MORPHOLOGICAL INDICATORS FOR PREDICTING THE NUMBER OF PRESACRAL VERTEBRAE

by

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ABSTRACT

Numerical variations in the human vertebral column exist in all populations. Although most people have twenty-four presacral vertebrae, a small number have either twenty-three or twenty-five. The prevalent view is that variations in the position of attachment of the ilia influence the number of vertebrae between the skull and the sacrum.

I tested the hypothesis that identification of anatomical features on the sacrum that indicate the position of attachment of the ilia provide a predictor of presacral vertebral number. Data was collected from 180 skeletons at the Cleveland Museum of Natural History and grouped into three subsamples of 23, 24, and 25 presacral vertebrae. I developed a measurement of the sacrum which was found to be associated with the number of presacral vertebrae at a highly significant level. A number of other characteristics were analyzed for association with presacral vertebral number. Attempts to correlate stature were unsucessful, but a number of variables were associated with my measure. The position of the auricular surface, with respect to the vertebral column, provided the best indicator of presacral vertebral number as it allowed the discrimination of a number of long columns from the rest.

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Chapter I

INTRODUCTION

The human vertebral column exhibits variation in the number of vertebral elements that make up the spine. This has been reported by many researchers regarding both contemporary and past human populations, worldwide. It would appear that a small but significant proportion of every human population has a number greater or less than "normal". The modal number of presacral vertebrae is twenty-four: 7 cervical, 12 thoracic, and 5 lumbar; and of sacral elements is 5. Still other individuals have "compensated columns" with the modal number of twenty-four presacral vertebrae but different numerical arrangements of the types of vertebrae.

Numerous theories have been postulated to account for the variations, and explanations include: an hereditary anomaly expressed by the embryonic germ tissue; an individual functional adaptation; and a progressive evolutionary trend. Studies of complete spines with numerical variation reveal certain changes in the area of the hips which tend to support one explanation of why the number of vertebrae in the presacral column and sacrum is not constant.

The area of attachment of the ilia to the spinal column reveals the greatest evidence of variability. The aim of this thesis is to determine if observations and measurements of only the sacrum and ilia can indicate the number of pre-sacral elements which had been present. This would provide physical anthropologists with information about the individual, and that population, even when the remains of the vertebral column are incomplete, as is so often the case archaeologically.

It would appear from the literature that numerical variation in the vertebral column became of interest in the late 1800's. A large number of reports since the turn of the century refer to the theories proposed by individuals who published in the 1870's to 1890's.

According to Willis (1923b:95): "Early in this study the lumbar group was considered separately, but it soon became apparent that a variation in the number of lumbar vertebrae is often coincident with, and compensated by, a reverse variation in the thoracic group" or "a reverse variation in the number of sacral segments." In addition, the "number of cervical vertebrae has been found practically constant not only in man but throughout the mammalian class" and the "number of coccygeal segments is of negligible importance" (Willis 1923b:95). This is because they "represent a vestigial structure and it is very difficult if not impossible in many cases to state how many segments are present" (Willis 1923b:95). Dwight (1901b:326) pointed out that: "All the spine below the vertebrae supporting the ilium, has but a subordinate function, and consequently is in an unstable condition." For this reason it "is convenient to divide the entire column into pre-sacral and sacral groups" (Willis 1923b:95).

In 1875, Struthers published descriptions of numerous specific cases of variation in the vertebrae and ribs in humans, and included descriptions of similar cases found in other animals in the footnotes. He reported a variation in the form of a first sacral vertebra being created by the addition of the lower lumbar vertebra, and cases where the sixth sacral vertebra is borrowed from the coccyx. One case is described as having an extra lumbar obtained from the sacrum which was compensated by gaining one from the coccyx (Struthers 1875:69). Evidently, Struthers surmised that individual segments could take on different forms but he made no attempt to account for why this might happen. He also analysed a skeleton with six cervical and six lumbar vertebrae, in addition to typical numbers of thoracic (twelve), and sacral (five) and only three caudal, ankylosed together. Although the overall number of precaudal vertebrae is normal, he did not think that borrowing and compensating explained this case. He considered a vertebra to have been suppressed in some part of the column, and he suggested either the cervical or the lumbar region, and gave arguments for both:

> The lumbosacral nerves would seem to indicate that the lowest vertebra is the usual 1st sacral set free, thus accounting for the seemingly deficient

> pelvic vertebra, and leaving 23 instead of 24 vertebrae above. The appearance of suppression of a vertebra in the neck, is met by the consideration that the 7th vertebra carries ribs, imperfectly developed on one side, like cervical ribs. Then although only 11 ribs remain, the next vertebra below, though rib-less, has the normal articular processes of a 12th dorsal (19th vertebra). If it is to be regarded as such, and not as a first lumbar, then the suppressed vertebra would be really a lumbar, although there are six free vertebrae between the thorax and the pelvis (Struthers 1875:75).

In 1876, Rosenberg "maintained that each individual vertebra may be definitely identified and its homology established by determining its serial number, counting backwards from the atlas" (Danforth 1930:464). He believed that "the vertebrae are in a sense plastic and that the character of each is largely a function of its position" (Danforth 1930:465). Rosenberg advocated the existence of an evolutionary phylogenetic process with a trend to shortening of the presacral spinal column by the progressive upward movement of the hind limb. The reason for this contention is the smaller numbers of presacral vertebrae in man and anthropoid apes, as compared to the successively greater numbers "in the line of Primate evolution leading back from them to the primitive mammal" (Willis 1923b:97). Barclay-Smith (1911:162) stated that Regalia predates Rosenberg in offering the "explanation of numerical variation in presacral vertebrae in the relative position of the pelvic girdle, which may presumably shift headwards or tailwards along the vertebral axis." However, no references were given in the Barclay-Smith article.

Rosenberg believed the "iliac attachment of the limb skeleton is supposed to advance along the spinal column during ontogeny" and he ascribes "variation in the adult ... to a failure during ontogeny to carry the processes of reduction ... as far as they are usually carried in the race, or to their being carried beyond this limit" (Bardeen 1904:497). In 1877, Topinard also reported "that ontogenetically there is a progressive shifting forwards of the ilium along the vertebral axis" (Paterson 1893:125). However, this recapitulation of phylogeny through ontogeny is dubious as Bardeen (1904:499) found that the "iliac blastema is differentiated in a region more anterior with respect to the spinal segments than that which the ilium later occupies." In addition, Mall (1905:455) observed that the "center of the ilium appears a little anterior to its center on the 50th day."

In 1889, Rosenberg claimed that the thoracic is a region which is being encroached upon from above by the cervical and from below by the lumbar regions (Willis 1923b). In keeping with the phylogenetic trend, Rosenberg considers an increase in the number of lumbar vertebrae to be progressive if it occurs at the expense of the thoracic region, and retrogressive if it is at the expense of the sacral region (Willis 1923b:98). However, Willis (1923b:102) disapproved of Rosenberg's use of the term retrogression for conditions which are opposite to the general trend; these examples "express merely a lagging behind of a certain number of individuals in the general process of evolution." A criticism raised by Dwight (1901b:325) is that there was no explanation of cause offered.

Willis (1923b:98) agreed with the existence of a phylogenetic process with a trend toward shortening, but unlike Rosenberg, he does not feel the process is taking place at the expense of the thoracic region. When referring to spines with 7 cervical, 11 thoracic, 6 lumbar, and 4 sacral elements, or 7 cervical, 13 thoracic, 4 lumbar, and 6 sacral, Willis (1923b:98) states that:

> ... according to Rosenberg, there is both a progressive and retrogressive variation in the same column, and yet the number of presacrals is unchanged. In applying this theory to those examples one must recognize Rosenberg's 'futuristic' and 'atavistic' tendencies as occuring in one and the same column. This is a rather difficult bit of mental gymnastics, requiring one to lose hold on the phylogenetic process and to seize upon Paterson's theory of 'inherent variability', applying it to each segment individually.

Many authors, including Bateson 1894:110), felt as Willis (1923b: 102) did, that partial lumbarization and sacralization are "lesser stages of the processes concerned in the numerical variations."

The definition of the 'vertebra fulcralis' as the one having the most to do with supporting the ilium, (by contributing the largest portion of auricular surface), was helpful for dealing with the question of how to compare vertebrae of one spine to those of another. For example, should the nineteenth segment of one spine be compared to the nineteenth of another, as suggested by Rosenberg and supported by Keith (1903), or should the first lumbar be compared to the first lumbar, regardless of numerical position? The vertebra fulcralis provides a starting point and reference for comparison for researchers using structural characteristics to determine homology (Dwight 1901b:325, Danforth 1930:464). "In general, the fulcralis is no. 25, but when it is not, some modification is assumed to have occurred elsewhere in the column" (Danforth 1930:466). Paterson (1893:126-127) attributed the naming of the vertebra fulcralis to Holl in his paper dated 1882. However, Danforth (1930:466) reports that Welcker "emphasized the importance of the 'vertebra fulcralis'" as early as 1878.

To explain the different

> number of vertebrae appearing between the fulcralis and cranium, in Welcker's scheme, appeal was had to the idea of intercalation and excalation of vertebrae ... [which is] a theory invoked by Baur [in 1891] (Danforth 1930:467).

Dwight (1901a,b) found cases where different vertebrae acted as the fulcralis on opposite sides of the same individual. This is inconsistent with this theory, but he pointed out that anomalies can be expected in the fulcralis, like those in other parts. In 1881, Welcker described two types of evolution involving the vertebral column: the auxispondylous form, in which there is an increase in the number of thoracicolumnbar vertebrae, which has influenced the majority of mammals; and the lipospondylous form, in which there is a decrease in the number of thoracicolumnbar vertebrae, as has been the case for the higher primates (Willis 1923a:31).

Paterson believed in individual peculiarities and not a phylogenetic process. His hypothesis is one of inherent variability, of shifting of one region at the expense of another. An undifferentiated vertebra becomes a vertebra of a certain type by the reduced or exaggerated development of the costal element of the vertebra due to the correlation of skeletal parts and the shifting of the limb with respect to the vertebral column (Paterson 1889:289). Variations in the position of the hind limb dictate the form of the segments adjacent to them, regardless of numerical position, as they must "serve a similar purpose in supporting the limb-girdle" (Paterson 1889:298).

Paterson (1892) reported that an increase in the number of vertebrae of a certain type is more commonly due to an addition from the lower series than from the higher series. "Liberation of the first sacral vertebra is more common than assimilation of the fifth lumbar vertebra; and assimilation of the first caudal vertebra is more common than liberation of the fifth sacral" (Paterson 1892:523). Thus, he felt there was a greater tendency toward elongation of the column than abbreviation. He discarded inter- and excalation as well as Rosenberg's theory of phylogenetic shortening. He stated that:

> [t]here is no evidence to show that any definite process of either shortening or lengthening of the vertebral column is going on phylogenetically. The variations found are apparently individual peculiarities; which, however, taken together, indicate a tendency to elongation rather than contraction of the presacral region (Paterson 1892:524).

Rather, he felt there is "in the human vertebral column a certain limited variability in the correlation of the several parts" (Paterson 1892:524). Willis (1923b:98) is justified in critisizing Paterson for failing to view the human body as a product of the process of evolution. Paterson seems to have confused what Rosenberg meant by a phylogenetic process operating "in the line of Primate evolution leading back from them to the primitive mammal" (Willis 1923b: 97), with the greater tendency for the pelvic girdle to attach more caudally than cranially in the small percent of individuals exhibiting numerical variation. The human condition has evolved, from a greater number, to have 23, 24, or 25 presacral vertebrae, whereas the majority of mammals have evolved from the primitive mammalian vertebral column to have an increased number (Willis 1923a:31).

In 1891, Baur advocated a theory of inter- and excalation, which referred to the addition or loss of vertebral segments from the body of the column rather than at its extremities, at the stimulus of the embryonic germ cell. Baur (1891:331) stated that:

> "Most morphologists are inclined to the opinion of addition or subtraction of segments at the distal end. But there are others, like Jhering and Albrect, for instance who adopt intercalation.

Despite this mention of others before him, Baur's name is generally associated with this theory. Baur believed the extra vertebrae were created either by "intercalation, or by division of the original segments, or by addition at the caudal end", and the loss of segments was due to either "excalation, union, or loss of segments at the caudal end" (Willis 1923b:99). Some researchers, such as Keith (1903:16), do not support the theory of inter- or excalation but do feel that segments can be shed from the caudal end of the column. Because the last presacral vertebra has particular characteristics even when there is a numerical variation present, Baur believed there was no change at the lumbosacral joint and the variation must have occurred farther up the column (Willis 1923b:100). Willis (1923b:100) felt that the partial sacralization of a lumbar vertebra and the partial lumbarization of a sacral segment were evidence that the variation is localized at the lumbosacral junction. According to Willis (1923b:99), Baur "has based his study upon the modern type of animal without investigating the steps by which it has acquired its present morphological structure ... thereby explaining nothing."

Birmingham (1891:527) used segmentation of nerves, which is primary, instead of segmentation of vertebrae, which is secondary, as the true indication of the condition present. "The last nerve which goes to the limb is the third sacral ... and by observing its numerical position in the spinal series, the wandering of the limb headwards or tailwards may be recognised" (Birmingham 1891:528).

On posing the question as to whether an extra vertebra was due to the "interpolation of a supernumerary segment in the lumbar region or to the conversion of a dorsal on the one hand or a sacral on the other", Birmingham (1891:531) concluded that "the interpolated segment would have no corresponding nerve ... So the connections of the nerves show quite clearly that the abnormal number is not the result of an interpolation." This conclusion is made because the <u>nervus</u> <u>bigemus</u>, which normally comes through the third sacral foramina, comes through the second in individuals with twenty-five presacral vertebrae. This indicates that the "sacrum is but a number of vertebrae modified and consolidated for the support and attachment of the pelvic girdle" and "the increased number of vertebrae in the lumbar region depended upon the connection of the pelvic girdle to the vertebral column, one vertebra further back than normal" (Birmingham 1891:532). He followed Rosenberg's view that there is a gradual shortening of the vertebral column. Referring to Rosenberg, Birmingham (1891:534) said "a condition similar to his ancestral type does occur in man, and this occurrence, which may be considered a reversion to an early type, is a strong argument in favour of the theory which he has advanced."

In 1892, Paterson (1892:524) described three types of individual differences which can occur with respect to the correlation of the spinal nerves and the vertebrae:

> (1) a variation in the arrangement of the nerves without any concomitant variation in the vertebral column; (2) a variation in the vertebral column without any concomitant variation in the nerves; and (3) a coincident variation in both the nervous system and vertebral column.

He went on to point out that: "These varying relations of the nervous system to the vertebral column diminish the value of the spinal nerves in the determination of the serial homologies of the vertebral segments (Paterson 1891:524). However, he added that:

> [f]urther information as to the relative frequency of abnormalities in the disposition of the spinal nerves in the limb-plexuses and the relative frequency of the various modes of correlation of the spinal nerves and vertebral column is required before adequate conclusions can be formulated on this point (Paterson 1892:524).

Bardeen and Elting (1901) studied the variations in the formation and position of the lumbosacral nerve plexus in humans, and found a number of different plexus types, each belonging to individuals with various vertebral formulae. Often the plexus was a different type on the right and left sides of the same individual, and the last spinal nerve to supply the limbs varied from the twenty-sixth to the twenty-ninth.

Bateson (1894:102) distinguished between two types of variation: meristic, which is variation in the total number of segments in the whole spine; and homeotic, which is the variation in the number or ordinal position of the vertebrae in one or more regions of the column and compensated for by changes in neighbouring regions, not necessarily involving change in the total number of segments. He pointed out that it is frequently difficult or impossible to determine the total number of segments due to the problems associated with the caudal series, as mentioned earlier. Thus, it is rare for a case of meristic variation to be identified, although in almost any of the cases of homeotic variation, meristic variation may be present, but obscured.

Bateson (1894:111) also introduced the terms forward homeosis and backward homeosis in order to eliminate the misleading use of phrases sush as 'the movement of the pelvis, either forward or backward along the spine'. Forward homeosis refers to cases where a vertebra develops in the form of a segment which belongs to the series above it, and backward homeosis occurs when a vertebra develops in the form of one from the series below it.

