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I am submitting herewith a thesis written by Jennifer Adair entitled "The Relationship of the Bi-Spinous Diameter and Femoral Head Diameter to Body Size in Females". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

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THE RELATIONSHIP OF THE BI-SPINOUS DIAMETER AND FEMORAL HEAD DIAMETER TO BODY SIZE IN FEMALES

A Thesis Presented for the
Master of Arts Degree
The University of Tennessee, Knoxville

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May 1998

ABSTRACT

The aim of the present study is to add to the knowledge of the relationship between certain skeletal measurements and body weight and height of female adults. To this end, 72 individuals were selected from the Hamman-Todd Collection of the Cleveland Museum of Natural History. For each individual, the diameter between the ischial spines of the pelvis and the diameter of the femoral head were measured. These variables were analyzed and correlated with body weight and height. Only three significant relationships were found to exist between the measured variables and body weight or height, but these relationships are not very strong. The results lead to the conclusion that these skeletal diameters are of limited use in estimating live body weight. The body height of a woman may have some value in predicting the diameter between the ischial spines, a measurement important in obstetrics since it indicates potential difficulties with labor and birth. It is suggested that perhaps the condition of the sample population contributed to these results, and modifications of this study for future use are presented.

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LIST OF ABBREVIATIONS

BSD	bi-spinous diameter
FH	diameter of femoral head
FHSQ	value of femoral head squared
FH3	value of femoral head cubed
HT	height
PC	principal component
RT3WT	cubed root of weight
WT	weight

I. Introduction

This study addresses the relationship of certain skeletal measurements to variables of body size in females. The purpose of the study is to test the hypothesis that the distance between the ischial spines of the pelvis (bi-spinous diameter) and/or the femoral head diameter are indicators of body weight. The study also examines whether or not body weight or height is a good predictor of the bi-spinous diameter for obstetric purposes.

The form of the human pelvis has long been of interest to the fields of physical anthropology and obstetrics. Sexual dimorphism, the evolution of bipedalism, both hominid and modern human birth processes, and the effects of reproduction on the body are just some of the many areas of research that focus on the pelvis. Within the fields of anthropology and obstetrics, there are three areas of research that are most relevant to this study. The first is the sexual dimorphism of the pelvis. The next is the factors that shape the modern adult human pelvis. The final area is anthropometrics, in both physical (including forensic) anthropology and in obstetrics. Each of these research areas has contributed to the present study, and will be reviewed in turn.

II. Literature Review

A. Sexual Dimorphism

The primary function of the human pelvis is to support bipedal locomotion. Bipedalism is not a sex-specific characteristic; therefore, the basic structures of the male and female pelvis, like other elements of the skeletal system, are similar. The secondary function of the human pelvis is obstetric. The obligation to give birth is unique to females. This additional obstetric function of the female pelvis is what distinguishes it from the male pelvis in both size and shape (see Fig. 1).

Physical anthropologists have long recognized and studied in detail the sexually dimorphic characteristics of the adult human pelvis. The bony pelvis is the area of the skeleton that is most clearly sexually dimorphic, and understanding the details of its structure and growth enable us to better compare male and female physiology (Washburn 1948, Segebarth-Orban 1980, Berge et al. 1984, Nwoha 1995, Tague 1989, 1992, LaVelle 1995). This understanding of sexual dimorphism in the bony pelvis is important for two reasons.

Being able to determine the sex of a skeleton is important in both archaeological and forensic settings. Washburn (1948) devised a sexing method using the ischium-pubic index. He found that this method alone "will sex over 90% of skeletons, provided that they belong to one major racial group" (Washburn 1948: 201). This method works because the pubic bones of a female (in proportion to the ishium) are longer than the pubic bones of a male. Detailed metric and visual studies of pelvic sexual dimorphism concur that the female pelvis is generally broader, with a wider pelvic inlet. The ilium

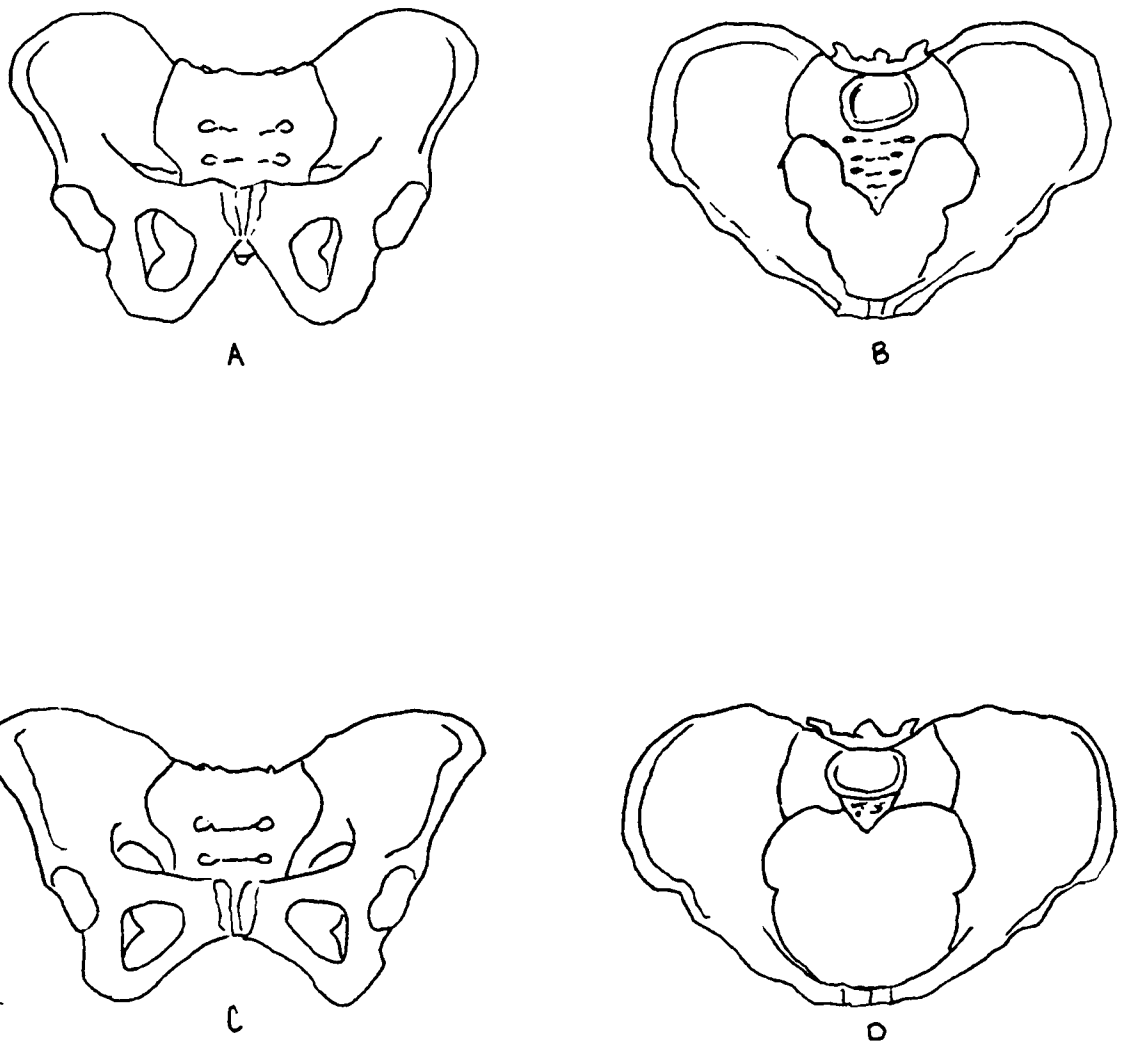


Figure 1. Male and Female Pelves. *A*, Anterior view of the male pelvis. *B*, Superior view of the male pelvis. *C*, Anterior view of the female pelvis. *D*, Superior view of the female pelvis.
Source: Crouch, J.E. *Functional Human Anatomy*. Philadelphia: Lea & Febiger, 1978.

