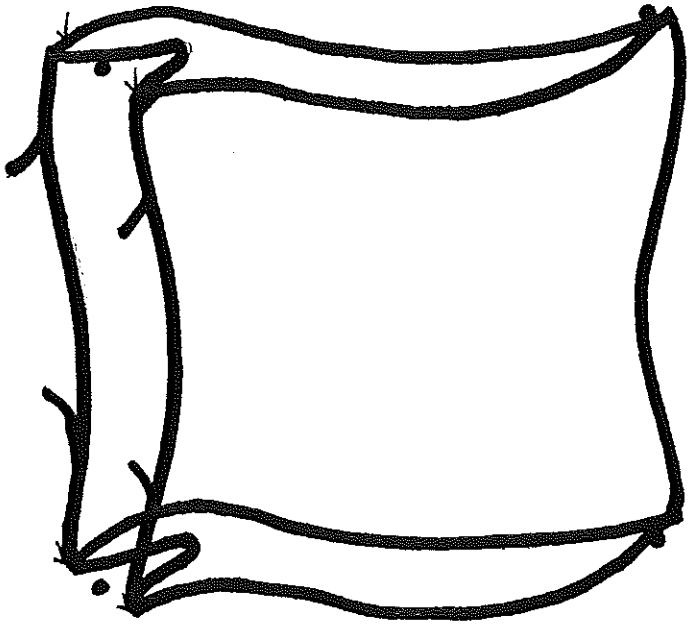
THE ROTATED VERTEBRA

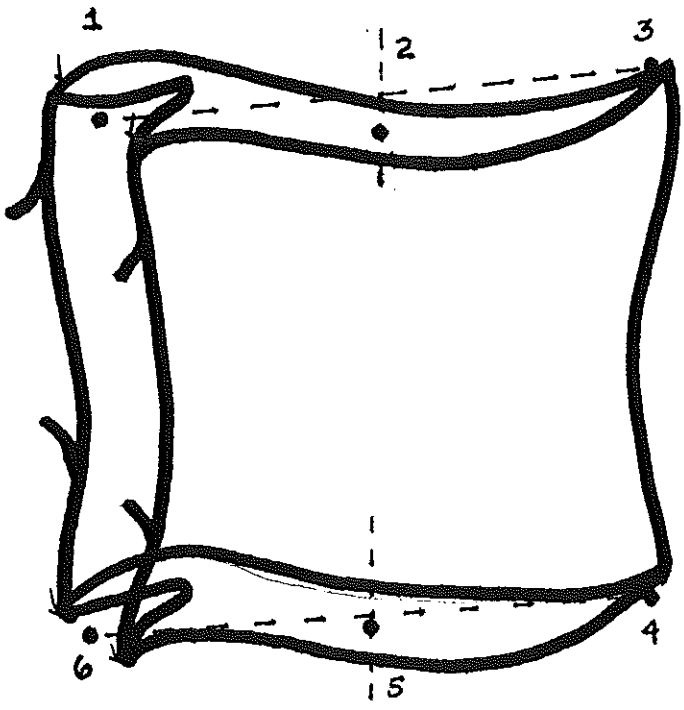
Figure 4



A.
PLACING ANTERIOR POINTS

B.
PLACING POSTERIOR POINTS

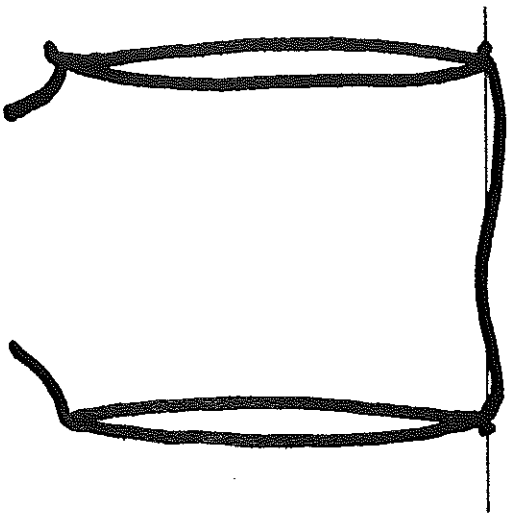




C.
PLACING MIDDLE POINTS