Dwight (1901b:346) accepted Rosenberg's "views on the changes of position of the ilium, and the consequent modification of vertebrae according to the position it finally assumes" but felt the "need of some explanation of cause of these modifications". He could see no other than the operation of a "vital principle", which is a "force acting throughout the organism", implied because "[a]fter the occurrence of the original error in development there is a tendency for the spine to assume as nearly as possible its normal disposition and proportions". Dwight (1901b:339,324,326) felt that irregular segmentation and inter- and excalation are responsible for some numerical variations.

In Dwight's view, irregular segmentation accounts for changes such as unilateral duplication of a transverse process resulting in two transverse processes on one side of the same vertebra. Willis (1923b:100) prefered to consider these types of occurrences as pathological in nature, caused by errors in segmentation and different from the numerical variations and transitional vertebrae which are considered results of a phylogenetic process. Dwight (1901b:324) considered examples of inter- and excalation to differ from irregular segmentation only in that they "imply a correspondence between certain vertebrae at the ends of the series between which the change occurs." He felt the fact that "the vertebrae at the borders of certain regions are characteristic ones and yet there is an abnormal number between them" is evidence that inter- and excalation do occur (Dwight 1901b: 326). However, Dwight (1901b:339,329) said "the condition of a certain vertebra affects that of others, as for instance the effect of a certain vertebra being the fulcralis on the two vertebrae above it and on the sacrum as a whole", and "[i]t seems beyond question that certain vertebrae are capable of having characteristics of those above or below them in numerical order". Believing this to be the case, it seems inconsistent to rely on intercalation to account for an extra vertebra, or excalation for the lack of one. Generally, authors who feel the vertebrae can take on the form required by their function, such as Bardeen (1905:267), who says: "[d]ifferentiation in the post-thoracic region depends apparently in the main upon the position of the posterior limb", do not support Baur's theory of inter- and excalation.

Keith (1903:39,16), supported Rosenberg's view that segments of the same numerical position correspond, and he dismisses suppression and intercalation from the evolution of higher mammals, and claims that only at the caudal end can suppression or addition occur. In his opinion: "it is not a matter of lifting out or inserting a segment, but the gradual transformation of the characters of one segment into those of the one lying next it in the series" (Keith 1903:40). Keith (1903:19) said: "[t]he process of transmutation of the pre-sacral segments and suppression of the caudal began with the change from the horizontal to the upright posture during the evolution of the orthograde type from the pronograde." Keith (1923:500) pointed out that:

> the developmental process which transforms a last lumbar into a first sacral vertebra is not one which works only on bones; all the elements which lie in the same segment of the embryonic body - nerve, muscle, and vessel - undergo a transmutation corresponding to that of the vertebra ... The evolutionary machinery which shapes new forms has to be sought for ... in factors which control the development of embryonic tissues ...

Bardeen (1904) believed numerical vertebral variation to be an inherited condition (racially not individually), which is manifest early in embryonic development. Bardeen (1904:513) reported that "[a]fter attachment of the ilium to the vertebral column is made it is not segmentally altered during subsequent development."

> During the sixth week of embryonic development the scleroblastema of the ilium becomes united to the costal processes of the sacral vertebrae and by various stages the blastemal skeleton of the embryo becomes converted into a cartilaginous skeleton (Bardeen 1904:499).

He considered the primitive vertebrae to be potentially equivalent (Bardeen 1905).

Smith (1907, 1909) described an individual spine of the normal number of vertebrae which exhibited fusion of the atlas and axis. There were "a whole series of harmonious variations and not the disharmonious but compensatory anomalies, which commonly occur in abnormal spinal columns" (Smith 1909:357). The changes are suggestive of a shifting back of the precaudal column by one element, but with fusion and partial assimilation where it was not possible to change an atlas into an axis. His conclusion is that: "It is not an isolated, localized error of development, but part of a widespread indecision on the part of nature as to which somatome was to develope [sic] a definite vertebra" (Smith 1909:358).

Manners-Smith (1909:154) studied the variability of the last lumbar vertebra and found two types of articulation or fusion of the transverse processes to the alae of the sacrum, which can occur on one or both sides. The first type is an articulation of the lateral process which he felt was due to a post-natal mechanical cause. In the second type the lateral process is resolved into its transverse and costal parts and the "costal element may either articulate or fuse with the sacrum" (Manners-Smith 1909:154,155). While he felt "the mechanism is probably the same in both types", this second type is "most certainly produced _in utero_ ... whilst those elements were still in a plastic state" (Manners-Smith 1909:157). He pointed out that "evidence which has been accumulating within recent years would, however, suggest that the sacralisation of the last lumbar vertebra has not the morphological significance it was once thought to have", and "would imply that the transition is an easy one; that a slight mechanical cause is sufficient for its production ... and may, in the Primates, occur at any period of life" (Manners-Smith 1909:159).

Barclay-Smith (1911:162) claimed that the most commonly accepted explanation of the variations was the "compensation theory", which:

> assumes that a more or less fixed homology exists between the individual vertebrae of all spines; that the form value of any vertebra is not absolute, it may assimilate to a greater or less extent to a neighbouring vertebra; variation in form value may lead to numerical reduction or increase in one region, compensated for by numerical in-

> crease or reduction in adjoining region or regions.

He does not attribute this theory to any individual or individuals, but it appears to be in keeping with interpretations made by Struthers as early as 1875.

Mitchell (1936:147) stated that:

> Man's assumption of the erect posture has necessitated many skeletal modifications and they are nowhere more apparent than about the lumbosacral junction. Finality in structure has not yet been attained and developmental abnormalities are abundant ...

Like most researchers by this time, Mitchell (1936:147) believed the:

> total number of segments seldom varies ... [there is] no proof that intercalation or excalation of whole segments occurs naturally, any addition of a vertebra to one region must be associated with loss of a vertebra from another.

A similar view expressed by Danforth (1930:465) was that "the vertebrae are in a sense plastic and ... the character of each is largely a function of its position."

Numerous authors have concluded that there is a genetic basis for numerical variations in the vertebral column (Lanier 1939, Allbrook 1955, Bornstein & Peterson 1966, Tulsi 1972). In experiments with rabbits, Sawin (1937) found that an increase in the number of presacral vertebrae can be "increased by selection which shows that it has a genetic basis." Studies of various human groups are suggestive that the frequencies of the variations are characteristic of a population, as suggested by de Beer Kaufman (1974:369).

The frequency of twenty-three and twenty-five presacral vertebrae from a number of studies can be seen in Table 1. There are some difficulties in making direct comparisons between the studies; the values are influenced by sample size, and differences in the definitions of what constitutes a presacral vertebral variation in number. This latter aspect is often a result of the author's research interest and perspective. Authors dealing with the presacral column often consider the transitional vertebra to be a lumbar if it is free and a sacral if it is fused, however incompletely. Some authors report cases with transitional vertebrae separately, as do Cushway and Maier (1929:703) who, in a study of 931 males, found fifty cases with some degree of sacralization, in addition to the forty-six cases with extra or lacking vertebrae in either the thoracic or lumbar regions. With this method of reporting variations it is impossible to determine frequencies of the tendency to either increase or decrease in number of presacral vertebrae.

Shore (1930) discussed abnormalities of the lumbosacral junction, including transitional vertebrae, in a section separated by thirty pages from his section on numerical variations. He found four cases with a transitional lumbosacral vertebra and seven columns with numerical variation. Because Shore was not particularly interested in the presacral column, it required careful scrutiny of his descriptions to determine that one of his transitional vertebrae

TABLE 1

Reported Numerical Variations

Investigators	Population	Sample Size	% 23	% 25
Paterson (1893)	adult	132	5.3	5.3
Paterson (1893)	embryo	30	3.3	3.3
Staderini 1894 **	Florence, Italy	100	7.0	4.0
Bianchi 1894/1895 **	Prov. of Sciena	130	9.2	2.3
Ancel & Sencert 1901 **	Nancy, France	908	4.7	4.3
Bardeen (1904)	embryo	32	3.1	3.1
Bardeen (1904)	adult, white & black	70	7.1	8.6
Steinbach 1889 **	fetus (4-6 mo)	25	0	4.0
Steinbach 1889 **	fetus (3-9 mo)	55	1.8	9.0
Steinbach 1889 **	children (<1 yr)	50	0	2.0
Steinbach 1889 **	adult	83	3.6	7.2
Topinard 1877 **	Museum, Paris	350	2.3	2.9
Willis (1923(a))	American white	557	4.2	0.7
Willis (1923(a))	American black	185	4.9	1.6
Trotter (1926)	Egyptian adult	39	2.6	7.7
Trotter (1929)	white & black adult	189	4.8	9.5
Danforth (1930)	Inuit	49	6.1	2.0
Shore (1930)	South African	82	1.2	1.2
Stewart (1932)	Inuit	217	0	12.0
Hodges & Peck (1937)	American male x-ray	447	6.7	3.0
Lanier (1939)	American black	100	5.0	7.0
Lanier (1939)	American white	100	3.0	2.0
Allbrook (1955)	East African	206	3.4	11.6
Bornstein, Peterson (1966)	white	488	*4.9	5.3
Bornstein, Peterson (1966)	black	517	*8.3	3.1
Bornstein, Peterson (1966)	asian	234	*3.0	8.5
Tulsi (1972)	Australian	125	4.8	4.0
de Beer Kaufman (1974)	South African black	462	5.8	10.8
de Beer Kaufman (1974)	San	28	7.1	17.9

* includes 1 individual with 22 presacral vertebrae

** reported in Bardeen (1904)

was a twenty-fourth which was partly fused to the sacrum. Thus, this individual had only twenty-three free presacral vertebrae. Of his seven spines with variations, only one had a change in number in the presacral region. This individual had twenty-five presacral vertebrae. Therefore, although Shore's study was not readily comparable to most of the others, it was possible to determine the percentages of twenty-three and twenty-five presacral vertebrae found in the eighty-two skeletons studied.

Trotter (1929:97) analyzed 189 Black and White American vertebral columns and reported only that 9% of the individuals exhibited lumbarization or sacralization and that 6% showed unusual arrangements not involving the lumbar or sacral regions, without further clarification. Three years after her study of South African presacral columns, de Beer Kaufman (1977) conducted a study of precaudal columns of South African Blacks, San, and American Blacks.

Although there is an approximately equal tendency for humans to develop either twenty-three or twenty-five presacral vertebrae instead of twenty-four (Bardeen 1904:516), in the studies of sufficient sample sizes of both males and females, an increased tendency is found for males to have twenty-five and females to have twenty- three (Bornstein & Peterson 1966, Tulsi 1972, de Beer Kaufman 1977).

Paterson (1892) found lower frequencies of variations in the adult than the fetal skeletons he studied. According to Bardeen (1904:510), this "differs greatly from Steinbach ... " Bornstein and Peterson (1966:142) stated that numerical variation is not associated with age, "in contrast to pathologic lumbosacral fusion - a condition which was not present in any skeleton under the age of 40 years ... " Manners-Smith (1909:155) believed that lumbosacral fusion can occur at any stage of life. Lanier (1954:366) felt that lumbosacral fusions "are found in embryos and fetuses and have never been observed to develop in the postnatal period." Thieme (1951:151) reported that the frequency increases with age. Bohart (1929:699) said "[i]t appears to me that a sacralization of the transverse process is an effort of nature to overcome a structurally weak spine at its base, to bolster up and strengthen a weak framework ... "

When determining the bones which fuse to form the sacrum, some authors have attempted to differentiate between sacra of the same number with segments of different origin. For example, Paterson (1893:135) tabulated the frequency of cases with various numbers of bones in the sacrum. He distinguished sacra with five segments from those with four plus one coccygeal, and those with six from those with five plus one coccygeal. Based on appearance of the sacrum alone, these distinctions are of dubious accuracy. The position of a vertebral segment relative to the position of the ilia determines the function of that segment, which in turn determines it's form. Once a lumbar or coccygeal segment has been incorporated into the sacrum it is difficult or impossible to distinguish this vertebra from other sacral segments of the same position. Even in cases of incomplete fusion, it is not readily apparent whether the sacrum has almost gained a coccygeal or has almost released the last sacral.

Le Double (1912:357) expressed this viewpoint:

> Quand on ne possède pas la colonne vertébrale tout entière, il est très difficile, impossible même, de différencier le sacrum à 5 paires de trous de chaque côté, résultant de l'annexion de la 1re vertèbre coccygienne, de celui à 5 paires de trous de chaque côté, résultant de l'adjonction de la 5e lombaire et de celui à 5 paires de trous de chaque côté dont aucune vertèbre n'est empruntée ni aux lombes ni au coccyx.

Apparently Le Double believed in intercalation as well as function determining form and the shifting of the ilia, because he assumes a third case exists where there are six segments with the extra being neither lumbar or coccygeal in origin. If the vertebral column is complete the numerical position of any vertebra can be used to determine its origin, (if the "normal" formula of 7,12,5,5 for cervical, thoracic, lumbar and sacral, respectively, is applied as a standard from which the variations originate).

The possibility of determining the number of presacral vertebrae from an analysis of only the pelvic girdle depends on the existence of evidence on the sacrum of the position of the embryonic attachment of the ilia with respect to the overall column. In individuals with the modal number of twenty-four presacral vertebrae, the ilia attach to the twenty-fifth vertebral segment, which becomes the first sacral element. In cases with either twenty-three or twenty-five presacrals, the ilia attach further up or down the colum, respectively, resulting in the incorporation of different vertebral segments into the fused sacrum.

At the beginning of this century, Dwight (1901b:339) found it "rather surprising that no effort has ever been made to decide whether sacra could be distinguished one from another according to the particular vertebra that happens to be the fulcralis", which is the vertebra contributing the most area to support of the ilium. He then went on to describe certain distinctions between columns with sacra of different numerical composition. Apparently, no one has attempted this yet, and because the method requires knowledge of the entire column in order to decide the numerical position of the fulcralis from the skull, it was not directly applicable to the problem at hand. However, due to the fact that the vertebra fulcralis is determined by the position of attachment of the ilia, I chose it as a characteristic worthy of study, as it may help to reflect the number of presacral vertebrae.

In 1893, Paterson described the characteristics of sacra of spines where the hips had shifted.

> If the ilium is attached higher up on the first sacral vertebra, the transverse process is not well marked, the promontory between the first and second vertebra does not exist, and the first vertebra is fused with the second. If the attachment is lower down, we obtain a gradual series showing liberation of the first vertebra, until at last cases arise, in which, on one or both sides there is a free, non-articulating transverse process to the vertebra which normally is the first sacral (Paterson 1893:129).

Thus it appears that a sacral hiatus between the first and second sacral vertebra is of interest when attempting to determine the position of attachment of the ilia and the resulting number of presacral vertebrae.

Paterson (1893:161) also found that:

> A promontory between the first and second sacral vertebrae occurs frequently; in the majority of cases in association with the presence of six sacral vertebrae, and more frequently in the male than in the female, indicating a greater tendency in the male toward liberation of the first sacral vertebra.

However, these characteristics may be similar to those of sacra incorporating a last lumbar as well as those cases liberating a first sacral.

Thieme (1951) found an anatomical relationship of the pelvic girdle which predisposed individuals to lumbosacral fusion, which is the complete or partial incorporation of the last lumbar vertebra into a sacral member. Thieme's purpose was to investigate whether lumbosacral fusion is a "functional adaptation to the mechanical requirements of erect posture" (Thieme 1951:149). He chose the point of intersection of the arcuate line of the hips to the sacral ala, which was "not arbitrarily chosen because of ease of measurement", but because it is a functional point where the "division of the forces that are transmitted down the spine and out to the right and left legs" occurs (Thieme 1951:157). He found that "persons who have this point of intersection close to, or anterior to, the sacral promontory are predisposed to normal lumbosacral fusion" (Thieme 1951:156-157). In these cases the sacrum is completely or partly out of the direct line of force and new bone is built up, bridging the last lumbar to the first sacral in response to the strain (Thieme 1951).

Although Thieme was interested only in cases where lumbosacral fusion develops during a person's lifetime, it seemed to me that the relationship of the arcuate line to the sacral promontory could be used to determine the position of attachment of the hips with respect to the whole vertebral column. Knowing which segment formed the first sacral element would then reveal the number of presacral vertebrae in the individual.

My hypothesis, in order to be useful to physical anthropologists dealing with frequently incomplete archaeological vertebral columns, had to deal with only the pelvic girdle, assuming no other knowledge of the vertebral column. Therefore, rather than trying to identify cases of lumbosacral fusion (whereby a lumbar has fused to the sacrum) and taking the measure on the original sacrum as Thieme did, I included all of the fused and partially fused segments in my definition of the sacrum, regardless of origin. In this way, an individual with lumbosacral fusion would provide a large measurement of distance from the intersection to the sacral promontory (which was originally the last lumbar). This is in contrast to the small measurement derived by Thieme, who measured only to the original promontory, one complete segment back.