is generally taller and larger among men, and males have larger acetabulae. The auricular surface on the female ilium is placed more posteriorly than it is on the male ilium. The sciatic notch is broader and shallower on female ilia. Though size accounts for much sexual dimorphism of the pelvis, such visual and other metrically evaluated shape variations are clearly sex-specific (Arsuaga and Carretero 1994). Probably the most popular visual method of assessing sex is that of Phenice (1969). This method assigns sex to a skeleton based on the presence or absence of three characteristics of the pubic area: a ventral arc on the pubis, a subpubic concavity, and a pinched medial aspect of the ischiopubic ramus. Presence of these characteristics indicates that the individual is female (Phenice 1969). The unique and obstetrically significant features of the female pelvis allow for fairly confident identification of a skeleton as male or female.

In addition to simply being able to determine the sex of an unknown individual, studies of sexual dimorphism of the pelvis contribute to a better understanding of the growth process and the effects of reproduction on the body.

For example, the rate of growth in the female pelvis does not parallel the rate of growth in stature. Though a woman's growth in stature decelerates soon (within a year) after menarche, growth in the dimensions of the birth canal continues at a fairly constant rate until late adolescence (Moerman 1982). This indicates possible obstetric risk for girls who have children soon after menarche, since their pelves are not yet fully mature. The growth patterns of various elements of the pelvis are sexually dimorphic. During adolescence, females exhibit more growth in the pelvic cavity, pubis length, and bi-ischial spine diameter, whereas males show more growth in the size of the acetabulum, height

of ilium, and breadth of the anterior superior iliac spines (LaVelle 1995).

Another area of study focusing on the female pelvis is the degree to which childbirth affects the bony pelvis. Stewart (1957) was one of the first to recognize how gestation and childbirth can alter the appearance of the female pelvis. Since then, many researchers have attempted to use morphological features in the bony pelvis to conclude how many times a woman gave birth. The studies focus on specific areas or features of the pelvis that are thought to be sexually dimorphic. Such features include pits or grooves on the dorsal aspect of the pubis and unique grooves near the auricular surface. Though some studies conclude that there is at least a slight correlation between these features and a woman's history of live births (see Stewart 1957, Angel 1969 and Gilbert and McKern 1973), most researchers find no such correlation (Houghton 1974, Holt 1978, Suchey et al. 1979, Kelley 1979).

Studies that focus on sexually dimorphic features and patterns of growth of the pelvis lead to a better overall understanding of human reproduction. One must first be able to recognize the basic differences between the forms of the male and female adult pelves. Inquiries into the growth patterns of the pelvis then contribute to a better understanding of the mechanics of successful reproduction. Furthermore, studies focusing on some sexually dimorphic features of the pelvis help in understanding how the reproductive process affects the skeleton. All these areas of study help us understand the function of the pelvis and the physical differences between the sexes. The next step is to study what factors lead to these physical differences.

B. Factors Which Shape the Pelvis

1. Evolutionary history

Examining the female (or "obstetric") pelvis of various primate species is valuable because it yields information about the processes of pregnancy and parturition. Studying the female pelvis also reveals information concerning the size of offspring and mode of delivery. The obstetric pelvis helps us to understand the reproductive patterns of our own species as well as those of other primate species. This information, in turn, can be applied to the few examples that are available of hominid female pelves and can give insight into the reproductive patterns of hominid species.

One of the major issues involved in understanding the form of the modern female pelvis is being able to reconstruct the process of hominid childbirth. Attempts at analyzing this process are limited due to lack of specimens, but much work has been done with the few available samples. Two samples commonly used are the fragmentary pelvis of Sts 14 and more complete pelvis of AL 288-1, both thought to be *Australopithecine* females. Most interpretation is based on the pelvis of AL 288-1 since it is better preserved. The pelvis of AL 288-1 has been described as "ultra-female" (Arsuaga and Carretero 1994) because of its very long pubic bones, long iliopectineal lines, and generally broad and wide shape. In fact, the transverse diameters of the pelvic planes exceed the anterior-posterior diameters throughout the birth canal, a condition never found in modern humans (Arsuaga and Carretero 1994, Tague and Lovejoy 1986, Abitbol 1991, 1996a, Berge et al. 1984). Tague and Lovejoy (1986) conclude that this pelvic

shape means the fetus descended through the birth canal oriented transversely, possibly causing obstetric difficulty for the australopithecines. Luetenegger (1974, 1987) uses the size of non-human primate neonates to estimate the size of newborn hominids and concludes that because of small neonate size (significantly in the not-yet-encephalized cranium) birth was quick and easy, at least for *A. africanus*. The gestation and birth process has also been explored for Neandertals (see below) (Leutenegger 1973, 1982, Berge et al. 1984, Tague and Lovejoy 1986, Tague 1989, 1992, Abitbol 1987, 1988, 1991, 1996a, Rosenberg 1988, Fischman 1994,Walrath and Glantz 1996).

Physical anthropologists argue the degree to which locomotor and obstetric forces have shaped the human pelvis throughout our evolution as a species. Most researchers agree that hominids were fully bipedal before the issues of fetal encephalization and altriciality had any significant effect on the form of the pelvis (Tague and Lovejoy 1986, Trevathan 1987, Abitbol 1996a, Leutenegger 1974). Only after the pelvis was restructured for habitual bipedalism (see below) did selection for larger crania and subsequent obstetrical difficulties develop.

According to Trevathan (1987), this selection for larger fetal crania spurred two differing methods of adaptation among the pongids and hominids. The pongids increased overall body size, thus creating a larger birth canal. This option was not feasible for hominids, because by this point they had developed bipedal locomotion, and increasing their overall body size would compromise its efficiency as a method of transportation. Rather, she states,

> Another way to meet the problem of producing young too large to deliver successfully is to deliver them "prematurely" when the fetus has not reached the normal neonatal size" (Trevathan 1987:28).

Therefore humans still give birth to relatively immature young, who require a great deal of postnatal care.

However, some degree of morphological change in the female pelvis has obviously accompanied encephalization. The modern birth canal is rounder and narrower transversely than that of the australopithecines. Having already adopted habitual bipedalism, hominids were unable to expand the birth canal transversely since it would compromise bipedal transportation. Most of the birth canal's widening had to occur in the anterior-posterior direction. This is what led to the modern rounder form of the female pelvis (Abitbol 1991, Tague and Lovejoy 1986, Berge et al. 1984). The modern human pelvis is a continual compromise between the wide birth canal needed for encephalization and the narrow pelvis needed for efficient bipedalism.