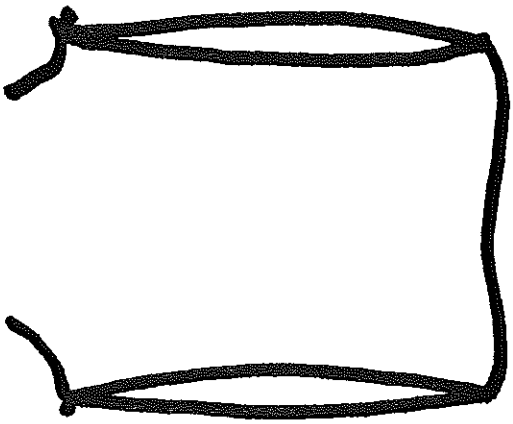
Figure 5

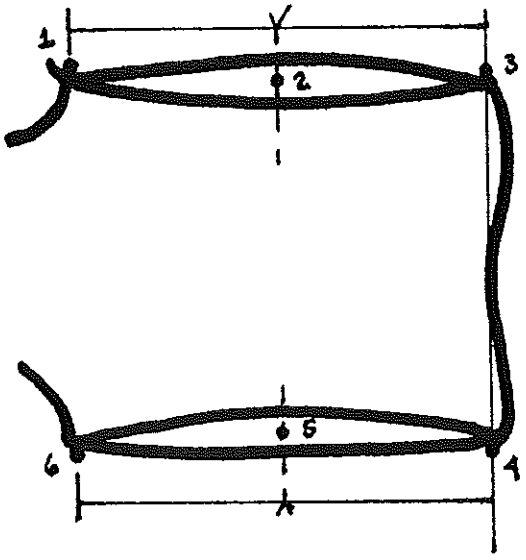
THE NON - ROTATED VERTEBRA



A.
Placing the anterior points.

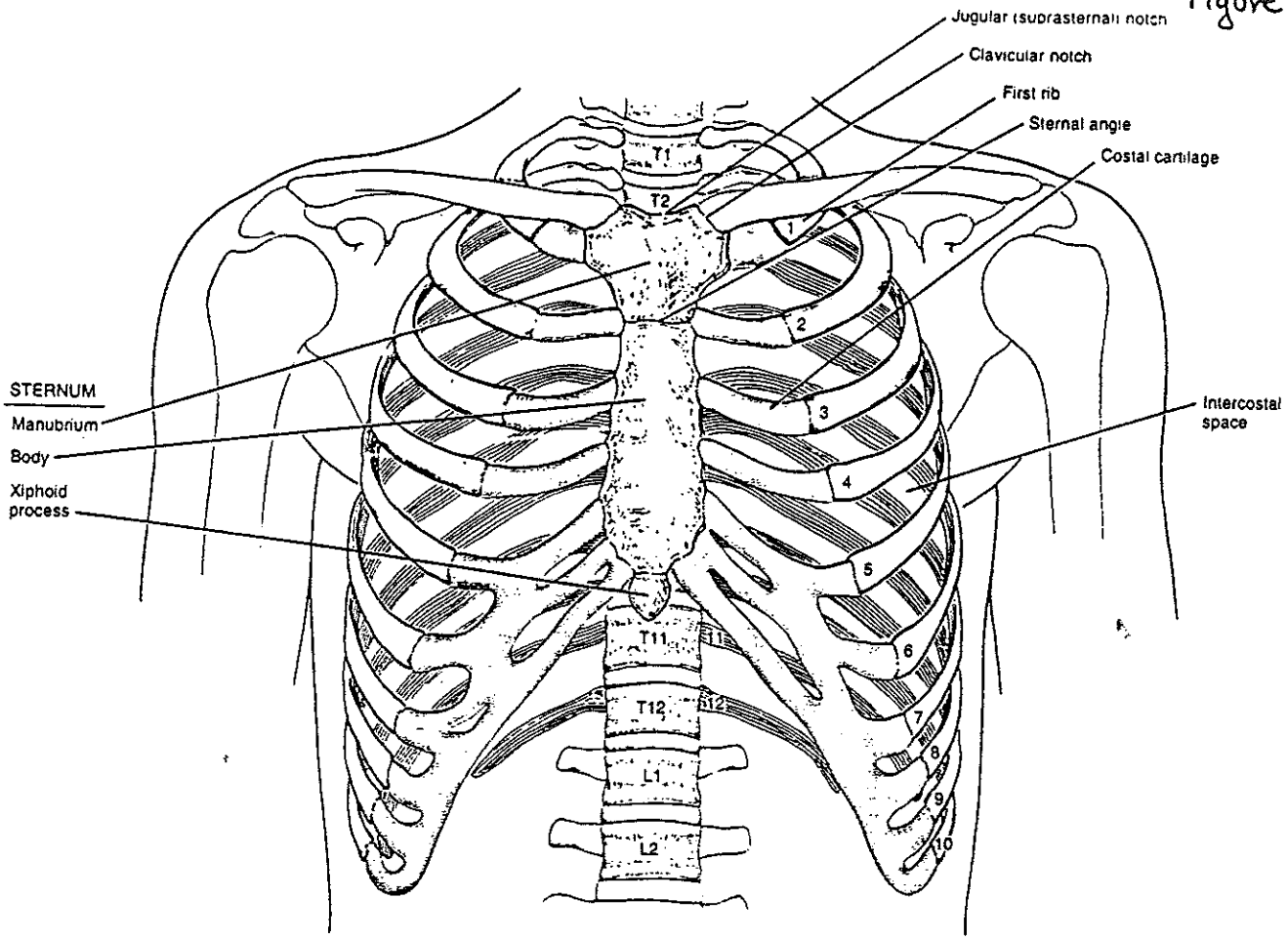
B.
Placing the posterior points.