It seemed to me that the large measure would belong to individuals who had incorporated a lumbar into the sacrum. This would be true regardless of whether or not this incorporation of a lumbar occurred during embryonic development, or post-natally as a result of stress from upright posture. Either way, these people would have only twenty-three segments superior to the sacrum. It should follow, then, that individuals with a small measure are those in which the hips attached far enough posteriorly that the usual first sacral element (the twenty-fifth segment), was not required for the transmission of forces from the spine through the hips to the legs. In these cases, the twenty-fifth segment would never have fused to the sacrum, resulting in twenty-five presacral vertebrae. If this is indeed the case, then intermediate values should be found for individuals with the modal number of twenty-four presacral vertebrae, where the hips attached near the middle of the twenty-fifth segment.

Although this hypothesis seemed promising, I realized that the measure would never be an accurate predictor for all cases. Where a "shift" of one entire segment occurs in the attachment of the ilia, the arcuate line would intersect near the center of a segment, looking for all intents and purposes, "normal". There would be no indication that the hips had joined to the twenty-fourth or twenty-sixth vertebra instead of the usual twenty-fifth. However, as these full segment shifts are near the extremes of this type of variation, I expected that they would be relatively infrequent.

Other cases which would not fit well into this scheme would be those individuals with twenty-four presacral vertebrae and a low measurement (typical of twenty-five presacrals), who have not yet developed the lumbosacral fusion resulting from the strain of forces transmitted to the sacrum when the intersection of the arcuate line is close to the sacral promontory. However, I hoped that secondary characteristics, such as articulation of the sacral alae with the last lumbar, would distinguish which individuals were likely to develop the lumbosacral fusion later in life, had they lived. Because these exceptions might prove to be rare, I hoped that they would not stand in the way of finding a measure which could be used as a reliable indicator of the number of presacral vertebrae.

The literature pertaining to numerical vertebral variaton has overwhelmingly supported the view that the form of a vertebra is determined by its function, which can be determined by the position of attachment of the hips. There is some debate as to whether the variation in the level of attachment of the hips is due to a progressive evolutionary trend or individual peculiarities, but there is evidence for a genetic basis, and lumbosacral fusions can develop postnatally. It was this discussion of the varying height of iliac attachment, and especially Thieme's (1951) discovery of an anatomical relationship predisposing to lumbosacral fusion, that led me to investigate the hypothesis that it might be possible to predict the number of presacral vertebrae from the pelvic girdle alone.

Chapter II

MATERIALS AND METHOD

2.1 MATERIALS

Because of the low frequencies of numerical variations in the presacral vertebral column, a large skeletal population was required in order to obtain adequate sample sizes for statistical analysis. The data were gathered at the Cleveland Museum of Natural History which houses the Hamann-Todd collection of over 3,000 human skeletons of known sex and age. These individuals were Cleveland's unclaimed corpses from the first four decades of this century. Because of this, the skeletal population is in no way representative of the population as a whole. The people were mostly immigrants and indigents who had no family to claim them or the family had no money to bury them. Most were male; only about five hundred were female. A large proportion of the people were American Blacks and the Whites were frequently of recent European extraction. For the most part these people were in poor physical health and many died of diseases, especially tuberculosis.

Although the collection is not representative of the overall population, the skeletons are invaluable for research. The vast numbers ensure statistical sample sizes of most skeletal variations, and a large number of pathologies are present. There is a file for each skeleton, and in addition to age and sex information, most contain photographs, autopsy reports, and skeletal assessments.

Approximately 2000 files were searched and all cases with numerical vertebral variations recorded were selected for study. In addition, a number of normal files were chosen for analysis. An attempt was made to include a sufficient number of both males and females over the age of sixteen, for statistical analysis. The analysis forms were prepared by copying down all relevant information from the files before I conducted the analysis of the skeletons. Complete data were gathered for 180 individuals. The raw data can be found in Appendix A. These data are not representative of any real population because of the selection for variants.

Sixty-nine of these 180 individuals (30 female and 39 male) had the modal number of twenty-four presacral vertebrae. Sixty-eight skeletons (3 female and 65 male) had twenty-five presacrals, and forty-three (13 female and 30 male) had twenty-three. Ideally, more females with numerical variations would have been included. However, only one in six or seven individuals in the collection is female, and an increase in number to twenty-five presacral vertebrae, especially, is very rare in females. Every variant female column encountered was analyzed, and the same is true for the males, but time did not permit further searching of the files.

2.2 METHOD

The hypothesis that the pelvic girdle could be used to predict the number of presacral vertebrae rests on the assumption that there are morphological indicators that reveal the position of the attachment of the ilia with respect to the overall vertebral column.

In 1951, Thieme found a relationship which predisposed individuals to lumbosacral fusion. He found that people with small distances from the sacral promontory to the intersections of the arcuate lines of the ilia with the sacral alae, were more likely to develop a lumbosacral fusion. Lumbosacral fusion is, in fact, one type of numerical variation; a lumbar vertebra is partly or completely incorporated into the sacrum, leaving only twenty-three free vertebrae above the sacrum, instead of the modal number of twenty-four.

The relationship of the sacral promontory to the intersection of the arcuate line with the sacral ala is critical to my hypothesis (see figures 1 and 2). However, Thieme's measure could not be adopted per se. Thieme (1951) determined the distance of the intersection from the promontory from x-rays as well as skeletal material. In order to make both samples comparable, he made mathematical corrections to compensate for distortion in the radiographic films. However, the two samples were not compared, and his method was only described for finding the points and taking his measure from the x-rays.

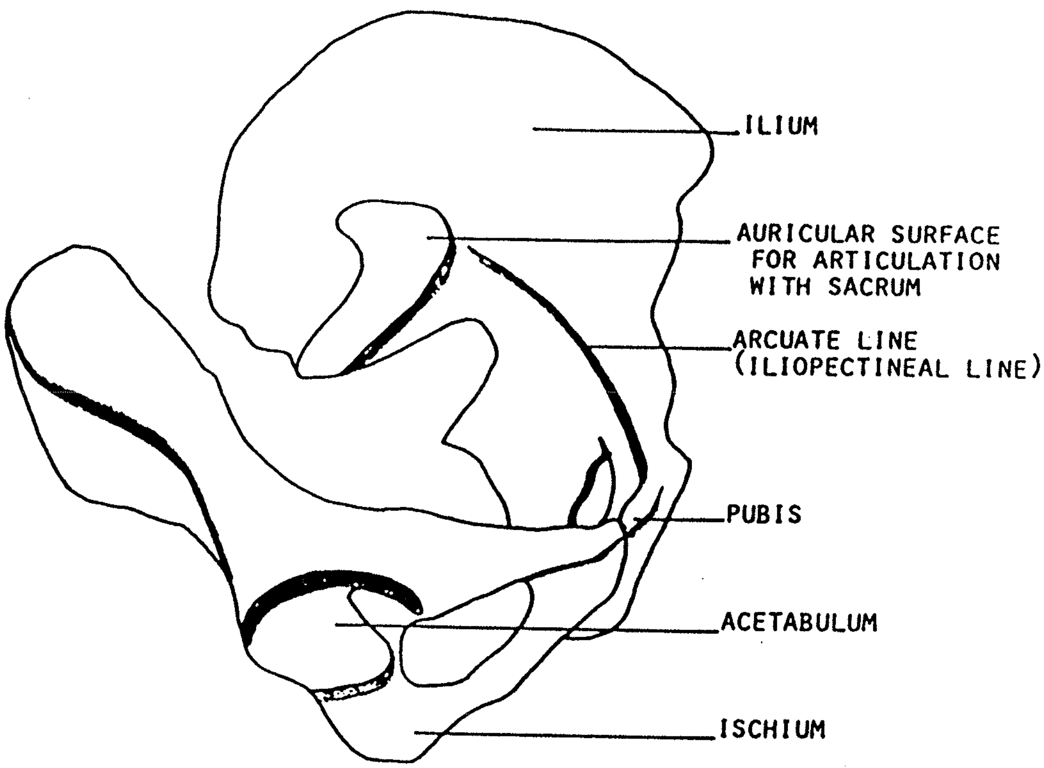


Figure 1: Right and Left Innominates

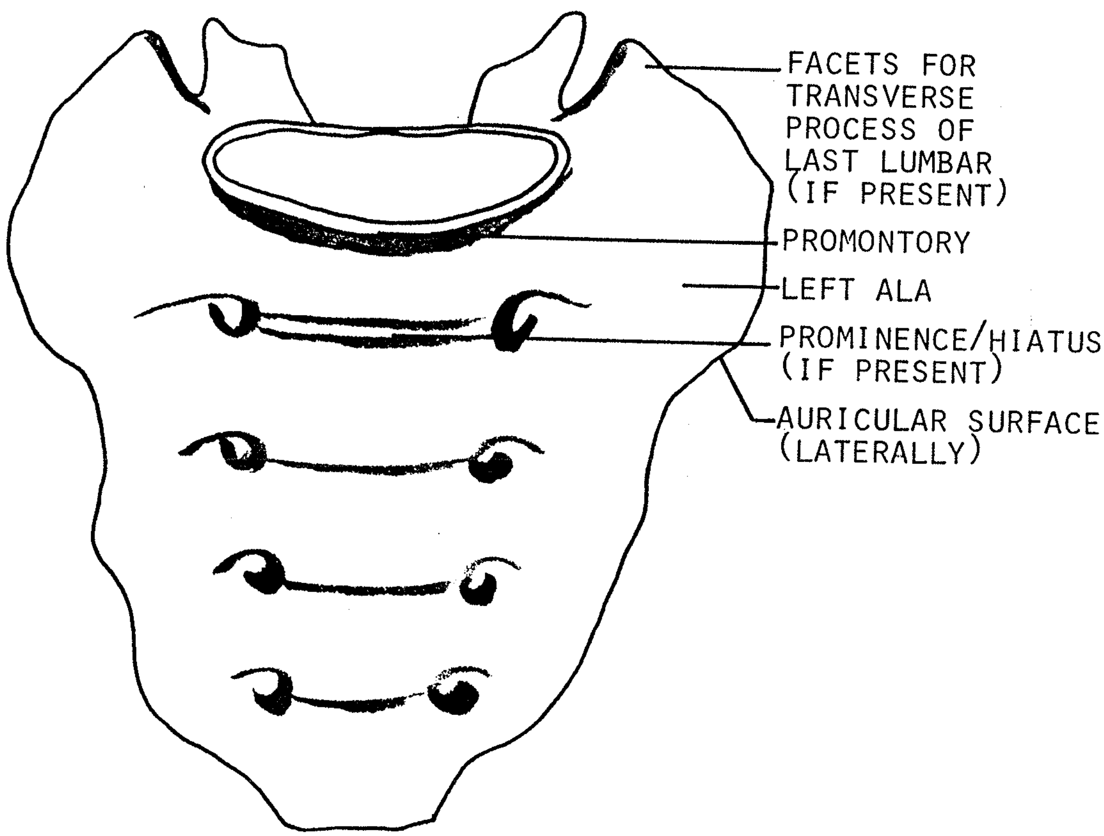


Figure 2: Sacrum

Referring to skeletal material, Thieme (1951:154) said only that although the "point of intersection of the projected iliopectineal line and the sacrum" is "not an easily defined landmark ... it can be quite accurately found if the orientation of the pelvis in the x-ray film is kept in mind." The distance to the sacral promontory is determined by measuring perpendicularly from the intersection of the arcuate line on the x-ray to the most anterior point of the sacral promontory. To establish this plane in skeletal material would be difficult, at best, and I developed another method, described below, of determining this distance.

Also, I decided that a straight measure might not be strictly comparable between individuals because it did not take into account the differences in size of the sacra. In addition to measuring the distance from the promontory to the point of intersection, I measured the width across the sacrum at the points of intersection of the arcuate lines with the alae. The former measure was then divided by the latter and multiplied by 100 in order to provide a ratio that controlled for size differences between individuals.

I also decided to record which sacral segment acted as the vertebra fulcralis, the maximum height of the auricular surface, a profile drawing showing the position and shape of the auricular surface, as well as any evidence of asymmetries, incompleteness of fusion of sacral elements, and articulation of the sacrum with the last lumbar.

The actual method of analysis as applied to each individual skeleton and recorded on the form shown in figure 3, is as follows:

From the files:

1. Record the identification number, sex and age information.
2. Record height and weight data when provided.
3. Record any information from the skeletal assessment card relevant to the vertebral column.

From the skeletons:

1. Determine and record the number of vertebrae of each type:

   Cervical - foramina in transverse processes, no rib facets;

   Thoracic - rib facets;

   Lumbar - no rib facets, not fused to sacrum;

   Sacral - fused segments, however incompletely.
2. Record any evidence of asymmetry, incomplete fusion, anomalies, and articulation of the last lumbar with the sacrum or hips.
3. Record which segment of the sacrum is the vertebra fulcralis (that segment which contributes most to the auricular surface, and thus to the articulation of the ilium), for both the left and right sides.

VERTEBRAL COLUMN DATA

AUG '86
P. SMITH
DATE : Wed
TIME : 4:10

I.D. 1081
SEX wm AGE 45 HEIGHT 1769 WEIGHT 95

VERTEBRAE	#	NOTES
CERVICAL	7	
THORACIC	13	
LUMBAR	5	
SACRUM	5	
COCCYX	3 ?	
LUMBOSACRAL JT	"	
# PRESACRAL	25	

Commencing lipping T No ciduli[illegible] [illegible]
C7 massive, trans. proc. T10-11-12 typ
L1 Typ
L5 short, stout prism trans. proc.
inf. art. proc. widely separate
body [illegible] [illegible]
Sacrum typical Coccyx fused

SACRUM

	R	L
SEGMENT WHICH IS FULCRALIS	S1	S1
MAX. LENGTH OF AURICULAR SURFACE	69	63
WIDTH WHERE ILIOPECTINAL LINES MEET ALAE	110	
HEIGHT OF PROMONTORY FROM ILIOPECTINAL JT	5 = MEASURE X	

RATIO .05

DRAW: (1) SIDE VIEWS OF SACRUM + LAST LUMBAR
(2) SHOW AURICULAR SURFACE SIZE + SHAPE
(3) SHOW POINT ILIOPECTINAL LINE MEET SACRUM

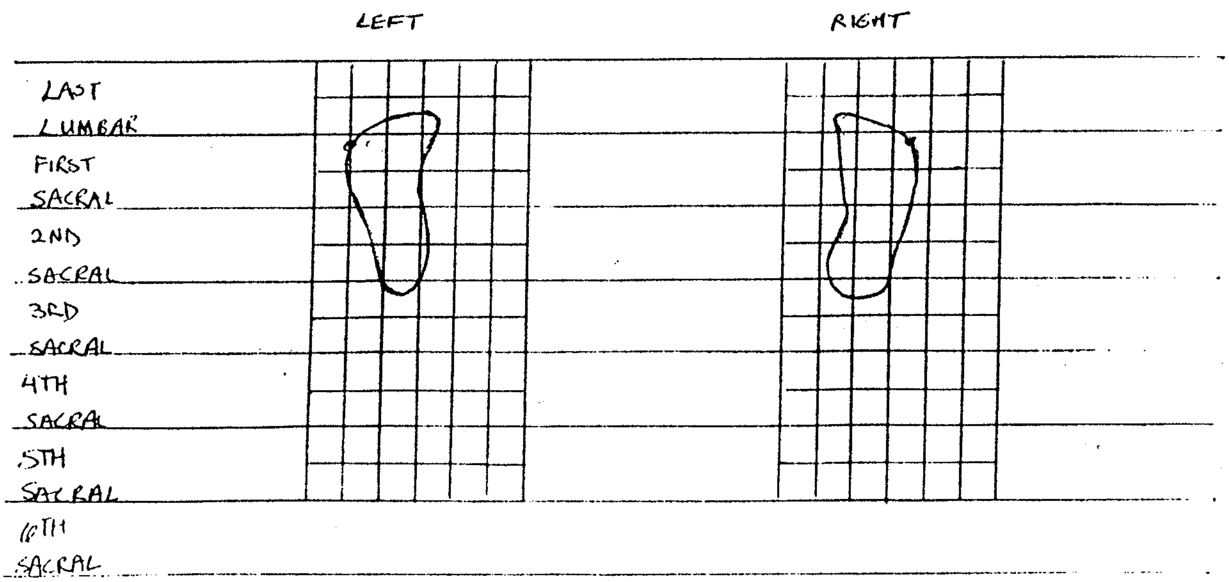


Figure 3: Sample Data Recording Form

4. Measure and record the maximum length of the auricular surface, both left and right.
5. Hold an innominate in position on the sacrum and make a pencil mark (A) on the sacral ala at the point the arcuate (iliopectineal) line of the ilium meets the sacrum (see figure 4). If the arcuate line diverges before meeting the sacrum, and one branch is much more prominent than the other and does meet the ala, use this line. If the arcuate line diverges and disappears, and thus does not meet the sacrum, extrapolate from the heavy arcuate line of the innominate (before it diverges), directly to the sacrum.
6. Repeat the last step with the other innominate in order to get pencil mark (B).
7. Measure and record the distance between the two pencil marks (A) and (B), across the sacrum.
8. Sketch the auricular surface indicating the shape and location with respect to the sacral elements, both left and right. Include a dot to represent the location of pencil marks (A) and (B) (the intersections of the arcuate lines and the sacral alae).
9. Hold a straightedge across the sacrum such that it passes through both pencil marks (A) and (B) on the alae, and make a pencil mark (C) at the midline of the sacral body, in line with the two points along the straightedge (see figure 5). Check to see that the three pencil marks line up, as it is awkward to