2. Modern Influences on Pelvic Variation

Of special interest to obstetricians and gynecologists are the factors that influence the final form of the modern adult female pelvis. Caldwell and Moloy (1933) classified the variations in the adult female pelvis into four major categories, based on the shape of the inlet (see Fig. 2). The gynecoid pelvis, or that of a "normal female", has a round or transversely oval inlet. The android, or male pelvis, has a heart-shaped inlet. The anthropoid, or ape-like pelvis, is long anteriorly-posteriorly and relatively short transversely. Finally, the platypelloid pelvis is opposite of the anthropoid, long transversely and short in the anterior-posterior direction. (The platypelloid form is ascribed to the australopithecines). Caldwell and Moloy estimate the percentage of the gynecoid android, anthropoid, and platypelloid types in women at 50%, 20%, 25%,

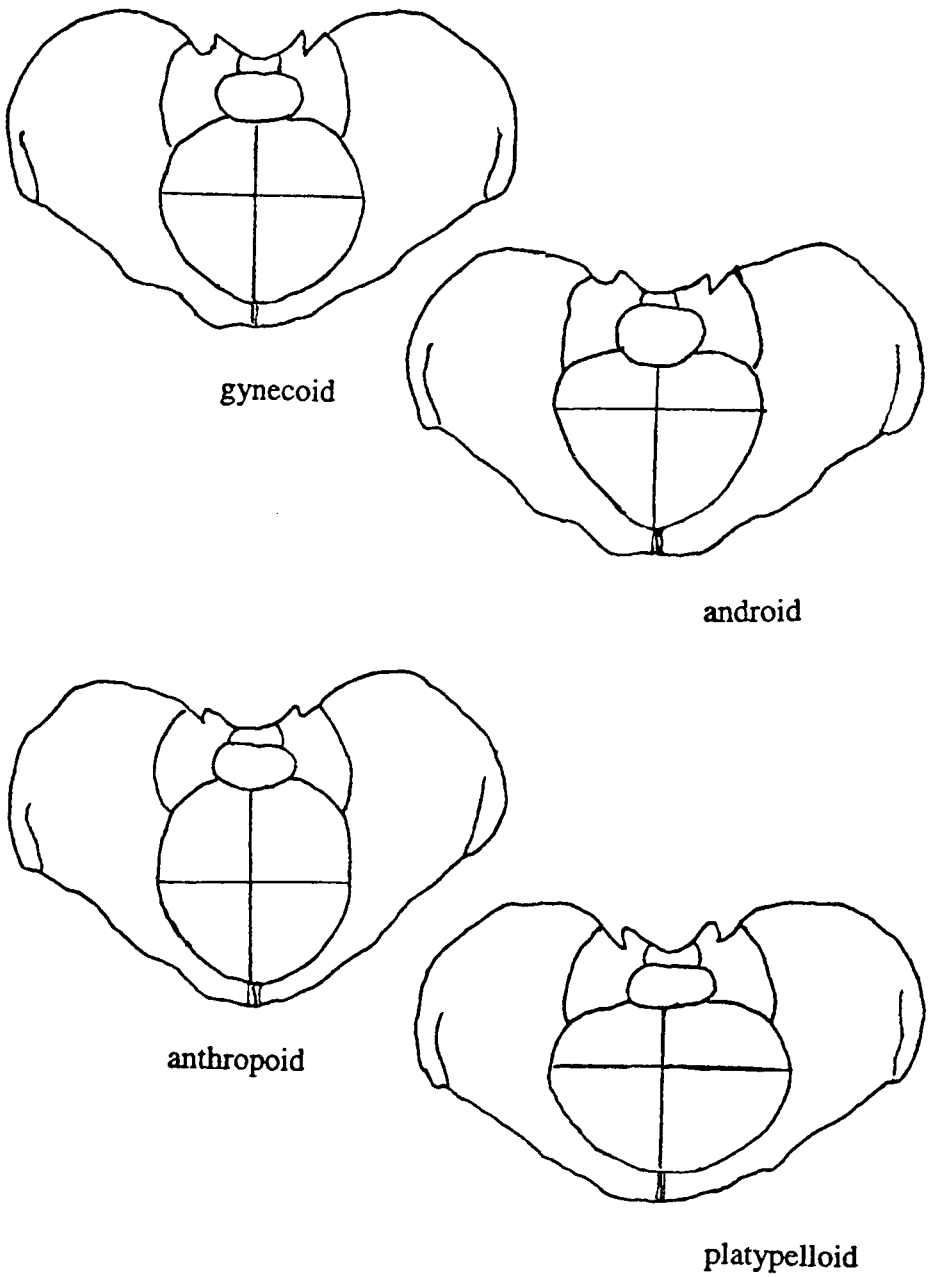


Figure 2. Pelvic inlet shapes (Caldwell-Moloy classification).
Source: Oxorn, H. *Human Labor and Birth.* Norwalk, CT: Appleton-Century-Crofts, 1986.

and 5%, respectively. The actual percentage of women whose pelves fall into each of the previous categories varies, depending on the nature of the study sample. Though this classification scheme is not universally accepted as having practical value (see Ince and Young 1940), physicians and anthropologists continue to utilize it in demonstrating morphological variation and predicting the difficulty of labor (Oxorn 1986, Tague and Lovejoy 1986, Abitbol 1996b).

Though the factors that influence these various adult forms are thought to be mostly hereditary, environment (including nutrition and disease) also plays a role in shaping the individual characteristics the female pelvis (Baird 1945, Thoms 1947, Micozzi 1982, Kelley and Angel 1987, Sibley et al. 1992).

For example, Sibley et al. (1992) examined pelvic dimensions in a sample of medieval females from Sudanese Nubia. Contrasting the pelvic dimensions to those of other prehistoric populations as well as to samples of modern Americans, they found that the pelves of the Nubian population were significantly smaller in most dimensions than those of either the prehistoric or modern American populations. In fact, one third to one half of the Nubian sample was found to be contracted (compared to the modern standard) in one or more pelvic planes. The authors explain this high incidence of pelvic contraction as a likely response to nutritional stress, inferred from high frequencies of porotic hyperostosis and enamel hypoplasia (Sibley et al. 1992).

Abitbol (1996b) found that the amount of physical activity or labor a woman experiences during childhood and puberty may also be related to the shape of the adult female pelvis. Of the 611 women who participated in the study, 83.6% with an

android pelvis experienced moderate to strenuous physical activity (due to either labor or sports) during adolescence. As for women with other pelvic shapes, the majority experienced no previous strenuous activity. Abitbol concludes:

> ...western culture spares the female strenuous physical work, ... although, as shown in this study, this is not a general rule. Therefore, one can also speculate that in the culture of previous humans and even hominids, pelvic dimorphism must have been accentuated when the culture allowed different physical activities between males and females...(Abitbol 1996b:250)

The shape of an individual female's pelvis, then, is a result of many factors. The evolutionary history of human beings in general as a bipedal species, and the evolutionary history of females in particular as the sex responsible for giving birth have led to the modern standard of the female pelvis. The particular life history of an individual woman, including her nutrition and level of physical activity during growth, leads to variation between individuals in pelvic shape.