C.
Placing the middle points.

Figure 6


Jugular (suprasternal) notch
Clavicular notch
First rib
Sternal angle
Costal cartilage
STERNUM
Manubrium
Body
Xiphoid process
Intercostal space
T1
T2
T11
T12
L1
L2
1
2
3
4
5
6
7
8
9
10

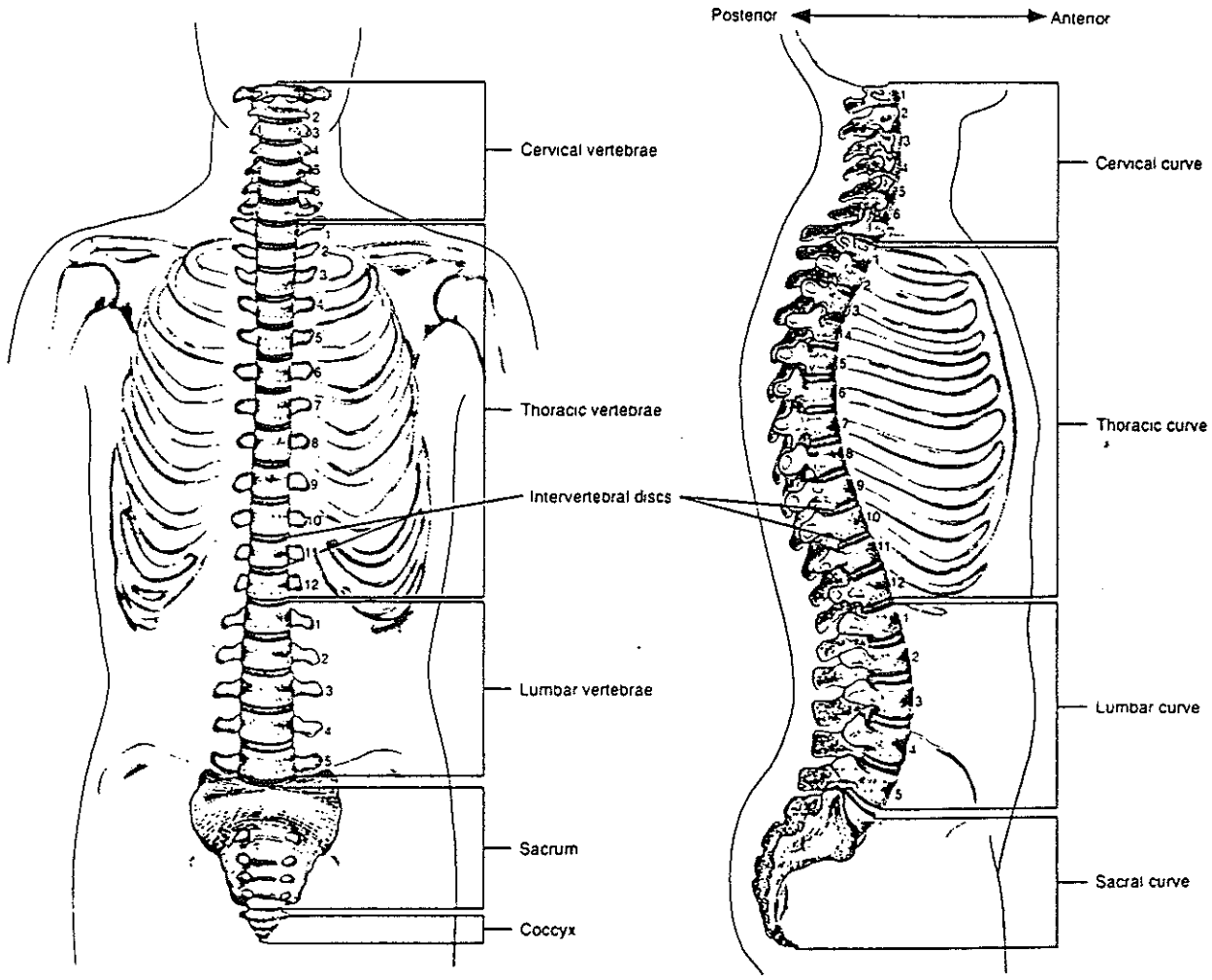