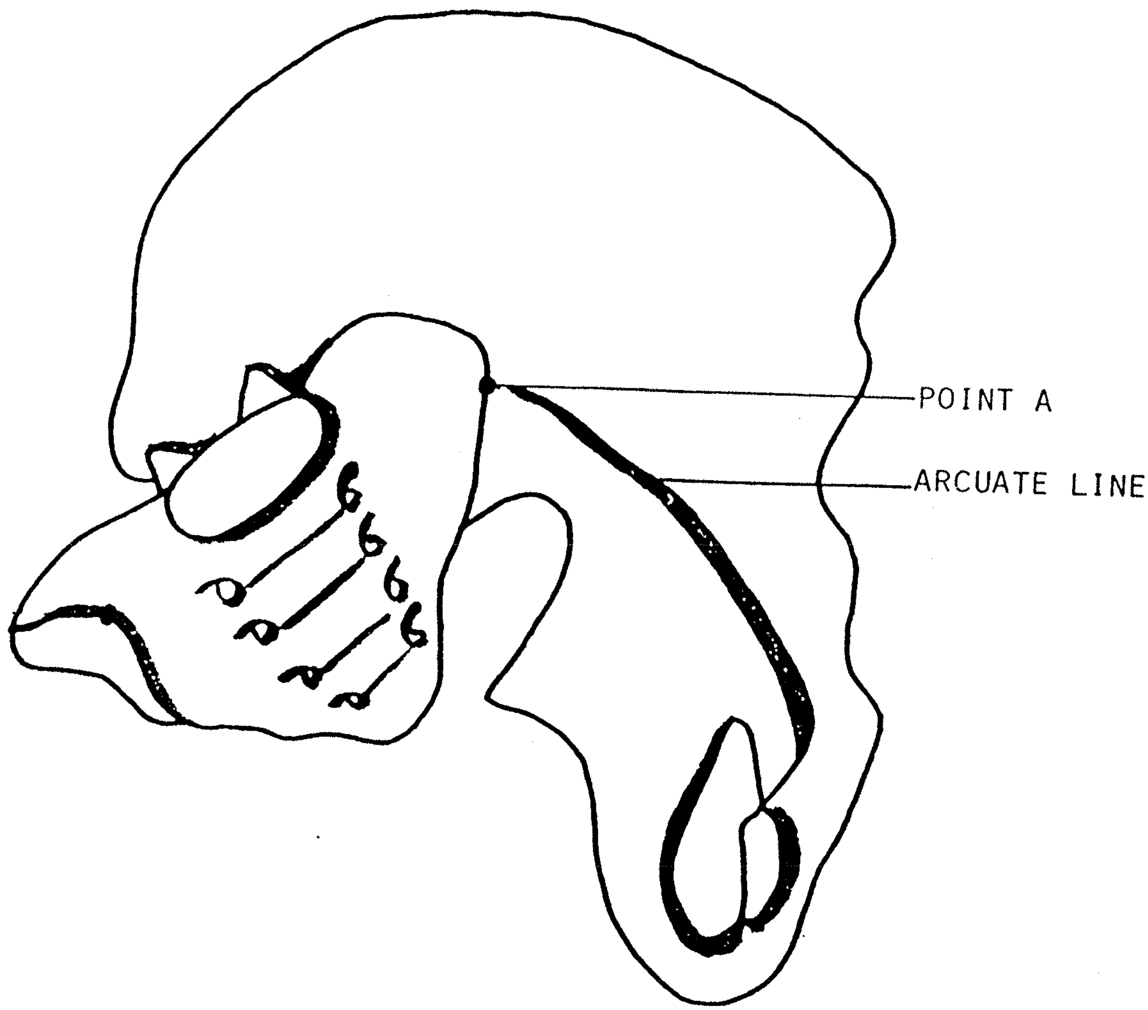


Figure 4: Method of Determining Point A

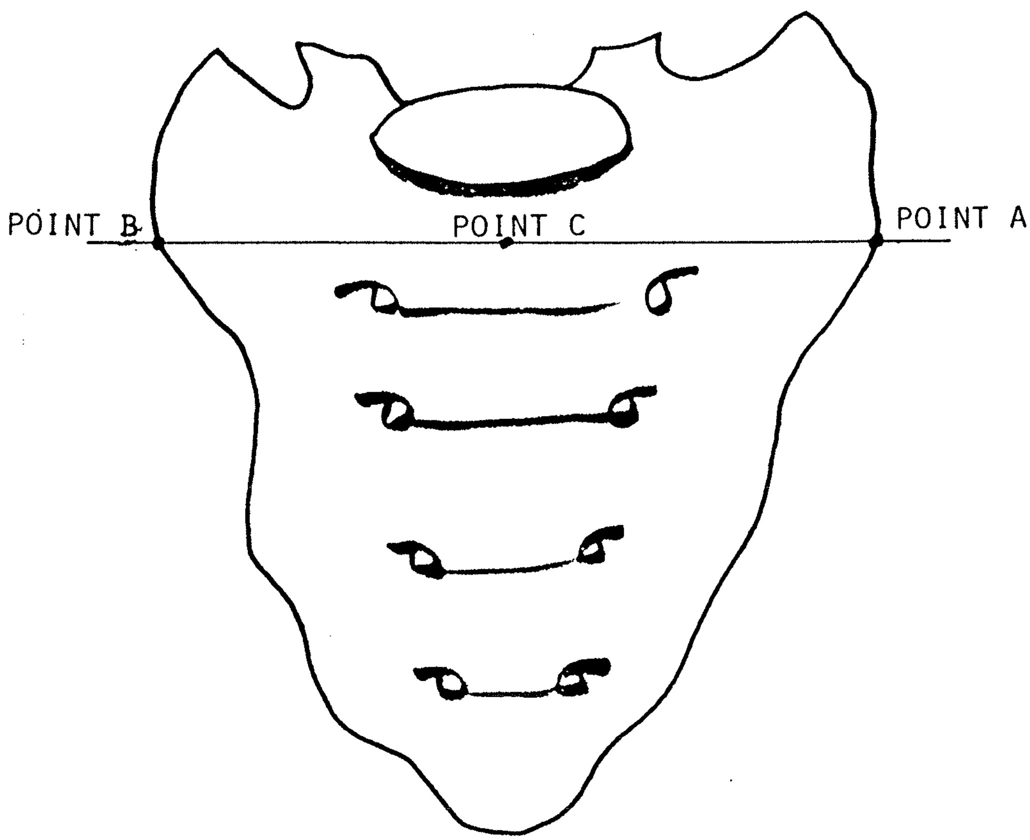


Figure 5: Method of Determining Point C

hold the straightedge in place and the point (C) is quite a depth below the straightedge. Adjust if necessary, and ensure that the points line up. If this central point is above the sacral promontory, the measure taken in the next step will be negative, and difficult to determine precisely. This relatively rare instance is described at the end of the next step.

10. Use coordinating calipers with the movable end removed, leaving only the fixed end and the sliding ruler attachment. With the sliding ruler in its furthest (deepest) position it extends past the fixed end. Hold this sliding part so that it rests on the superior surface, centrally, across the body of the first sacral segment, antero- posteriorly. This establishes the plane of reference for the measurement. The caliper arms must then be brought together until the fixed arm is at the point (C) in the centre of the sacral body at the point between the arcuate lines (see figure 6). Ensure that the sliding arm is still in position against the superior sacral surface. Record the measure of distance on the caliper, (not on the sliding arm). This measure (X) is the distance from the sacral promontory to Point C, with the calipers held across the body of the superior sacral segment (see figure 6). In many cases, it is easier to reverse the calipers, with the fixed arm on

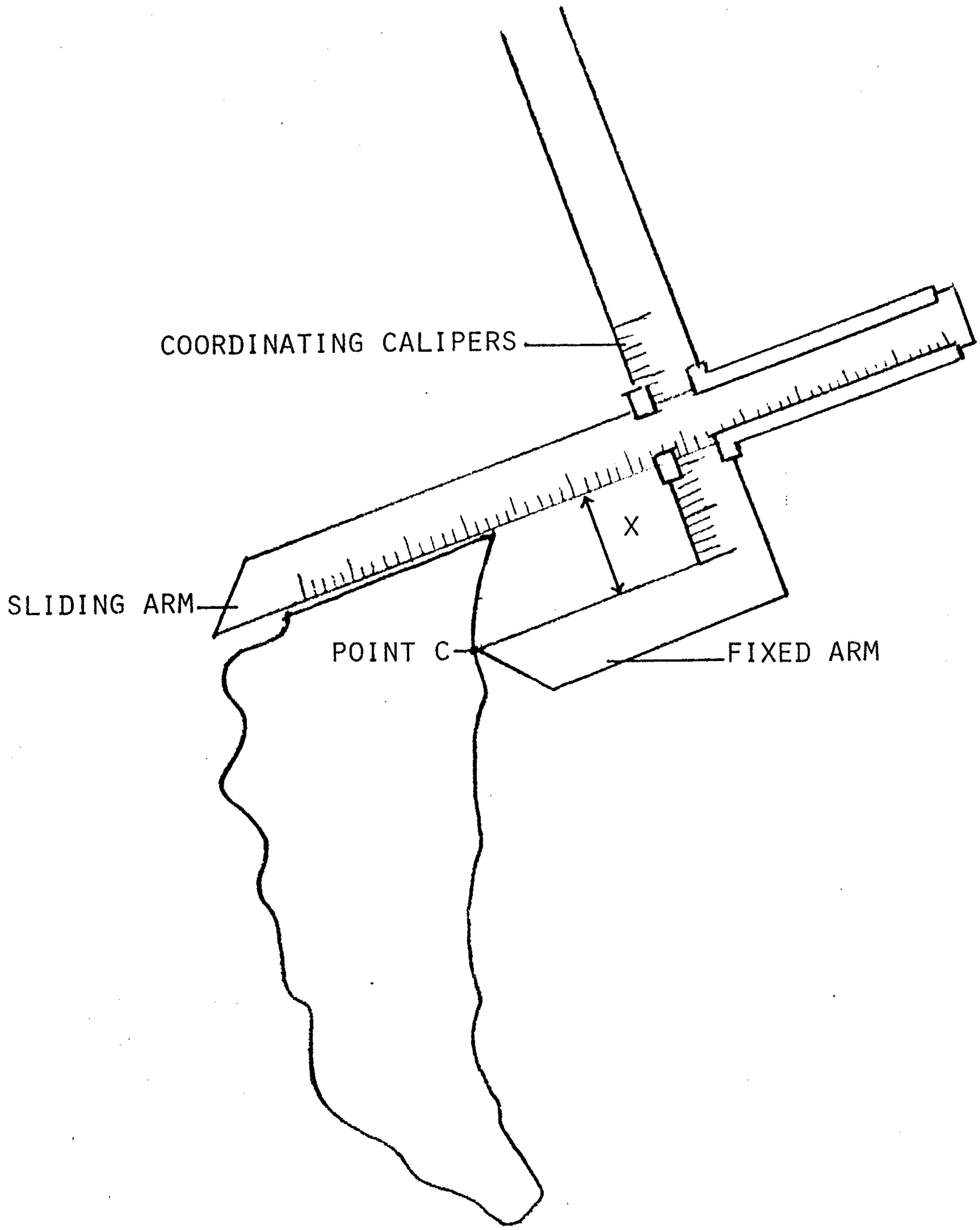


Figure 6: Method of Determining Measure X

the superior surface and the sliding arm brought to point (C). Frequently, however, the longitudinal curvature of the sacrum will not permit this; the posterior segments obstruct the calipers, making it impossible to establish the plane of reference. If the superior sacral surface is not flat, but convex, hold the arm of the caliper across it such that a flat plane is approximated with equivalent gaps on either side of the central rise. If the superior surface is concave, make sure the caliper arm crosses both the anterior and posterior rims to establish the plane. In rare instances where the point (C) is superior to the sacral promontory, the best measure of the distance from the promontory to the estimated point (C) was taken, without attempting to establish a plane across the promontory surface.

Although a test of intra- and interobservor error was not done, a modification in the method, which required a number of measurements to be repeated, provided encouraging results. For the cases where the modification had no effect, measure X was reproduced quite accurately. Originally, I was holding the straightedge across the sacrum, through points (A) and (B), while placing the sliding arm of the coordinating calipers on the superior surface and bringing the fixed arm to the straightedge (to establish point (C)). On the second day, I realized that in certain cases the shape of the sacrum resulted in inaccurate measurements, somewhat larger than they should have been. The problem arose when the lateral curvature was great, (keeping the calipers far above point (C)), and when the sacral promontory was the apex of an acute angle between the superior surface and ventral surface (as opposed to an approximate right angle). In these cases the coordinating caliper would butt against the straightedge while the fixed end would be pointing below point (C). At this point I switched to the more accurate method of drawing point (C) with a pencil and removing the straightedge, as described in step 9 of the actual method. I then went back and redid this measure (X) for all of the skeletons I had completed on the first two days. As it turned out, I did sixty duplicate measures, and only thirteen of these were different from the first attempt by more than 2 mm, with a range from 3 to 6 mm. The errors were systematically larger than the remeasure and were likely from the cases which prompted the change in method in the first place. I found the fact that 27 of the pairs of measures were identical and another 20 were out by only one or two millimetres encouraging. Improving the method obviously made a difference in at least thirteen cases, but because the decision as to where to put points (A) and (B) sometimes requires some judgement, I was interested to learn that I could reproduce the measure (X) so closely.

On returning to Winnipeg, I applied my method to eight archaeological skeletons from the Gray Site, Saskatchewan. These remains are housed in the Piltdown Memorial Laboratory at the University of Manitoba. Each individual has only one surviving ilium in addition to the sacrum, requiring the assumption of symmetry in order to establish point (B). Even with this additional difficulty thrown in, five of the eight cases were measured identically on two separate occasions, and the other three pairs were only out by 1 mm in every case. These preliminary attempts imply that intraobservor error may not be a problem, although both intra- and interobservor error should be tested for using statistical sample sizes.

Chapter III

ANALYSIS OF RESULTS

The 180 individuals in my sample were grouped into three sample populations according to the number of presacral vertebrae (23, 24, or 25). To minimize confusion dealing with numbers, these groups will be referred to as short, normal, and long for 23,24, and 25, respectively. These terms do not refer to the actual length of the columns, but only to the number of presacral vertebrae. Short columns have one less vertebra between the skull and sacrum than the normal columns, and long columns have one more than normal. Cases with numbers other than 23, 24, or 25 are not included as none were encountered. Both the measure (X) itself and the ratio derived by dividing X by the sacral width measurement and multiplying by 100, were used. All statistical calculations were carried out using SAS, Statistical Analysis System, which is a package of routines produced by the SAS Institute of Cary, N.C.