C. Anthropometrics

The obstetric pelvis of the modern human female is made up of three major planes (Oxorn 1986) (see Fig.3). The first plane, or the pelvic inlet, extends anteriorly-posteriorly from the pubic crest and spine to the promontory of the sacrum. It is bordered laterally by the iliopectineal lines of the innominate bones. The third plane, or the pelvic outlet extends anterior-posterior from the arcuate pubic ligament and pubic arch to the tip of the sacrum. It is bordered laterally by the ischial tuberosities. The second plane lies between the inlet and the outlet. It is known as the pelvic cavity. The pelvic cavity is actually made up of several planes. It is a curved canal and it contains within its limits both the widest and narrowest planes of the birth canal. The plane of greatest

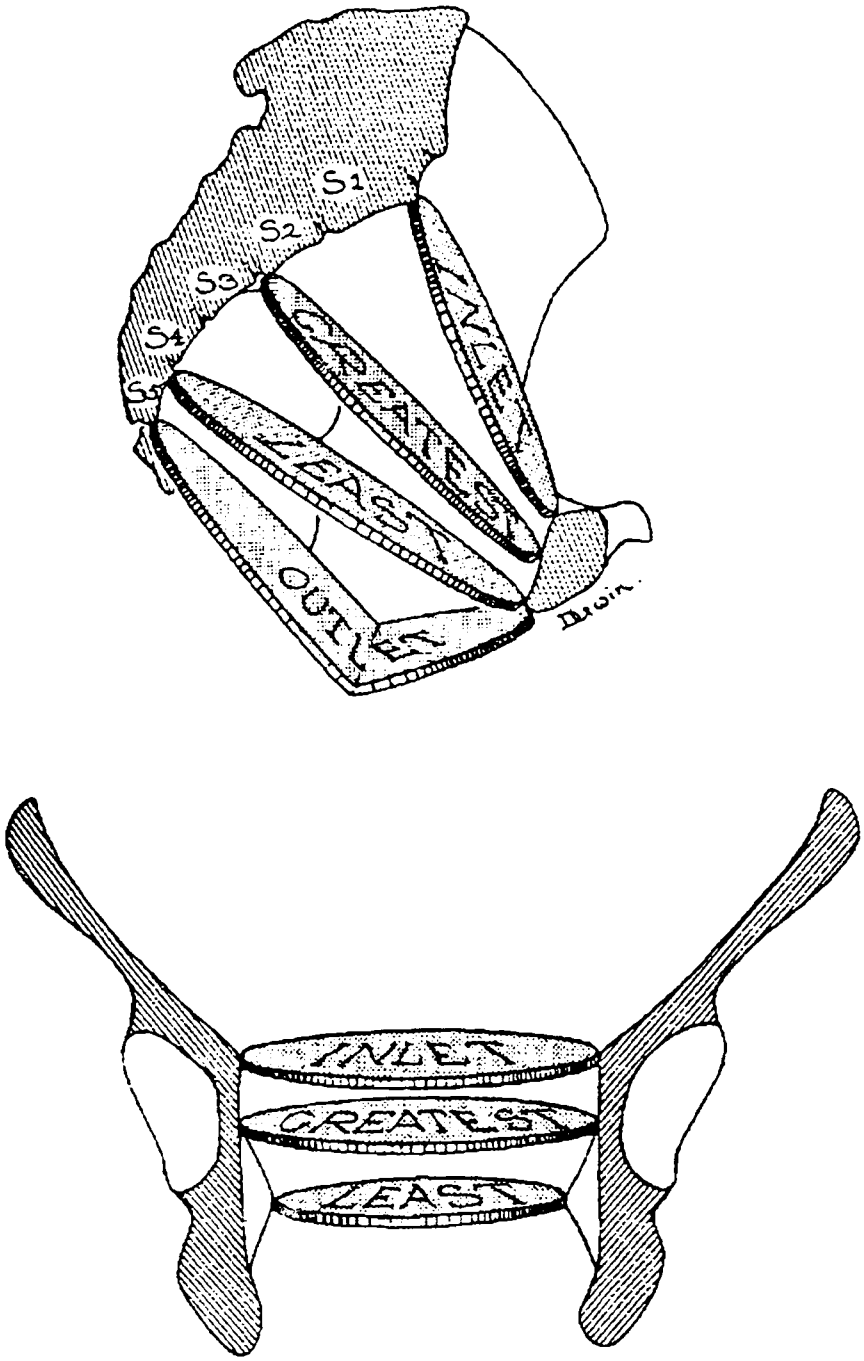


Figure 3. Sections showing pelvic planes (sagittal, above; coronal, below).
Source: Oxorn, H. *Human Labor and Birth.* Norwalk, CT: Appleton-Century-Crofts, 1986.

dimensions extends anterior-posterior from the midpoint of the posterior pubis to the junction of the second and third sacral vertebrae. Laterally it is bordered by the obturator foramina. This plane provides the most room for the fetus as it descends through the birth canal.

The plane of least dimensions extends anteriorly-posteriorly from the lower border of the pubic symphysis to the junction of the fourth and fifth sacral vertebrae. Its lateral borders, the ischial spines, make this plane the narrowest of the canal. Being the narrowest plane, this area presents the most problems during childbirth (Oxorn 1986). It is this diameter, the distance between the ischial spines, that "most significantly restricts normal delivery in modern humans" (Abitbol 1988). It is interesting to note that studies concentrating on both modern and early hominid obstetric pelvimetry often overlook this diameter (sometimes simply because it is difficult to measure), instead concentrating on the diameters of the inlet and outlet (Berge et al. 1984, Gudgeon 1991, Ogedengbe et al. 1993, Nwoha 1995).

Humans have a process of birth that is unique among primates. For other higher primates, the area of the infant's head is smaller than the area of the pelvic inlet. This allows for relative ease in parturition. In humans, the area of the infant's head usually exceeds the dimensions of the pelvic inlet, at least when situated anteriorly-posteriorly. For this reason, the infant must twist its head sideways when moving through the inlet. The pelvic plane of least dimensions, found within the pelvic cavity, is restricted laterally, so the infant must again turn to align the narrowest dimensions of the head with the narrowest dimensions of the birth canal. Upon reaching the pelvic outlet, the infant

maneuvers face down to take advantage of the roomier anterior of the outlet. This results in the infant being born face down, away from the mother.

This series of contortions experienced during delivery is unique to humans. Most other primates have comparatively spacious birth canals relative to infant size. This can be because of two reasons: the fetus at term is small relative to the size of the mother, or the degree of encephalization in the species not great (Leutenegger 1973). The size of the mother (i.e. the dimensions of the mother's pelvic cavity) is related to the mode of transportation of the species. Locomotion shapes the pelvis in one way; obstetric pressures often act in contradiction and work towards a completely different shape of the pelvis. Other things being equal, the species in which this conflict is most extreme tend to have the most difficulty providing sufficient room for the descending fetus during parturition. *Homo sapiens* is probably the best example of this (see below). For most (though not all) other primates, the birth canal provides more than enough space for the descending fetus. In these species, the young do not have to rotate their position on the way out, and are born face up, towards the mother. Human infants, however, in order to squeeze through the birth canal, need to rotate their bodies at the level of the pelvic midplane (Leutenegger 1973, Trevathan 1987, 1996, Fischman 1994, Tague and Lovejoy 1986, Oxorn 1986, Abitbol 1996a).

The midplane twist of the infant is necessary because of the ischial spines that project medially into the birth canal. The ischial spines of humans are unique among mammals in both form and function. In animals with tails, the ischial spines are located close to the caudal vertebrae. Their function is to support the muscles that move the

tail. In quadrupedal animals, a vertical pelvic "wall" supports abdominal viscera, whereas in humans, a horizontal pelvic "floor" serves this purpose. As bipedalism developed over the course of human evolution, the pressure exerted from above by the abdominal viscera led to a strengthening of the muscles of the pelvic floor. These muscles, the pubococcygeus, iliococcygeus, and ischiococcygeus, insert either directly on the ischial spines or indirectly on them via ligaments (See Fig. 4) (Abitbol 1988).

The evolution of bipedalism restructured the entire pelvic region. Walking upright resulted in increased intra-abdominal pressure on the pelvic floor. This pressure in the modern human amounts to more than half of total body weight. In order to support the abdominal viscera, the ilia flared to a more outward position. The sacro-iliac joint moved superior to the hip joint. The functions of the muscles of the lower trunk changed. The gluteal muscles became abductors and functioned to control balance when one foot left the ground. The muscles of the pelvic diaphragm strengthened to support both the increased abdominal pressure and to control defecation and urination. This led to the "migration" of the ischial spines to a more anterior and medially prominent position in the human pelvis. It was both the strengthening of these muscles of the pelvic floor and the shifting dimensions of the pelvis that led to the prominence of the ischial spines. As mentioned above, the large and prominent ischial spines are the most dangerous aspect of obstetrical delivery for humans (Leutenegger 1974, Trevathan 1987, Tague and Lovejoy 1986, Tague 1992, Abitbol 1987, 1988, 1991).