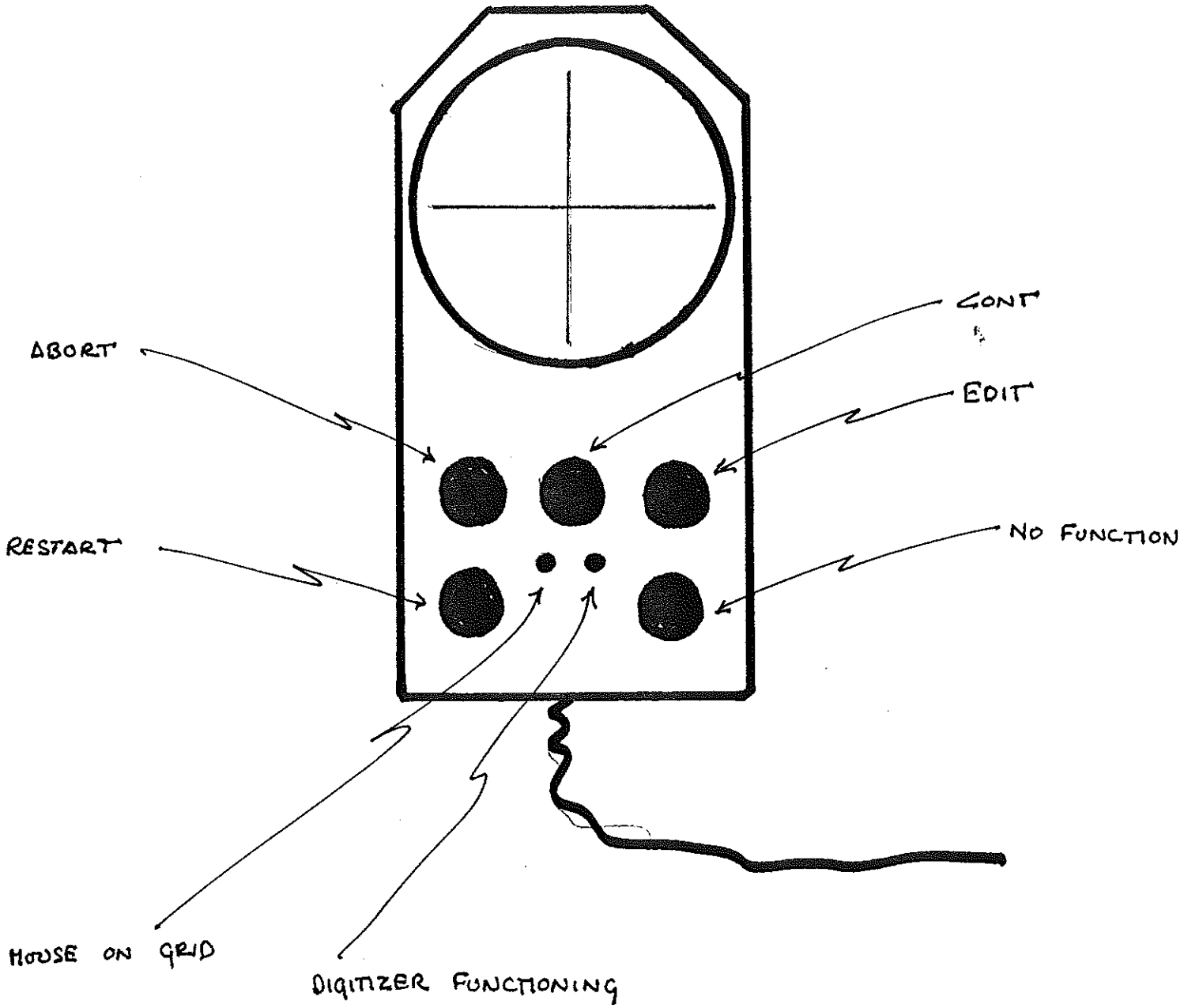

Posterior
Anterior
Cervical vertebrae
Thoracic vertebrae
Intervertebral discs
Lumbar vertebrae
Sacrum
Coccyx
Cervical curve
Thoracic curve
Lumbar curve
Sacral curve

Figure 7



THE DIGITIZER MOUSE BUTTONS