The MEANS procedure was used to calculate the mean, standard deviation, and variance for each of the three groups, and for both sexes within these groups. The TTEST procedure was applied to test the samples against each other. Because Student's t-test is only appropriate when applied to samples with normal distributions, the procedure UNIVARIATE was used to test for normality. The printed output from these procedures can be found in Appendix B. The frequency plots for each group and the entire group can be found in Figure 7 . A summary of these results given in Table 2 and as follows:

1. There is no significant difference between the results using measure X and those using the ratio. Either produces the same results so I recommend using the simple measure, rather than introducing another measurement, and its potential error.
2. There was no significant difference between the males and the females within each group. However, the numbers of females in the short and long groups were small. Because there were no apparent differences the sexes were not separated.
3. The three samples had means that were significantly different at the 0.0001 level. Thus, there is less than one chance in 10,000 that the short and long samples could be randomly drawn from either the normal group, or the total sample.
4. The variances for the short and normal samples were not significantly different. The variance for the long group was different from the others at the 0.01 level. Therefore, different t-tests were used for the samples with equal variances than those with unequal variances.

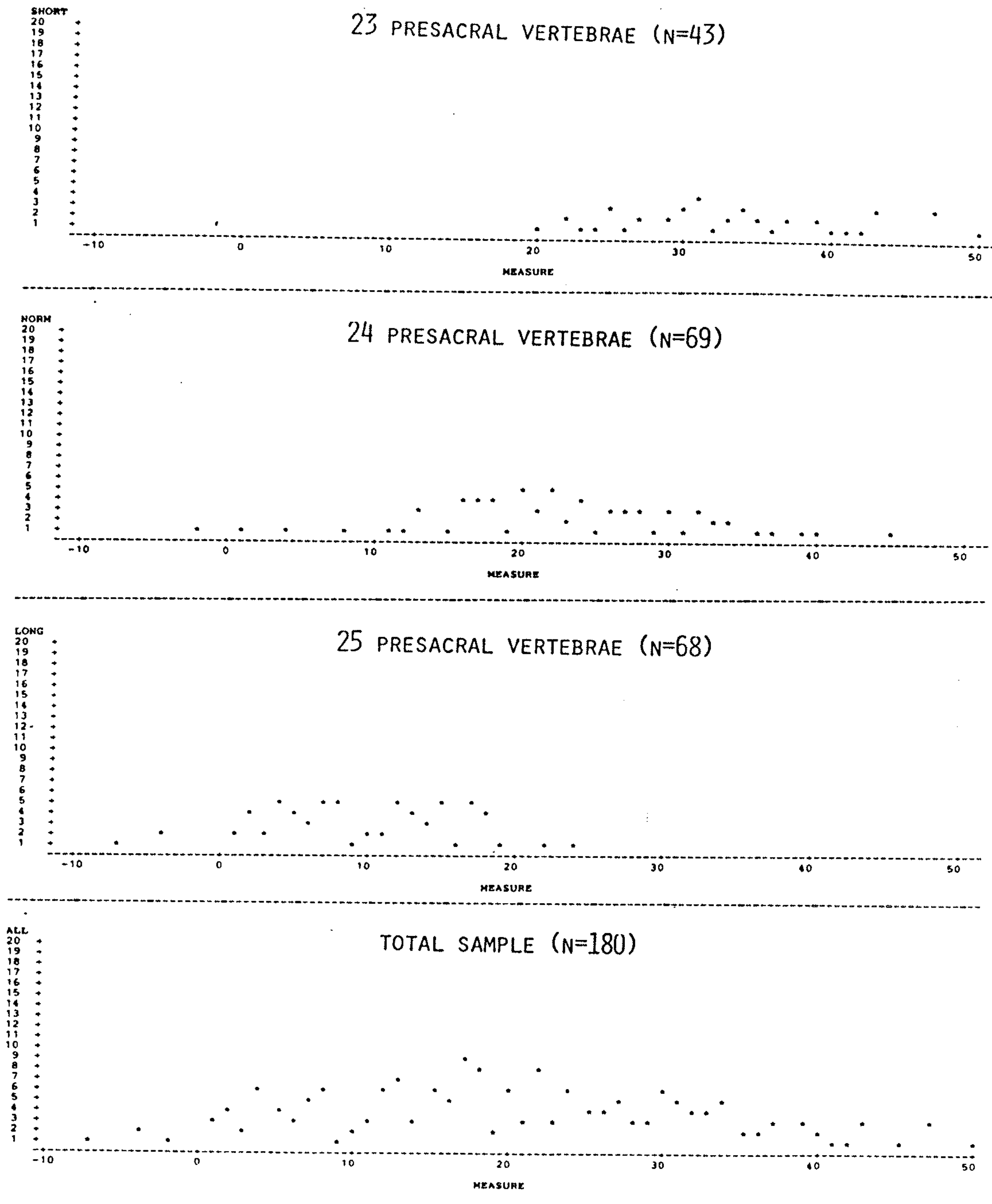


Figure 7: Frequency Plots for Measure X

TABLE 2

Summary of Results

<u>No. Presacral</u>	<u>23</u>	<u>24</u>	<u>25</u>
Sample Size	43	69	68
<u>Ratio</u>			
Mean (mm)	32.63	22.90	9.18
Standard dev. (mm)	7.22	8.88	6.03
Range (mm)	19 TO 47	-2 TO 43	-6 TO 23
<u>Measure X</u>			
Mean (mm)	33.47	22.77	9.59
Standard dev. (mm)	7.66	8.85	6.43
Range (mm)	20 TO 50	-2 TO 45	-7 TO 24
Female Mean (mm)	35.00	22.63	8.67
Female sd (mm)	8.26	6.22	5.86
Female Range (mm)	23 TO 50	11 TO 36	2 TO 13
Male Mean (mm)	32.80	22.87	9.63
Male sd (mm)	7.44	10.51	6.49
Male Range (mm)	20 TO 4	-2 TO 45	-7 TO 24
<u>T-Test</u>			
Ho: $X_i-\bar{X}=0$	11.23	2.28	-13.8
Significance Level	0.0001	0.026	0.0001
<u>Normality</u>			
Shapiro-Wilk(n<51)	0.964		
Significance level	0.338		
Kolomogorov (n>50)		0.077	0.087
Significance Level		0.15	0.15
Skewness	0.319	-0.185	-0.172
Kurtosis	0.649	0.582	-0.301
<u>Percentiles</u> (<u>mm</u>)			
95th	47	38	18.55
75th	39	28.5	15
50th	33	22	9.5
25th	27	17	5
5th	22	6	1.75
<u>Fulcralis</u>			
Sacral Segment (One Side/Other Side)			
First/First	14 32.56%	50 72.46%	68 100%
First/Second	1 }	2 }	0
Second/Second	25 } 67.44%	14 } 27.54%	0
Second/Third	2 }	2 }	0
Third/Third	1 }	1 }	0

Table 2 (continued)

No. Presacral	23		24		25	
Number of Sacral Segments						
Six	32	74.42%	21	30.43% *	3	4.41%
Five	11	25.58%	48	69.57%	58	85.29%
Four	0	0%	0		7	10.29%
Prominence/Hiatus						
Adults (age 20+)	31	72.09%	24	34.78%	2	2.94%
Position of Auricular Surface						
Relative to Vertebral Bodies (sacral or L=last lumbar)						
L-3/?broken	0		0		1	
L-3/L-3	0		1		23	
L-3/L-2	0		0		1	
L-3/1-3	0	} 0%	1	} 4.35%	6	} 60.29%
L-2/L-2	0		1		7	
L-2/1-3	0		0		2	
L-2/1-2	0		0		1	
1-3/1-3	29	} 67.44%	58	} 85.51%	25	} 38.24%
1-3/?broken	0		1		1	
1-3/1-4	8		3		0	
1-3/2-4	1		1		0	
1-4/1-4	2	} 32.56%	2	} 8.70%	1	} 1.47%
1-4/2-4	2		0		0	
1-4/?broken	1		0		0	
?broken	0	0%	1	1.45%	0	0%

* may be over represented due to selection for columns with lumbosacral vertebrae in attempts to find all cases of 25 presacral vertebrae, but some were fused to the sacrum.

5. The total population and each of the three samples were found to be normally distributed. This means the highly significant t-test results are reliable.

Obviously, although the samples are significantly different with respect to measure X, overlap occurs between the groups, especially the short and normal samples. In an attempt to further distinguish between the samples, secondary characteristics were compared. It soon became apparent that certain features were associated with measure X, but they were present on sacra with the same value of X, irrespective of the number of presacral vertebrae. For example, 32 of 43 in the short sample had 6 segment sacra and none had 4 segment sacra, whereas the long sample of 68 individuals had only 3 cases of 6 segment sacra and 7 cases of 4 segment sacra. The normal sample of 69, had 21 examples of 6 segment sacra and no cases of 4 segment sacra. However, the 6 segment sacra in the normal group may be slightly over represented because cases which were recorded in the files as having a lumbosacral vertebra were selected for study in case they were examples of 25 presacral vertebrae. Sometimes these individuals turned out to have a lumbosacral which was partly fused and therefore counted as a sacral. These cases were then included in the group with 24 presacral vertebrae.

The presence of a marked prominence or a hiatus between the bodies of the first and second sacral elements was found in 31 of the 43 individuals in the short group, 24 of the 69 in the normal group, and only 2 ot the 68 in the long group. This characteristic was found to be associated with large measures of X and occurs in 21 of the 23 individuals in the short group with values of X over 32mm (the 50th percentile of this group), as well as in all nine of those with the normal number of presacral vertebrae and values of X in the same range. A prominence or hiatus is very rare (only three cases), in adults from the normal group with values of X less than or equal to 22mm (the 50th percentile of this group). Only two adults in the long group also displayed this feature, and their values of X were in this same range.

The vertebra fulcralis was always the first sacral for individuals with long presacral columns, and for those with normal columns and values of X less than or equal to 22mm, except 1 case in 36. Above 24mm, only 12 of the 27 people with the normal number of presacrals had the first sacral as fulcralis on even one side, and all of these measured below 33mm. In this same range, the short sample had only 9 of 38 cases with the first sacral as fulcralis on at least one side, and all of these were below 33mm as well. All of the individuals with values of X greater than or equal to 33mm had the second or, less often, the third sacral segment acting as fulcralis, almost always on both sides.

I studied the actual position of the auricular surface with respect to the vertebral bodies, from the side view. If the auricular surface extended above the body of the first sacral, it was considered to include the position of the last lumbar, although it was really the transverse element of the first sacral and it did not necessarily articulate with the last lumbar. I found that 58 of the 69 in the normal group involved the first to third sacral segments in the extent of the auricular surface on both sides, and only three cases had the auricular surface extended above the body of the first sacral, and these cases were the only ones in this group to reveal facets on the ala(e) for articulation with the transverse process(es) of the last lumbar. Of the long sample, only 25 of the 68 had this pattern involving the first to third sacrals on both sides, and 41 had auricular surfaces which extended above the bodies of the first sacrals, on at least one side, 14 of which revealed facets for the transverse processes of the last lumbar. This latter group of 41 included all 25 of the sacra with measures less than 10. The short group had none which extended above the first sacral and all were either from the first to third or first to fourth on one or both sides. The individuals with high values of X from both the short and normal groups are alike, often including the fourth segment.

The individuals were also tested for a correlation between stature and number of presacral vertebrae, but the hypothesis of a link was not supported by the data. Even when the sexes were separated, the range of statures for all groups completely overlapped with no apparent clustering. Bardeen (1900:379) believed the tendency to shortening of the vertebral column was "more often found in bodies of less than average length". Bardeen (1900:379) studied 41 males, the normal ones averaged 165 cm and ranged from 145 to 175. Those with shortened columns averaged 163.5 cm and ranged from 152.5 to 176. There were only 18 females and the normal ones averaged 157.5 cm with a range from 150 to 165. Those with shortened columns averaged 146.6 cm and ranged from 134.5 to 161. However, his numbers were small, his body length ranges overlapped, and in the case of the males, his means were almost identical. Thus, it is not possible to give much weight to his conclusion.

Chapter IV

CONCLUSIONS

As stated earlier, the aim of this thesis is to determine if observations of only the sacrum and ilia can indicate the number of presacral vertebrae which had been present. This would be especially useful for physical anthropologists working with incomplete archaeological skeletons. In addition, establishment of a relationship between numerical variations and morphological features of the lumbosacral or sacroiliac regions would be of clinical interest to the medical profession. This area is critical for weight bearing and transmission of forces to the limbs. There may be functional implications relating to lower back disorders. As stated by Bohart (1929:698): "Anomalies and anatomic variations in the symptomless spine are therefore of interest to surgeons and roentgenologists in any attempt to determine the true etiology and prognosis of back sprain or other injuries to the spine." Certainly, Thieme (1951) found an anatomical relationship which predisposed some individuals to lumbosacral fusion. Many authors, including Mitchell (1936) and Keim (1974) attributed low back pain to sacralization and lumbarization, whereas many others, including Bohart (1929), Wiltse (1969) and Magora and Swartz (1978), found that these variations had no effect on the incidence of low back problems.

The literature relevant to numerical vertebral variation supports the view that the location of attachment of the ilia determines the number of presacral vertebrae. The fact that Thieme (1951) developed a measurement which indicated the position of attachment of the hips relative to the sacral promontory led me to think that this relationship could be used to indicate the number of vertebrae above the sacrum. Therefore, based on the literature research, I formulated the hypothesis that the position of the ilia (as indicated by the location of the intersection of the arcuate lines with the sacral alae), relative to the sacral promontory, would indicate the number of presacral vertebrae. At the same time, I decided to record a number of other characteristics of the individuals and their sacra that might reveal differences based on numerical variations of the vertebrae, as suggested for the fulcralis by Dwight (1901), and for a hiatus by Paterson (1893).

The measurement I developed to characterize the position of the ilia relative to the sacral promontory (measure X) proved to be different among the short, normal, and long columns, at a very high level of significance (0.0001). Using the normal distribution for the three groups, characterizing each with its mean and standard deviation, the UNIVARIATE procedure provided percentile information. It appears that the quartiles barely overlap. The upper 25% of the long group have values of X greater than or equal to

15mm, while the lower 25% of the normal group have values equal to or below 17mm. The upper 25% of the modal columns have values equal to or above 28.5mm, while the lower 25% of the short columns have values less than or equal to 27mm. It has already been established that these groups are significantly different. The task was to find a method of using this knowledge to predict presacral vertebral number from the measure. Because most (approximately 90%) of every population, has twenty-four presacral vertebrae, it is unacceptable to frequently assign normal columns incorrectly as short or long ones. If this were the case, it would be more accurate to assume all columns are from individuals with twenty-four presacral vertebrae. This means the error of incorrectly assigning a normal column should be no greater than 5% on either end, as either a short or a long column.

Using the fifth percentiles for the normal group we have a range from 6mm to 38mm which would be assigned as normal columns, and all values of X less than 6mm would be considered to be from long columns, and all numbers greater than 38mm would be from short columns. Only 25% of the long group have measures of 5mm or less, and only 25% of the short group have measures of 39mm or more. Because these variations are so rare in humans (about 5% each), this means that, in an assemblage of 400 sacra, only 5 in 23 of the sacra identified as having come from a column with twenty-five or twenty-three presacral vertebrae would be a correct identification. This is equivalent to a ratio of 1 correct identification for every 3.6 incorrect identifications in the upper and lower ranges, the short and long presacral groups.

Obviously, although the groups are significantly different, the direct use of this measure for the purpose of predicting the presacral vertebral number is minimized by the disparity between the frequency of normal columns and those with twenty-three or twenty-five presacrals.

I also analyzed the secondary characteristics studied, including: stature; the occurrence of a hiatus or marked prominence between the first and second sacral bodies; the identification of fulcralis; the number of sacral elements; and the position of the auricular surface relative to the vertebral bodies.

The results revealed that stature was not a useful indicator of the number of presacral vertebrae. This was the only characteristic included which would have required skeletal elements other than those of the pelvic girdle, had the relationship proved positive.

Because of the association of most of the secondary characteristics studied, (i.e. hiatus, fulcralis, and number of sacral segments), with the distance X and not the number of presacral vertebrae, it appears to be impossible to use these features for differentiation between groups. What this revealed was that the sacrum of an individual with a partly assimilated lumbar looks like a sacrum with a partly released sacral vertebra, and this is not unexpected.

It is possible that sophisticated multivariate statistical procedures may reveal combinations of characteristics that would be accurate predictors of presacral vertebral number, although this is not readily apparent from the data. Certainly, this is one of the directions I would follow in future research into this problem.