Because the ischial spines are the most restrictive element of the birth canal, they are of major concern to obstetricians preparing to assist in delivery. They are the most

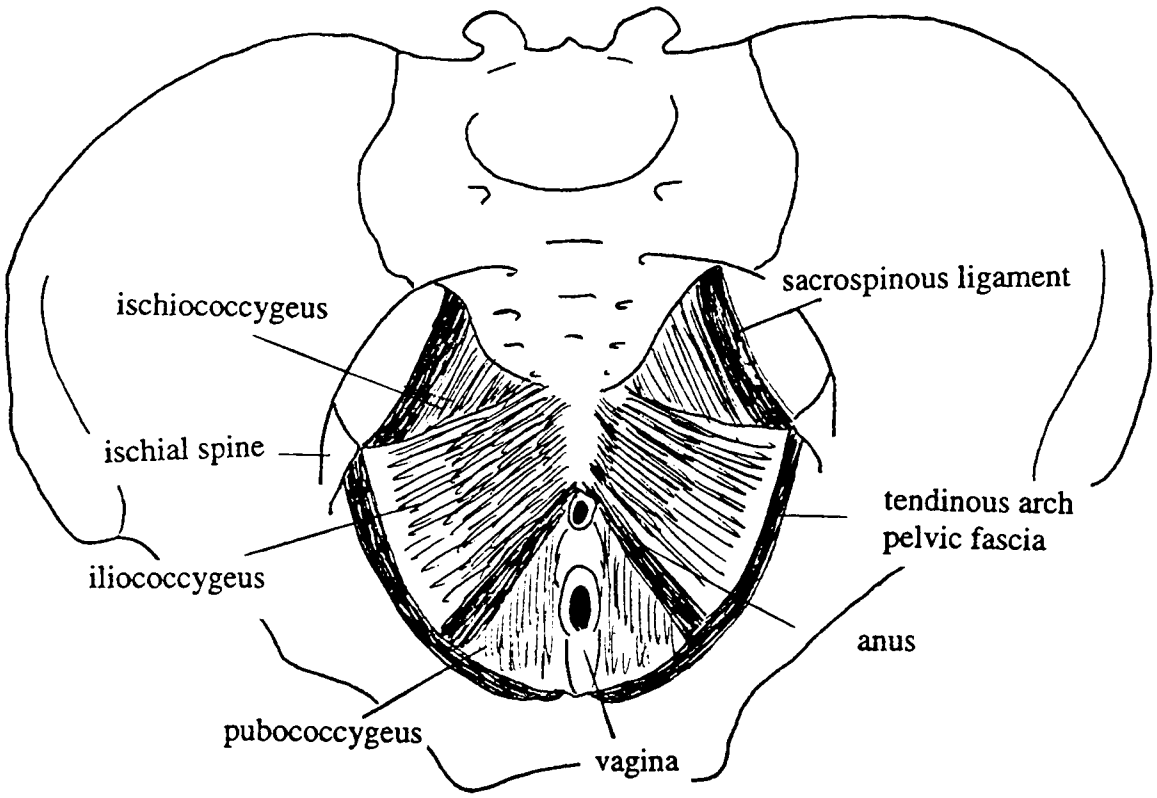


Figure 4. Diagram of the pelvic floor (superior view).
Source: Abitbol, M.M. "Evolution of the Ischial Spine and of the Pelvic Floor in the Hominoidea". *American Journal of Physical Anthropology* 75:53-67, 1988.

important of numerous pelvic size assessments taken before and during labor to help predict how likely it is that a particular woman will have difficulty with vaginal birth. Predicting the difficulty of vaginal delivery and the need for cesarean section has long been of concern to obstetrics. Obstetricians and midwives have studied numerous morphometric features of mother and fetus in hopes of being able to predict type of delivery. Studies of maternal and fetal anthropometrics have concentrated on everything from the shoulder width of the fetus to shoe size of the mother (Trevathan 1987, Gorman et al. 1997). Factors such as the weight of the fetus are not believed to have an influence on the type of delivery (Jagani et al. 1980). Rather, the dimensions of the fetus relative to maternal pelvic dimensions are thought to be crucial. Both X-ray and magnetic resonance imaging (MRI) pelvimetry are employed in obtaining these dimensions. Their value has been assessed according to how well they can predict the need for delivery by cesarean section. Using x-ray pelvimetry, Morgan et al. (1986) derived a fetal-pelvic index that was 85% accurate in predicting the need for cesarean section delivery and 92% accurate in predicting vaginal delivery. Tukeva et al. (1997) show that low-field MRI pelvimetry is a good alternative to X-ray because the method is clearer, possibly safer, and almost identical in measuring pelvic dimensions.

The structural changes of the pelvis that co-evolved with bipedalism led to a fairly rigid arrangement of bones of the birth canal. This limits the size of the fetus at term. Though the nutrition and health of the mother affects the size of a fetus, fetal size at term is ultimately limited by the size of the mother. Rosenberg (1986) used morphometric evidence from modern populations to support the hypothesis that infant size (birth

weight and head circumference) correlates better with maternal weight than with maternal stature. This work supported the conclusions of earlier studies in obstetrics (Kaltreider 1963, Garn and Pesick 1983). She later examined the relationship between maternal body size (height and weight) and pelvic measurements (Rosenberg 1988). Rosenberg found that women of disparate geographical populations, though they vary greatly in absolute height and weight, share the same relationships between pelvic measurements and body size. These relationships are also the same for Neandertals. The purpose of her 1988 study was to help interpret Neandertal reproductive patters, a controversial issue because of the very long pubic bones of Neandertals. Paleoanthropologists debate the meaning of this distinctive characteristic of the Neandertals. Wolpoff (1980) states that the long pubic bones are evidence of expanded crania relative to stature, first expressed in utero. Trinkaus (1984) claims the long pubic bones are evidence of an extended gestation period. Rosenberg concludes:

> Female Neandertal pubic length is near the upper end of the modern range of variation of pubic length in females (as is Neandertal femoral-head diameter) and has the same relationship to skeletal estimates of stature and weight as it does in modern females. That is, there is no evidence that Neandertal maternal-weight: infant-size relations differ from those of recent humans or early anatomically modern humans (Rosenberg 1988:605).

In other words, Neandertals have longer pubic bones than do modern humans because they were overall heavier relative to their height than any modern human population. In this study, Rosenberg uses the diameter of the femoral head squared as a substitute for body weight when analyzing the Neandertal samples. Following Lovejoy et al. (1973), Rosenberg accepts the diameter of the femoral head squared as proxy for body weight

because it is the surface area of a weight-bearing joint. Tague (1992) analyzes variation in sexual dimorphism of the Neandertal pelvis. He does not contradict Rosenberg, but shows that the Neandertal pelvic outlet falls into the lower range of variation in modern females. He points out that this would have caused obstetric difficulties since the Neandertals were overall larger in size than modern humans.