I found that the position of the auricular surface, relative to the vertebral bodies (as determined from a lateral view), is a characteristic worthy of further study. As the position of the auricular surface is determined by the position of attachment of the ilia, the association of this feature with the number of presacral vertebrae is not surprising. By scanning my data sheets when they were filed in numerical order by distance X, within the short, normal and long groups, it became apparent from my drawings of the auricular surfaces that the position is highest in individuals with 25 presacral vertebrae and lowest in those with 23.

Further analysis revealed that sacra with an auricular surface extending above the superior surface of the first sacral body, and without facets on the alae for articulation with the last lumbar, are from individuals with long presacral columns (23 out of 23 cases). Those with this type of auricular surface and facets are also likely to be from long individuals (14 out of 17, or 82.7%). Using just the position of the auricular surface, cases with extension above the height of the first sacral body are from columns with 25 presacrals 93% of the time (41 out of 44 cases).

This relatively clearcut distinction between long and other columns looks somewhat more promising with respect to very slight overlap, than does measurement X. However, in order to test this relationship, the data should be collected in a different manner than applied in this thesis. I would make a tracing of the actual auricular surface, and mark on it where the vertebral bodies line up, as well as the contribution of the transverse element of each segment to the auricular surface. To clarify what I mean by distinguishing between these two features, it is necessary only to picture a sacrum with the transverse element of the first segment which extends above the height of the first sacral body. The last lumbar does not contribute to the auricular surface, but the upper extent of the auricular surface lines up with the last lumbar, at some fraction of body height of the last lumbar. I would also attempt to quantify this information by developing a method to measure the proportion of each segment involved.

It is possible that this relationship would prove to be like the one I found with the measurement I tested in this thesis: highly significant, but of reduced utility due to the large numbers of normal columns relative to the short and long ones. However, the indication that 41 of 44 of the cases with auricular surfaces above the first sacral body are from individuals with twenty-five presacrals, appears promising; there may be more to discover with in-depth study in this area.

Although the method I developed was not as applicable as I had hoped, the high significance of the differences leads me to believe that there may be some way to use this information, possibly in conjunction with a feature I have not yet thought of. As yet, the best anatomical indicator on the sacrum for predicting the number of presacral vertebrae is the occurrence of an auricular surface which extends above the superior surface of the first sacral body. Ninety-three percent of these individuals had twenty-five presacral vertebrae, (one hundred percent, if there are no facets for articulation with the transverse process(es) of the last lumbar). Further research may provide more anatomical indicators for determining the number of presacral vertebrae.

LITERATURE CITED

Allbrook, D.B. 1955 The East African vertebral column: a study in racial variability. American Journal of Physical Anthropology, 13(3):489-513.

Bardeen, C.R. 1900 Costo-vertebral variation in man. Anatomischer Anzeiger, 18:377-382.

Bardeen, C.R. & A.W. Elting 1901 A statistical study of the variations in the formation and position of the lumbo-sacral plexus in man. Anatomischer Anzeiger, 19:124-135,209-238.

Bardeen, C.R. 1904 Numerical variation in the human adult and embryo. Anatomischer Anzeiger, 25:497-519.

----- 1905 Studies of the development of the human skeleton. American Journal of Anatomy, 4:265-302.

Barclay-Smith, E. 1911 Multiple anomaly in a vertebral column. Journal of Anatomy and Physiology, 45:144-171.

Bateson, W. 1894 Materials for the Study of Variation. MacMillan and Co., New York.

Baur, G. 1891 On intercalation of vertebrae. Journal of Morphology, 4:331-336.

de Beer Kaufman, P. 1974 Variation in the number of presacral vertebrae Bantu-speaking South African Negroes. American Journal of Physical Anthropology, 40(3):369-374.

de Beer Kaufman, P. 1977 The number of vertebrae in the Southern African Negro, the American Negro, and the Bushman (San). American Journal of Physical Anthropology, 47(3):409-414.

Birmingham, A. 1891 Variability in the level of attachment of the lower limb to the vertebral axis in man. Journal of Anatomy and Physiology, 25:526-534.

Bohart, W.H. 1929 Anatomic variations and anomalies of the spine: relation to prognosis and length of disability. Journal. American Medical Association, 92:698-701.

Bornstein, P.F. & R.R. Peterson 1966 Numerical variation of the presacral vertebral column in three population groups in North America. American Journal of Physical Anthropology, 25(2):139-146.

Cushway, B.C. & R.J. Maier 1929 Routine examination of the spine for industrial employees. Journal. American Medical Association, 92:701-705.

Danforth, C.H. 1930 Numerical variation and homologies in vertebrae. American Journal of Physical Anthropology, 16(3):463-481.

Le Double, A.F. 1912 Traite des variations de la colonne vertebrale de l'homme: et de leur signification au point de vue de l'Anthropologie Zoologique. Paris.

Dwight, T. 1901(a) Description of the human spines showing numerical variation in the Warren Museum of the Harvard Medical School. Memoirs. Boston Society of Natural History, 5(7):237-312.

----- 1901(b) Description of the human spines showing numerical variation in the Warren Museum of the Harvard Medical School. Anatomischer Anzeiger, 19:321-332,337-347.

Hodges, F.J. & W.S. Peck 1937 Clinical and roentgenological study of low back pain with sciatic radiation. American Journal of Roentgenology, 37:461-468.

Keim, H.A. 1974 Low back pain. CIBA Clinical Symposia, 26(2):2-32.

Keith, A. 1903 The extent to which posterior segments of the body have been transmuted and suppressed in the evolution of man and allied primates. Journal of Anatomy, 37:18-40.

----- 1923 Man's posture: its evolution and disorders. British Medical Journal, 1:451-454, 499-502, 545-548, 587-590, 624-626, 669-672.

Lanier, R.R. 1939 The presacral vertebrae of American white and negro males. American Journal of Physical Anthropology, 25(3):341-420.

----- 1954 Some factors to be considered in the study of lumbosacral fusion. American Journal of Physical Anthropology, 12(3):363-371.

Magora, A. & A. Schwartz 1978 Relation between the low back pain syndrome and x-ray findings. Scandanavian Journal of Rehabilitation Medicine, 10:135-145.

Mall, F.P. 1905 On ossification centers in human embryos less than one hundred days old. American Journal of Anatomy, 5:433-458.

Manners-Smith, T. 1909 The variability of the last lumbar vertebra. Journal of Anatomy, 43:146-160.

Mitchell, G.A.G. 1936 The significance of lumbosacral transitional vertebrae. British Journal of Surgery, 24:147-158.

Paterson, A.M. 1889 The position of the mammalian limb; regarded in the light of its innervation and development. Journal of Anatomy and Physiology, 23:283-299.

----- 1892 The human sacrum. Abstract by D. Cunningham in Proceedings. Royal Society of London, 51:520-524.

----- 1893 The human sacrum. Scientific Transactions. Royal Dublin Society, Vol. 5, Series II:123-204 + Plates XVI-XXI.

Sawin, P.B. 1937 Preliminary studies of hereditary variation in the axial skeleton of the rabbit. Anatomical Record, 69:407-428.

Shore, L.R. 1930 Abnormalities of the vertebral column in a series of skeletons of Bantu natives of South Africa. Journal of Anatomy, 64:206-238.

Smith, G.E. 1907 On a case of fusion of the atlas and axis. Anatomischer Anzeiger, 31:166-168.

----- 1909 A further note on the case of fusion of the atlas and axis. Anatomischer Anzeiger, 34:357-358.

Stewart, T.D. 1932 The vertebral column of the Eskimo. American Journal of Physical Anthropology, 17(1):123-136.

Struthers, J. 1875 On variations of the vertebrae and ribs in man. Journal of Anatomy and Physiology, 9:17-96.

Thieme, F.P. 1951 An anatomical relationship predisposing to lumbosacral fusion. American Journal of Physical Anthropology, 9(2):149-158.

Trotter, M. 1926 The movable segments of the vertebral column in Old Egyptians. American Journal of Physical Anthropology, 9(4):457-466.

----- 1929 The vertbral column in Whites and American Negroes. American Journal of Physical Anthropology, 13(1):95-107.

Tulsi, R.S. 1972 Vertebral column of the Australian Aborigine: selected morphological and metrical features. Zeitschrift fuer Morphologie und Anthropologie, 64(2):117-144.

Willis, T.A. 1923(a) The thoracicolumbar column in White and Negro stocks. Anatomical Record, 26:31-40.

----- 1923(b) The lumbosacral vertebral column in man, its stability of form and function. American Journal of Anatomy, 32:95-123.

Wiltse, L.L. 1969 Lumbosacral strain and instability. American Academy of Orthopedic Surgeons: Symposium on the Spine, November 1967, Ohio, C.V. Mosby Co., St. Louis.

ADDITIONAL LITERATURE

Arey, L.B. 1965 Developmental Anatomy. W.B. Saunders Co., Philadelphia.

Asmussen, E. & K. Klausen 1962 Form and function of the erect human spine. Clinical Orthopaedics and Related Research, 25:55-63.

Bick, E.M. 1961 Vertebral growth: its relation to spinal abnormalities in children. Clinical Orthopaedics and Related Research 21:43-48.

Butcher, E.O. 1929 The development of the somites in the White Rat (Mus norvegicus albinus) and the fate of the Myotomes, Neural Tube, and the Gut in the tail. American Journal of Anatomy, 44:381-439.

Carpenter, E. B. 1961 Normal and abnormal growth of the spine. Clinical Orthopaedics and Related Research 21:49-56.

Cave, A.J.E. 1930 On the fusion of the atlas and axis vertebrae. Journal of Anatomy, 64:337-343.

Chai, C.K. & K.H. Degenhardt 1962 Developmental anomalies in inbred rabbits. Journal of Heredity, 53:174:182.

Child, C.M. 1925 The physiological significance of the cephalocaudal differential in vertebrate development. Anatomical Record, 31:369-383.

Cobey, M.C. 1964 The notochordal spine. Clinical Orthopaedics and Related Research 34:33-41.

Crary, D.D. & P.B. Sawin 1952 A second recessive achondroplasia in the Domestic Rabbit. Journal of Heredity, 43:254-259.

Cunningham, D.J. 1886 The lumbar curve in man and apes. Nature, 33:378-379.

Cyriax, E.F. 1922 On certain normal irregularities in the vertebral column in its lower dorsal area. Journal of Anatomy, 56:147-148.

Denison, R.H. 1963 The early history of the vertebrate calcified skeleton. Clinical Orthopaedics and Related Research 31:141-152.

Detwiler, S.R. & H. Holtzer 1954 The inductive and formative influence of the spinal cord upon the vertebral column. Bulletin. Hospital for Joint Diseases, 15:114-123.

Ehrenhaft, J.L. 1943 Development of the vertebral column as related to certain congenital and pathological changes. Surgery, Gynecology and Obstetrics, 76:282-292.

Garn, S.M. 1966 The evolutionary and genetic control of variability in man. Annals. New York Academy of Sciences, 134:602:615.

Green, E.L. 1941 Genetic and non-genetic factors which influence the type of the skeleton in an inbred strain of mice. Genetics, 26:192:222.

Green, E.L. & M.C. Green 1946 The effect of uterine development on the skeleton of the mouse. Journal of Morphology, 78:113-120.

Gruneberg, H. 1957 The developmental mechanisms of genes affecting the axial skeleton of the mouse. American Naturalist, 91:95-102.

Jarcho, S. & P.M. Levin 1938 Hereditary malformation of the vertebral bodies. Bulletin. Johns Hopkins Hospital, 62:216-226.

Landauer, W. 1928 The morphology of intermediate rumplessness in the fowl: with remarks concerning hereditary and accidental rumplessness. Journal of Heredity, 19:453-467.

Noback, C.R. 1944 The developmental anatomy of the human osseous skeleton during the embryonic fetal and circumnatal periods. Anatomical Record, 88:91-117.

Odgers, P.N.B. 1933 The lumbar and lumbo-sacral diarthrodial joints. Journal of Anatomy, 67:301-317.

Promptoff, A.n. 1928 Inheritance of structural types in the dorsosacrum of domestic poultry. Journal of Genetics, 20:29-51.

Reimann, A.F. & B.J. Anson 1944 Vertebral level of termination of the spinal cord with report of a case of sacral cord. Anatomical Record, 88:127-138.

Rockwell, H., F.G. Evans & H.C. Phesant 1938 The comparative morphology of the vertebrate spinal column: its form as related to function. Journal of Morphology, 63:87-117.

Sawin, P.B. & D.D. Crary 1956 Morphogenetic studies of the rabbit XVI: Quantitative racial differences in ossification pattern of the vertebrae of embryos as an approach to basic principles of mammalian growth. American Journal of Physical Anthropology, 14(4):625-648.

----- 1964 Genetics of skeletal deformities in the Domestic Rabbit (Oryctolagus cuniculus). Clinical Orthopaedics and Related Research 33:71-90.

Schmorl, G. & H. Junghanns 1971 The Human Spine in Health and Disease. Grune & Stratton, New York.

Schultz, A.H. 1930 The skeleton of the trunk and limbs of higher primates. Human Biology, 2:303:438.

----- 1938 The relative length of the regions of the spinal column in Old World Primates. American Journal of Physical Anthropology, 24(1):1-22.

Todd, T.W. 1924 Stability. Scientific Monthly, 19:632-634.

Todd, T.W. & S.I. Pyle 1928 A quantitative study of the vertebral column by direct and roentgenoscopic methods. American Journal of Physical Anthropology, 12:321-338.

Trotter, M. 1926 The sacrum and sex. American Journal of Physical Anthropology, 9:445-450.

Turner, W. 1886 The lumbar curve of the spinal column in several races of men. Journal of Anatomy and Physiology, 20:536-543.

Wood-Jones, F. 1938 The cervical vertebrae of the Australian Native. Journal of Anatomy, 72:411-415.

Appendix A

DATA COLLECTED AT CLEVELAND MUSEUM OF NATURAL HISTORY

The raw data, as collected at the Cleveland Museum of Natural History, are presented in tabular form. The following is a list of abbreviations used as columnar heads, and an explanation of the content of the columns:

OBS - Observation number within the dataset

ITEM - Skeleton identification number (as per Cleveland Museum of Natural History)

SEX - Sex of inividual as recorded in file

AGE - Age of inividual as recorded in file

HEIGHT - Height of individual as recorded in file

WEIGHT - Weight of inividual as recorded in file (if given)

C - Number of cervical vertebrae

T - Number of thoracic vertebrae

L - Number of lumbar vertebrae

S - Number of sacral vertebrae

CA - Number of caudal vertebrae

RF - Sacral element which is the right fulcralis

LF - Sacral element which is the left fulcralis

RA - Maximum length of the right auricular surface (mm)

LA - Maximum length of the left auricular surface (mm)

A-B - Point A to Point B, width (mm) across the sacral alae at points where the arcuate lines of the hips intersect with the alae

X - Measure X (mm), from the sacral promontory to Point C using the superior sacral surface to determine the plane of reference

POS - Position of the auricular surface relative to the vertebral bodies (i.e. L-3: the auricular surface extends from the last lumbar to the third sacral)

LLA - Last lumbar (tranverse process(es)) articulation with sacral ala(e), (i.e. B=both sides, L=left, R=right)

H/P - Hiatus/prominence between the first and second sacral body segments, anteriorly.