Walrath and Glantz (1996) also examine the relationships of pelvic measurements to body weight. For 81 living men and women, they obtained body weight and (using computed tomography) measured the diameter of the femoral head. They also measured the distance between the ischial spines (Bi-Spinous Diameter, or BSD). Their reasoning was as follows: the size of the fetus is related to the weight of the mother, as suggested by Rosenberg. It is known that the size of the fetus is limited by the size of the birth canal (particularly at the BSD-the narrowest part of the canal), so it would follow that BSD is specifically related to maternal body weight. Walrath and Glantz found that both weight and the diameter of the femoral head squared significantly predict BSD for females but not for males. They conclude this is evidence for sex-specific selection on female pelvic morphology, since the dimensions of the birth canal must follow overall body size in women. They use the femoral head squared as an indicator of overall skeletal frame size, with higher values indicating relative massiveness and lower values indicating gracility or slightness of the skeleton. They also test the reliability of the femoral head (using the diameter alone, then using squared and cubed) as substitute for body weight. Femoral head correlates with body weight in both males and females, but it is three times more powerful in predicting body weight in males than females. Walrath and Glantz

conclude that maternal body weight, and to a greater degree overall skeletal frame size, predicts the critical dimensions of the obstetric pelvis. As body weight increases and/or overall skeletal frame gets larger, the critical dimensions, namely BSD, must increase as well to allow for successful reproduction.

One purpose of this study is to add to the knowledge of the relationship between the overall size of a female and her midplane pelvic dimensions. Though much has been done on the relationship of pelvic measurements to the size of the fetus, Walrath and Glantz state "the relationship of the pelvic midplane to maternal anthropometrics has not been systematically investigated" (Walrath and Glantz 1996). Studies that do deal with pelvic and overall maternal anthropometric dimensions tend to either ignore the value of the BSD or not use body weight as a correlate (Caldwell and Moloy 1933, 1934, Thoms 1937, Ince and Young 1940). This thesis is an attempt to better understand the relationship between the midplane pelvic dimensions of a female and her overall body size. A better understanding of this relationship can contribute to two areas of study:

1. Obstetrics

There is obvious value in enhancing the ability to predict a woman's pelvic dimensions from easily obtained external measurements of height and weight. Bi-Spinous Diameter (BSD) is usually around 100 millimeters. For a living woman, the bi-spinous diameter can only be accurately measured by X-ray, MRI or computed tomography (CT) scan (Oxorn 1986, Abitbol 1987, Walrath and Glantz 1996, Tukeva et al. 1997). Routine pelvic examinations for pregnant women involve a qualitative determination of the BSD as being narrow, average, wide, etc., but do not usually

metrically evaluate this diameter. The aim of this study was to see if this diameter, as measured directly on the skeleton, is correlated with height or weight to a significant degree. If there exists a significant correlation between weight or height and BSD, this would be helpful in planning for successful delivery. The reason the measurements were taken on the bony pelvis and not obtained through imaging technology was to assess their usefulness in a forensic setting as well.

2. Forensic Anthropology

Reversing the variables, being able to predict weight from BSD can help in determining the body weight of females in modern or prehistoric populations. Understanding how well femoral head (or femoral head squared) represents body weight or skeletal frame size also aids in reconstructing the overall skeletal massiveness or slightness (Rosenberg 1988, Walrath and Glantz 1996).

If a significant relationship can be found to exist between BSD and body weight, or between femoral head diameter and body weight, this would help in determining the body weight of a particular female for purposes of skeletal identification. There is currently no acceptable method for estimating body weight from skeletal remains. Sex, age, ancestry, and stature can all be determined or estimated with some degree of certainty from skeletal remains, but body weight can not. The possible lifetime fluctuations in an individual's body weight as well as the variability in weight for individuals with the same stature make estimating living weight very difficult. Testing the predictability of body weight from skeletal dimensions is a step towards understanding the potential (or lack thereof) for estimating body weight. Even being

able to determine overall skeletal frame size from the femoral head diameter would assist in creating a body size profile for an unidentified individual.

III. Materials and Methods

73 adult human skeletons of the Hamann-Todd collection at the Cleveland Museum of Natural History were used in this study. The Hamann-Todd collection houses the skeletal remains of thousands of individuals. Criteria for inclusion in the study were:

1. The individual was female.
2. The individual's age at death was 18 years or older (to include mature pelves only).
3. The individual's height and weight were recorded.
4. The cause of death recorded for the individual was not an illness normally associated with significant weight loss, such as tuberculosis.
5. Both femoral heads, the ischial spines, and the sacrum, were present and in sturdy condition so that the pelvis could be re-articulated and the appropriate measurements taken (this last point led to the exclusion of many specimens because often the ischial spines were not preserved).

Race was not considered in selecting the samples. The most limiting factor when choosing the study sample was the lack of preservation of the ischial spines. Individuals with well-preserved ischial spines were included, regardless of race, as long as they met the other criteria. The final makeup of the sample was X white females, X black females. Some of the measured samples with suspiciously low weight-to-height ratios were researched in the collection database to see if there was a significant explanation for the low weight. One individual was excluded as a result of this, because she had not been collected until ten days after death, during which time she had been embalmed. Two

additional females was excluded because of abnormally high body weight (300 lbs.) and unusually small stature (1219 mm).

The pelvis was re-articulated by arranging the two innominate bones and sacrum into their proper position and securing them together with two rubber bands. One large rubber band was placed around the iliac blades, and one smaller one encircled the pubes in front and the ishcia in back, generally at the level of the acetabulae. The pelvis was then set on its superior rim, upside-down, and the bi-spinous diameter was measured. This method did not account for the presence of a pubic symphysis. Next the diameters of the right and left femoral heads were taken, following Bass (1971). The right and left femoral head diameters were averaged, and this value was used as the femoral head diameter in the analysis. Measurements were taken using a Mitutoyo Digimatic caliper to the nearest tenth of a millimeter.

This study for the most part followed Walrath and Glantz (1996) in trying to understand better the relationship between pelvic dimensions and body size of a female. Unlike Walrath and Glantz (1996), the measurements were all made directly on the bony pelvis. Also, not only was an attempt made to predict BSD from body weight, but also the usefulness of body weight and height predicting BSD was examined.

IV. Results

The summary statistics are presented in Table 1.

Statistical analysis was performed using SAS. Procedures used included UNIVARIATE (for summary statistics), CORR (for correlation), REG (for multivariate regression), and PRINCOMP (for principal components analysis) (Schlotzhauer and Littell 1987, Saffer 1985).

Table 2 presents the correlation matrix of variables. No measurement taken on the bony pelvis or femur was able to predict body weight to any significant degree. Nor was body weight able to predict the bi-spinous diameter or femoral head diameter. The correlation between weight and height in this sample is low (r=.0847) (see Fig. 5). The correlation coefficient of the bi-spinous diameter with body weight is very low (r=.11, p=.36). An attempt was made to correlate the diameter of the femoral head with body weight, using the value of the diameter alone, squared and cubed. The highest coefficient of these correlations was found using the diameter alone (i.e. not squared or cubed), which had a correlation coefficient of .13 (p=.29) with body weight.

The multiple regression of both bi-spinous diameter and femoral head diameter with body weight produced an r-square value of .022 (p=.46). The regression of bi-spinous diameter, femoral head diameter, and height with the cubed root of body weight was similar at .022 (p=.69).

There are only three statistically significant relationships among the variables. The first of these is the relationship between femoral head and height. The correlation

Table 1.
Summary Statistics of Sample Population
N=72

	Age (yrs.)	Height (mm)	Weight (lbs.)	BSD (mm)	FH (mm)
Max	89	1800	180	116.8	48
Min	23	1477	92	76.0	36.7
Mean	41.2	1628.2	127.5	100.3	42.2
St. Dev.	13.4	71.04	17.7	8.5	2.1

Table 2. Correlation Matrix of Variables

	AGE	HT	WT	RT3WT	BSD	FH	FHSQ	FH3
AGE	1.0000	-.0216	0.0933	0.1263	-.1804	0.0423	0.0350	0.0317
HT		1.0000	0.0847	0.0828	0.2147	0.5327	0.5223	0.5214
WT			1.0000	0.9893	0.1086	0.1262	0.1203	0.1165
RT3WT				1.0000	0.0970	0.1306	0.1244	0.1207
BSD					1.0000	0.2530	0.2495	0.2582
FH						1.0000	0.9987	0.9974
FHSQ							1.0000	0.9989
FH3								1.0000

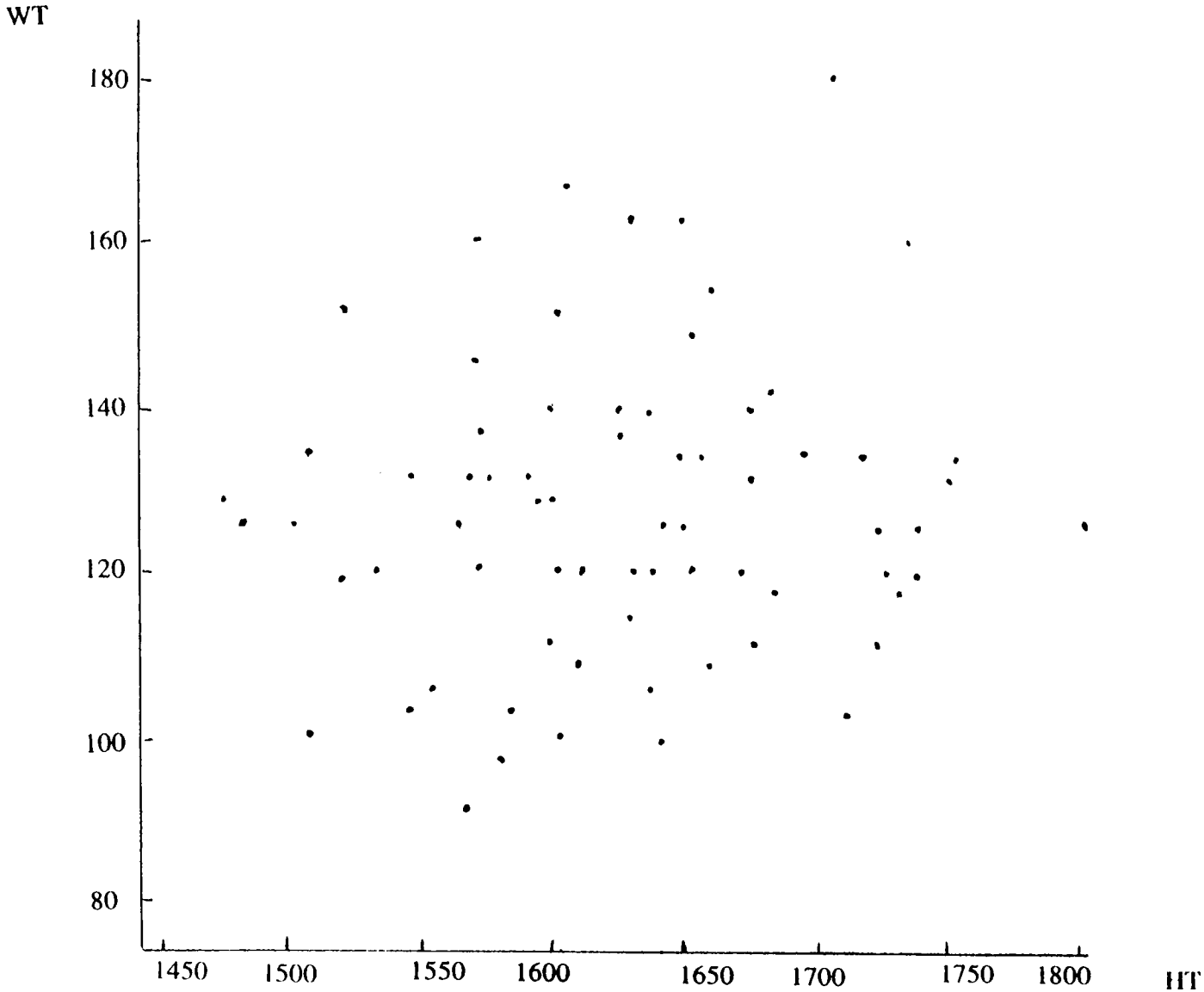


Figure 5. Plot of weight vs. height

coefficient for the femoral head diameter, area or volume with height is approximately .5 (p= .0001). This relationship, though significant, is not of much relevance to the present study because neither of these variables represent body weight or the pelvic midplane.

The second significant relationship is between bi-spinous diameter and femoral head. Of the femoral head dimensions, femoral head cubed is most highly correlated with BSD, though the three femoral head measurements (diameter, area, and volume) correlated with BSD all share a correlation coefficient of approximately .26 (p=.03). These variables, however, are both derived from measurements made directly on the skeleton. They do not help in predicting a skeletal measurement (such as BSD or femoral head) from a live measurement (such as body weight or height) or vice versa.

The final significant correlation is found between bi-spinous diamter and body height. This correlation (r=.21, p=.07) is relevant to the present study because it indicates that height may be used to predict BSD or vice versa. However, the fraction of total variation due to variables in these models (R-square value) is low in all instances of significant correlation (see Table 3). Table 3 presents the bivariate regression results of these relationships. Figure 6 is the plot of BSD with height. Variation due to error is at least ten times the variation inherent in the model in all cases. These results indicate that these relationships between variables, though significant, are not useful in generating predictions of one variable based on any other.

Principal components analysis was performed on the log-transformed data to explore the extent of allometric relationships between the measured variables.

Table 3.
Bivariate regressions of significant relationships between variables

Variables	R^2	p
FH and HT	.2838	.0001
BSD and FH	.0640	.0320
BSD and FHSQ	.0623	.0345
BSD and FH3	.0667	.0285
BSD and HT	.0461	.0701