RATIO - Measure X divided by A-B multiplied by 100

------------------------------------ NUMBER OF PRESACRAL ELEMENTS =23 ------------------------------------

OBS	ITEM	SEX	AGE	HEIGHT	WEIGHT	C	T	L	S	CA	RF	LF	RA	LA	A-B	X	POS	LLA	H/P	RATIO
1	25	M	40	.		7	11	5	5	1+	S1	S1	44	43	87	20.00	1-3			23.00
2	1146	M	49	1691	119	7	11	5	5	2+	S1	S1	60	58	113	22.00	1-3,1-4			19.00
3	1447	M	34	1718	137	7	11	5	5	4	S1	S1	56	55	100	22.00	1-3			22.00
4	1580	F	31	1709	150	7	11	5	5	4	S1	S1	63	65	110	23.00	1-3			21.00
5	75	M	64	.		7	11	5	6	?	S1	S1	64	62	102	24.00	1-3			24.00
6	1771	F	54	1509	100	7	11	5	5	4	S1	S1	55	52	94	25.00	1-3			27.00
7	1790	M	42	1816	140	7	12	4	5	2+	S1	S1	68	65	115	25.00	1-3			22.00
8	1376	M	42	1805	95	7	12	4	6	4	S2	S2	62	66	105	25.00	1-3		*	24.00
9	315	F	40	.		7	11	5	5	1+	S1	S1	53	59	99	26.00	1-3		*	26.00
10	799	M	36	1674	101	7	12	4	6	4?	S2	S2	66	66	104	27.00	1-4,1-3			26.00
11	1114	M	35	1694	147	7	12	4	6	3	S2	S2	62	58	93	27.00	1-3		*	29.00
12	1635	M	60	1650	135	7	12	4	6	1+	S1	S1	62	61	99	29.00	1-3		*	29.00
13	1631	M	49	1813	150	7	12	4	6	1+	S1	S1	78	74	97	29.00	1-4,1-3		*	30.00
14	1323	M	30	1681	90	7	11	5	5	4	S1	S1	53	53	89	30.00	1-3		*	34.00
15	715	F	47	1661	148	7	12	4	6	4	S2	S2	63	52	108	30.00	1-3		*	28.00
16	709	M	33	1772	131	7	12	4	6	2+	S2	S2	72	67	100	30.00	1-3		*	30.00
17	810	M	74	1685	106	7	11	5	5	1+	S1	S1	68	65	114	31.00	1-3			27.00
18	631	F	36	1617	128	7	11	5	6	?	S1	S1	52	50	96	31.00	1-3			32.00
19	1638	M	60	1649	125	7	12	4	6	2+	S2	S2	56	55	103	31.00	1-3		*	30.00
20	911	M	58	1742	131	7	12	4	6	4	S1	S1	64	62	96	31.00	1-3			32.00
21	886	F	32	1646	102	7	12	4	6	?	S2	S2	54	53	108	32.00	1-3		*	30.00
22	327	M	59	.		7	11	5	6	3+	S2	S2	68	69	91	33.00	1-3,		*	36.00
23	1256	F	55	1625	108	7	12	4	6	2	S2	S2	65	63	108	33.00	1-3		*	31.00
24	1546	M	28	1676	110	7	11	5	5	4	S2	S2	62	53	105	34.00	1-3		*	32.00
25	1775	M	50	1672	140	7	11	5	6	2+	S1	S2	56	62	103	34.00	1-3		*	33.00
26	1224	M	28	1686	120	7	11	5	6	4	S2	S2	61	60	97	34.00	1-4		*	35.00
27	1330	M	40	1645	130	7	12	4	6	4	S2	S2	59	53	110	35.00	1-3		*	32.00
28	835	M	49	.		7	12	4	6	3+	S2	S2	60	68	93	35.00	1-3,1-4		*	38.00
29	839	F	60	1559	120	7	11	5	6	?	S2	S2	50	55	106	36.00	1-3		*	34.00
30	1870	M	55	1727	121	7	11	5	6	3+	S2	S3	70	72	101	37.00	1-4		*	37.00
31	1717	M	38	1879	160	7	12	4	6	?	S3	S3	72	74	112	37.00	1-3		*	33.00
32	179	M	72	.		7	12	4	6	?	S2	S2	59	61	111	39.00	1-3		*	35.00
33	1117	M	45	1644	119	7	12	4	6	4	S2	S2	56	65	104	39.00	1-3		*	38.00
34	1152	M	32	1855	132	7	12	4	5	1+	S2	S2	64	60	100	40.00	1-3		*	40.00
35	1786	F	45	1651	125	7	12	4	6	4	S2	S2	58	56	107	41.00	1-3,2-4		*	38.00
36	1022	F	46	1587	56	7	12	4	6	2	S2	S2	60	56	92	42.00	1-3		*	46.00
37	728	F	50	1753	198	7	11	5	5	2+	S2	S2	61	67	117	43.00	2-4,1-4		*	37.00
38	1696	M	40	1777	150	7	12	4	6	4	S2	S2	62	64	105	43.00	1-3,1-4		*	41.00
39	1749	F	42	1629	115	7	12	4	6	4	S2	S3	56	62	92	43.00	1-4,1-3		*	47.00
40	924	M	60	1737	148	7	12	4	6	?	S2	S2	70	69	112	47.00	1-3			42.00
41	381	M	82	.		7	12	4	6	1+	S2	S2	72	.	112	47.00	1-4,?		*	42.00
42	1023	M	52	1633	119	7	12	4	6	1+	S2	S2	.	61	103	47.00	2-4,1-4		*	46.00
43	742	F	50	1628	124	7	12	4	6	1+	S2	S2	60	59	110	50.00	1-3,1-4		*	45.00

-------------------------------------- NUMBER OF PRESACRAL ELEMENTS =24 --------------------------------------

OBS	ITEM	SEX	AGE	HEIGHT	WEIGHT	C	T	L	S	CA	RF	LF	RA	LA	A-B	X	POS	LLA	H/P	RATIO
44	806	M	35	1697	130	7	12	5	5	3	S1	S1	67	71	117	-2.00	L-2	*B		-2.00
45	857	M	24	1680	135	7	12	5	5	5	S1	S1	63	66	93	1.00	L-3	*B		1.00
46	1773	M	60	1633	130	7	11	6	5	4	S1	S1	56	58	108	4.00	1-3,L-3	*L		4.00
47	686	M	65	.		7	11	6	5	1+	S1	S1	68	66	106	8.00	1-3			8.00
48	1122	F	70	1644	157	7	12	5	5	?	S1	S1	59	56	106	11.00	1-3			10.00
49	1232	F	16	1655	62	7	12	5	5	?	S1	S1	60	59	92	12.00	1-3			13.00
50	801	M	38	1746	154	6	13	5	5	4	S1	S1	60	.	104	13.00	??			13.00
51	808	M	20	1826	120	7	12	5	5	2+	S1	S1	66	64	99	13.00	1-3			13.00
52	1014	M	22	1648	98	7	12	5	5	1+	S1	S1	52	52	84	13.00	1-3			15.00
53	1171	F	71	.		7	12	5	5	1+	S1	S1	62	62	95	15.00	1-3			16.00
54	1339	F	20	1665	96	7	12	5	5	3	S1	S1	47	46	102	16.00	1-3			16.00
55	1301	F	67	1607	124	7	12	5	5	?	S1	S1	59	62	102	16.00	1-3			16.00
56	2171	M	20	1730	115	7	12	5	5	?	S1	S1	69	68	92	16.00	1-3			17.00
57	428	M	35	.		7	13	4	6	?	S1	S1	52	56	101	16.00	1-3			16.00
58	1157	F	25	1565	86	7	12	5	5	3?+	S1	S1	61	61	104	17.00	1-3		*	16.00
59	854	M	19	1764	131	7	12	5	5	4	S1	S1	63	67	96	17.00	1-3			18.00
60	1949	F	19	1670	115	7	12	5	5	1,4	S1	S1	52	54	94	17.00	1-3			18.00
61	1124	F	40	1568	92	7	12	5	5	2+	S1	S1	54	51	91	17.00	1-3			19.00
62	617	M	32	.		7	12	5	6	2+	S1	S1	64	67	120	18.00	1-3			15.00
63	1279	F	39	1656	82	7	12	5	5	1+	S1	S1	58	58	112	18.00	1-3			16.00
64	1205	M	21	1873	110	7	12	5	5	2+	S1	S1	53	54	102	18.00	1-3			18.00
65	1109	M	20	1800	108	7	12	5	5	1+	S1	S1	62	58	90	18.00	1-3		*	20.00
66	1300	F	39	1567	97	7	12	5	5	4	S1	S1	50	52	101	19.00	1-3			19.00
67	1606	F	17	1655	115	7	12	5	6	3	S1	S1	56	56	102	20.00	1-3			20.00
68	576	F	16	.		7	12	5	5	3	S1	S1	63	64	99	20.00	1-3			20.00
69	437	F	18	.		7	12	5	6	2+	S1	S1	55	53	99	20.00	1-3			20.00
70	1140	M	18	.		7	12	5	5	3	S1	S1	61	60	96	20.00	1-3			21.00
71	1693	M	20	1707	125	7	12	5	5	2+	S1	S1	58	60	91	20.00	1-3			22.00
72	345	M	38	.		7	11	6	5	1+	S1	S1	64	63	102	21.00	1-3			21.00
73	807	M	20	1728	135	7	12	5	5	1+	S1	S1	69	69	93	21.00	1-3			23.00
74	955	M	20	1774	128	7	12	5	5	1+	S1	S1	55	57	85	21.00	1-3		*	25.00
75	2065	F	19	1720	100	7	12	5	5	4	S1	S1	50	50	110	22.00	1-3			20.00
76	1092	M	25	1890	124	7	12	5	5	1+	S1	S1	49	49	106	22.00	1-3		*	21.00
77	1328	F	19	1716	75	7	12	5	6	?	S2	S2	55	57	100	22.00	1-3			22.00
78	1134	M	21	.		7	12	5	5	1+	S1	S1	58	58	91	22.00	1-3			24.00
79	859	M	26	1744		7	12	5	5	?	S1	S1	59	60	91	22.00	1-3		*	24.00
80	1243	F	24	1639	75	7	12	5	5	5	S1	S1	60	61	108	23.00	1-3			21.00
81	542	M	35	.		7	12	5	5	1+	S1	S1	63	60	81	23.00	1-3			28.00
82	1162	F	28	1643	88	7	12	5	5	1+	S1	S1	56	56	122	24.00	1-3			20.00
83	1562	F	21	1623	115	7	12	5	5	1+	S2	S2	49	49	103	24.00	1-3			23.00
84	947	M	47	1654		7	12	5	6	?	S1	S2	61	56	102	24.00	1-3		*	24.00
85	350	M	35	.		7	13	4	6	1+	S1	S1	51	54	93	24.00	1-3		*	26.00
86	1040	F	20	1672	70	7	12	5	5	?	S3	S3	55	55	101	25.00	1-3		*	25.00
87	1228	M	20	1787	109	7	12	5	5	4	S1	S1	59	58	114	26.00	1-3		*	23.00
88	1012	F	18	1624	65	7	12	5	5	1+	S1	S1	50	54	113	26.00	1-3			23.00
89	485	F	16	1600		7	12	5	6	4	S1	S1	56	59	101	26.00	1-3			26.00
90	1208	F	23	1585	103	7	12	5	5	1+	S1	S1	49	51	106	27.00	1-3			25.00
91	1590	F	19	1652	75	7	12	5	5	?	S1	S1	58	60	89	27.00	1-3			30.00
92	812	M	37	1758	108	7	13	4	5	4+	S1	S1	56	67	108	27.00	?,1-3		*	25.00
93	1238	F	19	1668	122	7	12	5	5	2+	S1	S1	52	52	110	28.00	1-3			25.00
94	527	F	16	1509	116	7	12	5	5	1+	S1	S1	55	55	96	28.00	1-31-4		*	29.00
95	1097	M	18	1740	121	7	12	5	5	3+	S1	S1	62	67	93	28.00	1-3			30.00
96	1200	F	68	1638	71	7	12	5	6	?	S1	S1	54	59	116	29.00	1-3			25.00
97	539	M	50	.		7	12	5	6	?	S2	S2	63	61	105	30.00	1-3			29.00
98	1041	F	17	1590	63	7	12	5	6	1+	S2	S2	54	54	91	30.00	1-3			33.00
99	607	M	49	.		7	13	4	6	4	S2	S3	55	61	100	30.00	1-3		*	30.00
100	365	M	42	.		7	12	5	6	?	S2	S2	68	69	104	31.00	1-3		*	30.00
101	644	F	20	.		7	12	5	5	3+	S1	S1	55	54	111	32.00	1-3		*	29.00
102	1161	F	24	1643	101	7	12	5	6	?	S2	S2	49	53	95	32.00	1-3		*	34.00
103	795	M	54	1781	125	7	12	5	6	?	S2	S2	62	63	94	32.00	1-3		*	34.00
104	847	M	50	1667	138	7	12	5	6	2?+	S2	S2	66	65	98	33.00	1-3		*	34.00
105	2104	M	20	1698	145	7	12	5	5	3	S2	S3	55	64	97	33.00	2-4,1-3		*	34.00
106	1707	M	20	1720	110	7	12	5	5	4	S2	S2	65	61	92	34.00	1-3		*	37.00
107	1233	M	27	1701	141	7	13	4	5	5	S2	S2	56	52	90	34.00	1-3		*	38.00
108	1760	F	70	1557	97	7	12	5	6	1+	S1	S2	59	56	110	36.00	1-3,1-4			33.00
109	1189	M	38	1650	91	7	12	5	6	1	S2	S2	57	60	87	37.00	1-4,1-3		*	43.00
110	512	M	25	.		7	12	5	6	4	S2	S2	66	64	109	39.00	1-3		*	36.00
111	1185	M	59	1738	129	7	12	5	6	3	S2	S2	71	65	99	40.00	1-4		*	40.00
112	1681	M	54	1764	142	7	13	4	6	4	S2	S2	65	66	120	45.00	1-4		*	38.00

------------------------------------- NUMBER OF PRESACRAL ELEMENTS =25 -------------------------------------

OBS	ITEM	SEX	AGE	HEIGHT	WEIGHT	C	T	L	S	CA	RF	LF	RA	LA	A-B	X	POS	LLA	H/P	RATIO
113	952	M	40	1725	152	7	12	6	5	4	S1	S1	66	.	109	-7.00	L-3	*L		-6.00
114	956	M	45	1738	135	7	12	6	5	1+	S1	S1	56	57	96	-4.00	L-2	*B		-4.00
115	1544	M	60	1841	160	7	12	6	5	4	S1	S1	70	71	104	-4.00	L-3			-4.00
116	879	M	45	1731	147	7	13	5	5	3?+	S1	S1	60	61	109	1.00	L-3			1.00
117	1410	M	30	1760	120	7	13	5	5	4	S1	S1	54	54	96	1.00	L-3			1.00
118	896	M	53	1738	145	7	12	6	5	1+	S1	S1	67	66	105	2.00	L-3			2.00
119	612	F	36	1405	90	7	12	6	5	4	S1	S1	43	45	99	2.00	L-2			2.00
120	1704	M	20	1704	145	7	12	6	4	1+	S1	S1	67	58	95	2.00	L-2,1-3	*B		2.00
121	101	M	.	.		7	12	6	5	?	S1	S1	62	65	94	2.00	L-3			2.00
122	558	M	41	.		7	12	6	4	2+	S1	S1	64	63	106	3.00	L-3	*B		3.00
123	1575	M	20	1753	130	7	12	6	4	4	S1	S1	59	60	97	3.00	1-3,L-3	*L		3.00
124	1514	M	59	1780	155	7	12	6	4	2+	S1	S1	66	65	112	4.00	L-3			4.00
125	1186	M	46	1730	133	7	12	6	5	3	S1	S1	67	62	99	4.00	L-2			4.00
126	94	M	28	.		7	12	6	5	4	S1	S1	60	64	98	4.00	L-3	*B		4.00
127	703	M	22	1736	130	7	12	6	5	4	S1	S1	52	56	84	4.00	1-3L-3	*B		5.00
128	489	M	34	.		7	13	5	5	4	S1	S1	57	53	101	4.00	L-3			4.00
129	1550	M	49	1847	138	7	12	6	5	1+	S1	S1	71	68	123	5.00	L-3			4.00
130	445	M	36	.		7	12	6	4	2+	S1	S1	66	64	108	5.00	L-3			5.00
131	1176	M	43	1700	130	7	12	6	5	1+	S1	S1	60	58	84	5.00	L-2,L-3			6.00
132	1081	M	45	1764	95	7	13	5	5	3?	S1	S1	69	63	110	5.00	L-3			5.00
133	1209	M	65	1705	86	7	12	6	5	4	S1	S1	56	57	105	6.00	L-2			6.00
134	1568	M	58	1647	120	7	12	6	5	3+	S1	S1	62	68	92	6.00	L-3	*L		7.00
135	586	M	40	.		7	13	5	5	1+	S1	S1	.	60	101	6.00	L-3			6.00
136	1535	M	60	1678	122	7	12	6	5	3+?	S1	S1	59	58	111	7.00	1-3,L-3	*L		6.00
137	707	M	32	1665	140	7	12	6	5	2+	S1	S1	65	64	107	7.00	L-3			7.00
138	964	M	20	1827	130	7	12	6	5	3	S1	S1	53	55	104	7.00	1-3,L-2	*L		7.00
139	247	M	30	.		7	12	6	5	1+	S1	S1	61	63	101	7.00	L-3			7.00
140	1077	M	45	1801	146	7	13	5	5	?	S1	S1	69	71	115	7.00	1-3,L-3			6.00
141	904	M	50	1629	136	7	12	6	6	3	S1	S1	63	63	104	8.00	L-3			8.00
142	845	M	21	1724	141	7	12	6	5	?	S1	S1	55	47	95	8.00	L-2,1-2			8.00
143	905	M	77	1776	141	7	13	5	5	2?+	S1	S1	65	64	112	8.00	1-3			7.00
144	814	M	35	1673	128	7	13	5	5	?	S1	S1	57	58	107	8.00	1-3	*R		7.00
145	855	M	28	1785	134	7	13	5	5	4	S1	S1	54	55	98	8.00	1-3	*L		8.00
146	354	M	48	.		7	12	6	5	?	S1	S1	54	54	108	9.00	L-3			8.00
147	1384	M	35	1713	130	7	12	6	4	1+	S1	S1	.	59	108	10.00	?,1-3			9.00
148	1222	M	45	1740	127	7	13	5	5	5	S1	S1	66	70	110	10.00	L-3,L-2	*L		9.00
149	643	M	26	.		7	12	6	5	3+	S1	S1	59	61	108	11.00	1-3	*B		10.00
150	1530	F	40	1685	118	7	13	5	5	?	S1	S1	52	50	100	11.00	1-3			11.00
151	1499	M	50	1855	140	7	12	6	5	4	S1	S1	69	70	100	12.00	1-3			12.00
152	1392	M	30	1668	125	7	12	6	5	4	S1	S1	57	55	82	12.00	L-3	*R		15.00
153	1246	M	39	1730	110	7	13	5	5	4	S1	S1	63	60	106	12.00	L-3			11.00
154	860	M	23	1820	120	7	13	5	5	4	S1	S1	56	59	103	12.00	1-3			12.00
155	1271	M	39	1664	80	7	13	5	5	2+	S1	S1	59	57	97	12.00	1-3			12.00
156	1395	M	48	1735	148	7	12	6	5	2+	S1	S1	63	63	107	13.00	L-3,1-3			12.00
157	379	M	27	.		7	12	6	5	5	S1	S1	58	59	106	13.00	1-3			12.00
158	1253	F	31	1540	76	7	12	6	5	4	S1	S1	51	51	99	13.00	1-3,L-3	*L		13.00
159	841	M	50	1720	110	7	13	5	5	5	S1	S1	68	67	109	13.00	L-3			12.00
160	941	M	22	1706	165	7	12	6	5	?	S1	S1	59	59	97	14.00	1-3			14.00
161	86	M	35	.		7	12	6	4	1+	S1	S1	67	67	91	14.00	L-3	*R		15.00
162	1428	M	54	1667	121	7	13	5	5	4	S1	S1	61	57	114	14.00	1-3			12.00
163	455	M	53	.		7	13	5	5	4	S1	S1	59	62	114	15.00	L-3			13.00
164	740	M	40	1703	142	7	13	5	5	4	S1	S1	67	64	106	15.00	L-3			14.00
165	1314	M	65	1693	122	7	13	5	5	2+	S1	S1	62	62	105	15.00	L-3			14.00
166	1201	M	29	1927	140	7	13	5	5	4	S1	S1	58	56	104	15.00	L-3			14.00
167	1326	M	82	1764	121	7	13	5	5	4	S1	S1	64	60	100	15.00	1-3			15.00
168	280	M	35	.		7	12	6	5	4	S1	S1	64	63	109	16.00	1-4			15.00
169	1532	M	37	1854	145	7	12	6	5	4	S1	S1	62	64	118	17.00	1-3		*	14.00
170	1075	M	35	1798	125	7	12	6	5	1+	S1	S1	63	63	111	17.00	1-3			15.00
171	397	M	81	.		7	12	6	5	?	S1	S1	63	.	109	17.00	L-3?			16.00
172	448	M	31	.		7	12	6	5	4	S1	S1	53	52	94	17.00	1-3			18.00
173	1313	M	35	1914	178	7	13	5	5	2+	S1	S1	62	64	110	17.00	1-3			15.00
174	1572	M	47	1856	135	7	12	6	5	4	S1	S1	61	61	108	18.00	1-3			17.00
175	1974	M	18	.		7	12	6	6	2+	S1	S1	58	58	93	18.00	1-3			19.00
176	531	M	45	.		7	13	5	5	3?4	S1	S1	64	61	123	18.00	1-3			15.00
177	1444	M	30	1860	135	7	13	5	5	3	S1	S1	58	64	107	18.00	1-3			17.00
178	282	M	45	.		7	12	6	5	1+	S1	S1	60	60	105	19.00	1-3			18.00
179	78	M	32	.		7	12	6	5	1+	S1	S1	66	63	110	22.00	1-3		*	20.00
180	383	M	35	.		7	13	5	6	5?	S1	S1	57	59	104	24.00	1-3			23.00

Appendix B

RESULTS OF STATISTICAL PROCEDURES

The following printed output are from SAS (Statistical Analysis System) statistical procedures.

TTEST PROCEDURE

VARIABLE: MEASURE SACRAL MEASUREMENT

PRESAC	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
23	43	33.46511628	7.66360862	1.16868936	20.00000000	50.00000000	UNEQUAL	6.7652	98.7	0.0001
24	69	22.76811594	8.84697510	1.06505064	-2.00000000	45.00000000	EQUAL	6.5429	110.0	0.0001

FOR H0: VARIANCES ARE EQUAL, F'= 1.33 WITH 68 AND 42 DF PROB > F'= 0.3196

TTEST PROCEDURE

VARIABLE: MEASURE SACRAL MEASUREMENT

PRESAC	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
24	69	22.76811594	8.84697510	1.06505064	-2.00000000	45.00000000	UNEQUAL	9.9859	124.2	0.0001
25	68	9.58823529	6.42809898	0.77952150	-7.00000000	24.00000000	EQUAL	9.9633	135.0	0.0001

FOR H0: VARIANCES ARE EQUAL, F'= 1.89 WITH 68 AND 67 DF PROB > F'= 0.0096

TTEST PROCEDURE

VARIABLE: MEASURE SACRAL MEASUREMENT

LONG	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
NO	112	26.87500000	9.87318235	0.93292804	-2.00000000	50.00000000	UNEQUAL	14.2192	177.1	0.0001
YES	68	9.58823529	6.42809898	0.77952150	-7.00000000	24.00000000	EQUAL	12.8695	178.0	0.0001

FOR H0: VARIANCES ARE EQUAL, F'= 2.36 WITH 111 AND 67 DF PROB > F'= 0.0002

TTEST PROCEDURE

VARIABLE: MEASURE SACRAL MEASUREMENT

NORMAL	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
NO	111	18.83783784	13.56904267	1.28791653	-7.00000000	50.00000000	UNEQUAL	-2.3517	177.6	0.0198
YES	69	22.76811594	8.84697510	1.06505064	-2.00000000	45.00000000	EQUAL	-2.1388	178.0	0.0338

FOR H0: VARIANCES ARE EQUAL, F'= 2.35 WITH 110 AND 68 DF PROB > F'= 0.0002

TTEST PROCEDURE

VARIABLE: MEASURE SACRAL MEASUREMENT

SHORT	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > |T|
NO	137	16.22627737	10.16047178	0.86806769	-7.00000000	45.00000000	UNEQUAL	-11.8414	92.4	0.0001
YES	43	33.46511628	7.66360862	1.16868936	20.00000000	50.00000000	EQUAL	-10.2411	178.0	0.0001

FOR H0: VARIANCES ARE EQUAL, F'= 1.76 WITH 136 AND 42 DF PROB > F'= 0.0365

PRESAC=23

UNIVARIATE

VARIABLE=MEASURE SACRAL MEASUREMENT

MOMENTS

N	43	SUM WGTS	43
MEAN	33.4651	SUM	1439
STD DEV	7.66361	VARIANCE	58.7309
SKEWNESS	0.318885	KURTOSIS	-0.64946
USS	50623	CSS	2466.7
CV	22.9003	STD MEAN	1.16869
T:MEAN=0	28.6347	PROB>|T|	0.0001
SGN RANK	473	PROB>|S|	0.0001
NUM ¬= 0	43		
W:NORMAL	0.964068	PROB<W	0.338

QUANTILES(DEF=4)

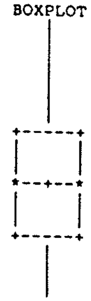
100% MAX	50	99%	50
75% Q3	39	95%	47
50% MED	33	90%	45.4
25% Q1	27	10%	23.4
0% MIN	20	5%	22
		1%	20
RANGE	30		
Q3-Q1	12		
MODE	31		

EXTREMES

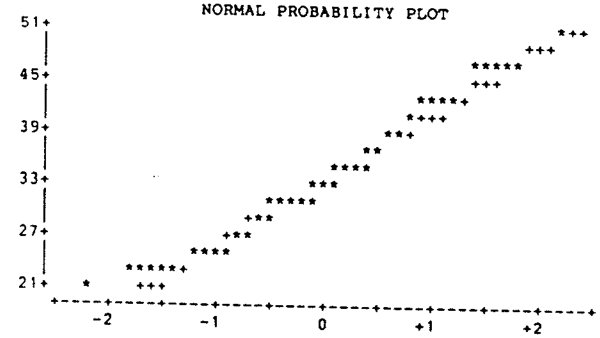
LOWEST	HIGHEST
20	43
22	47
22	47
23	47
24	50

```
STEM LEAF                     #
  50 0                        1
  48
  46 000                      3
  44
  42 0000                     4
  40 00                       2
  38 00                       2
  36 000                      3
  34 00000                    5
  32 000                      3
  30 0000000                  7
  28 00                       2
  26 000                      3
  24 0000                     4
  22 000                      3
  20 0                        1
     ----+----+----+----+
```

BOXPLOT



NORMAL PROBABILITY PLOT



PRESAC=24

UNIVARIATE

VARIABLE=MEASURE SACRAL MEASUREMENT

MOMENTS

N	69	SUM WGTS	69
MEAN	22.7681	SUM	1571
STD DEV	8.84698	VARIANCE	78.269
SKEWNESS	-0.185355	KURTOSIS	0.582278
USS	41091	CSS	5322.29
CV	38.8569	STD MEAN	1.06505
T:MEAN=0	21.3775	PROB>|T|	0.0001
SGN RANK	1205.5	PROB>|S|	0.0001
NUM ¬= 0	69		
D:NORMAL	0.0772022	PROB>D	>.15

QUANTILES(DEF=4)

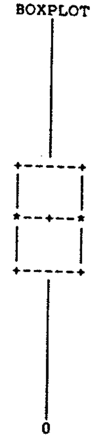
100% MAX	45	99%	45
75% Q3	28.5	95%	38
50% MED	22	90%	34
25% Q1	17	10%	13
0% MIN	-2	5%	6
		1%	-2
RANGE	47		
Q3-Q1	11.5		
MODE	20		

EXTREMES

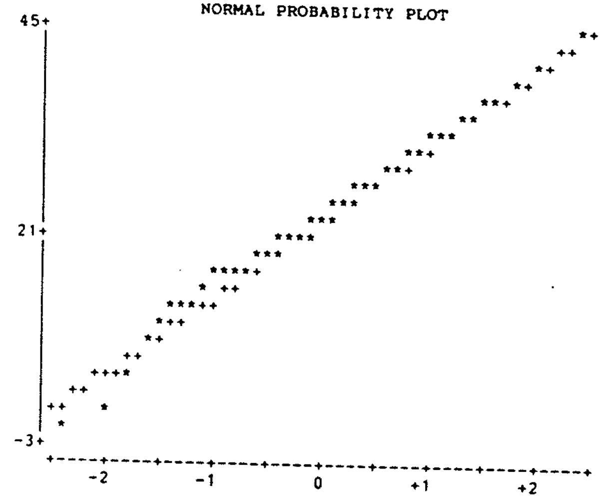
LOWEST	HIGHEST
-2	36
1	37
4	39
8	40
11	45

```
STEM LEAF                    #
 44 0                        1
 42
 40 0                        1
 38 0                        1
 36 00                       2
 34 00                       2
 32 00000                    5
 30 0000                     4
 28 0000                     4
 26 000000                   6
 24 00000                    5
 22 0000000                  7
 20 00000000                 8
 18 00000                    5
 16 00000000                 8
 14 0                        1
 12 0000                     4
 10 0                        1
  8 0                        1
  6
  4 0                        1
  2
  0 0                        1
 -0
 -2 0                        1
    ----+----+----+----+
```

BOXPLOT



NORMAL PROBABILITY PLOT



PRESAC=25

UNIVARIATE

VARIABLE=MEASURE SACRAL MEASUREMENT

MOMENTS

N	68	SUM WGTS	68
MEAN	9.58824	SUM	652
STD DEV	6.4281	VARIANCE	41.3205
SKEWNESS	-0.171913	KURTOSIS	-0.300713
USS	9020	CSS	2768.47
CV	67.0415	STD MEAN	0.779522
T:MEAN=0	12.3002	PROB>|T|	0.0001
SGN RANK	1123.5	PROB>|S|	0.0001
NUM ^= 0	68		
D:NORMAL	0.0874175	PROB>D	>.15

QUANTILES(DEF=4)

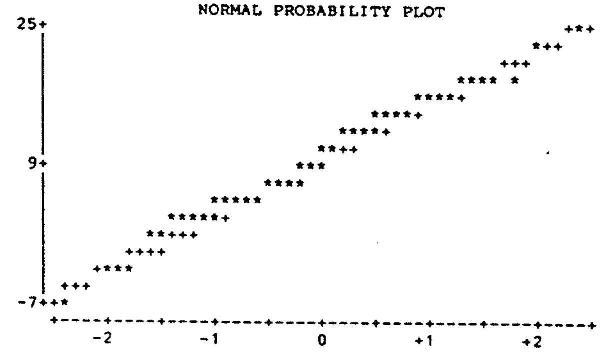
100% MAX	24	99%	24
75% Q3	15	95%	18.55
50% MED	9.5	90%	18
25% Q1	5	10%	2
0% MIN	-7	5%	-1.75
		1%	-7
RANGE	31		
Q3-Q1	10		
MODE	4		

EXTREMES

LOWEST	HIGHEST
-7	18
-4	18
-4	19
1	22
1	24

```
STEM LEAF                    #     BOXPLOT
  24 0                       1        |
  22 0                       1        |
  20                                  |
  18 00000                   5        |
  16 000000                  6        |
  14 00000000                8     +-----+
  12 000000000               9     |     |
  10 0000                    4     |     |
   8 000000                  6     *--+--*
   6 00000000                8     |     |
   4 000000000               9     +-----+
   2 000000                  6        |
   0 00                      2        |
  -0                                  |
  -2                                  |
  -4 00                      2        |
  -6 0                       1        |
     ----+----+----+----+
```

NORMAL PROBABILITY PLOT



UNIVARIATE

VARIABLE=MEASURE   SACRAL MEASUREMENT

MOMENTS

N	180	SUM WGTS	180
MEAN	20.3444	SUM	3662
STD DEV	12.1058	VARIANCE	146.551
SKEWNESS	0.172741	KURTOSIS	-0.568082
USS	100734	CSS	26232.6
CV	59.5043	STD MEAN	0.902315
T:MEAN=0	22.5469	PROB>|T|	0.0001
SGN RANK	8081.5	PROB>|S|	0.0001
NUM ^= 0	180		
D:NORMAL	0.0601128	PROB>D	0.111

QUANTILES(DEF=4)

100% MAX	50	99%	47.57
75% Q3	30	95%	41.95
50% MED	20	90%	36.9
25% Q1	12	10%	4
0% MIN	-7	5%	2
		1%	-4.57
RANGE	57		
Q3-Q1	18		
MODE	17		

EXTREMES

LOWEST	HIGHEST
-7	45
-4	47
-4	47
-2	47
1	50

```
STEM LEAF                                    #
   5 0                                       1
   4 5777                                    4
   4 0012333                                 7
   3 5566777999                             10
   3 000000111112222333344444               24
   2 5555666677777888999                    19
   2 00000011122222222233344444             26
   1 555555666667777777777888888899         30
   1 001112222223333333444                  21
   0 5555666777778888889                    19
   0 111222233444444                        15
  -0 442                                     3
  -0 7                                       1
     ----+----+----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**+01
```

BOXPLOT