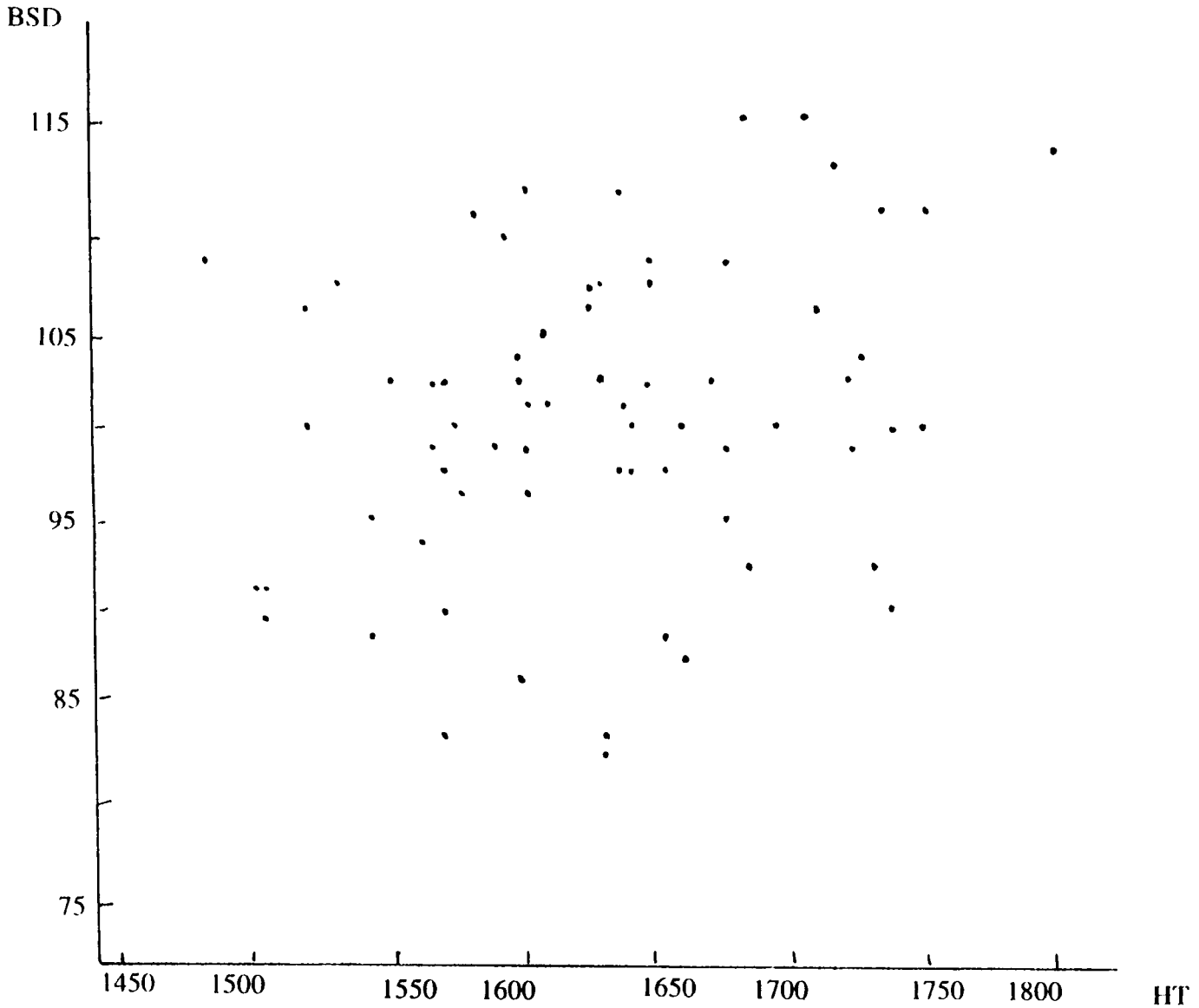


Figure 6. Plot of BSD vs. height

Jolicoeur (1963) demonstrates how to use a standardized loading ($1/\sqrt{p}$) to produce a coefficient of allometry. Here, p is the number of traits used in the analysis (in this case the four measured variables of height, cubed root of weight, BSD, and femoral head diameter). If the eigenvector of a trait in the first principal component is greater than the standard loading, the trait is positively allometric. If the eigenvector is less than the standard, the trait is negatively allometric.

Table 4 presents the results of the principal components analysis. Standardized loading ($1/\sqrt{4}$) is .50. The first principal component accounts for 54% of total variance. The highest loading is found from the variable bi-spinous diameter (.93). Bi-spinous diameter is very positively allometric, with a coefficient of 1.86. The next highest loadings are found from height (.26, allometry coefficient=.52) and femoral head diameter (.25, allometry coefficient=.50). The cubed root of weight has the lowest loading (.15). These results indicate that bi-spinous diameter increases a great deal relative to overall body size. Also, the two variables of height and femoral head diameter are actually increasing at similar rates in proportion to the increase in the bi-spinous diameter.

Table 4. Results of principal components analysis

A. Covariance matrix

	HT	RT3WT	BSD	FH
HT	0.0005710046	0.0000192542	0.0002174467	0.0002561073
RT3WT	0.0000192542	0.0004070015	0.0000679604	0.0000788623
BSD	0.0002174467	0.0000679604	0.0014719178	0.0002120814
FH	0.0002561073	0.0000788623	0.0002120814	0.0005108828

Total Variance = 0.0029608067

B. Eigenvalues of the covariance matrix

	Eigenvalue	Proportion	Cumulative
PC 1	0.001595	0.538754	0.53875
PC 2	0.000687	0.232106	0.77086
PC 3	0.000412	0.138992	0.90985
PC 4	0.000267	0.090148	1.00000

C. Eigenvectors

	PC 1	PC 2	PC 3	PC 4
HT	0.261038	0.686526	- .327246	0.594518
RT3WT	0.073931	0.130765	0.932094	0.329598
BSD	0.929755	- .367424	- .023335	0.003211
FH	0.248895	0.613663	0.153511	- .733419

V. Discussion

The body weight recorded for an individual at or near the time of death may not be an accurate estimate of that person's body weight during her lifetime. Most specimens in the Hamman-Todd collection were weighed within three days after death (L. Jellema, pers. comm.). Though an attempt was made to screen out individuals who died from illnesses associated with weight loss, factors such as nutrition and age may lead to fluctuations in body weight during adulthood.

The individuals that comprise the Hamman-Todd human skeletal collection are of relatively poor urban backgrounds (L. Jellema, pers. comm.). Their nutrition status is most likely not representative of individuals today, because of the generally improved nutrition of urban Americans since the early part of the century. It is likely that an individual today, rural or urban, would probably be heavier for her height than any one of the Hamman-Todd samples. Perhaps doing this study on a modern forensic sample would yield better results and find the correlation between body weight and bi-spinous diameter found by Walrath and Glantz. The Hamman-Todd collection, rather than a smaller (though modern) forensic collection was sought in this study in hopes of ensuring a sufficient sample size. As noted above, breakage of the ischial spines was the factor which most severely limited the sample size, and breakage of the spines in any modern forensic sample would probably have prevented attaining a sufficient study sample.

Studies of this kind done using living individuals, by means of MRI or CT scan, is useful in understanding the basic relationship of these diameters to body size. In fact, the poor results of this skeletal study indicate this is probably the only way to understand

the relationship of the diameters of the pelvic midplane to maternal body size for any one individual. When it comes to estimating individual body weight from skeletal remains, it seems there are too many factors involved that preclude a successful estimation. Body weight usually changes throughout adulthood for any individual. Perhaps a study like this (using skeletal remains) will produce better results if the sample is broken down by age, since weight gain and loss may closely follow the aging process. Bi-spinous diameter may be useful in predicting weight to a different degree at different ages. In this case, a larger sample would be needed to produce statistically significant results.

Lovejoy (1973), Rosenberg (1988), and Walrath and Glantz (1996) all employ the diameter of the femoral head in estimating body size. However, Ruff et al. (1991) suggest the diameter of the femoral head remains constant throughout lifetime fluctuations in body weight. They show that the proximal end of the femoral diaphysis is more representative than the femoral head diameter for estimating an individual's current weight. Their 1991 study uses 80 individuals for whom body weight at age 18 and current body weight is known. Using x-ray, Ruff et al. measured both the femoral head diameter and the diameter of the proximal femoral diaphysis. They found that the diameter of the femoral head correlates better with body weight at age 18 than with current weight. Conversely, measurements of the proximal femoral diaphysis (including subperiosteal breadth and cortical area) correlate better with current weight than weight at age 18. This is not to say that only diaphyseal areas change with increased loading. Rather, this relationship may be due to contrasting methods of bone remodeling for the two areas. Articulating areas such as the femoral head, constrained in area by the size

of the joint, may respond to mechanical loading by changing "trabecular architecture". Diaphyses, not restricted in area by joint size, respond by changing cortical thickness, which can be more easily quantified.

In sum, it is clear from these results that (contrary to the findings of Walrath and Glantz), body weight is not a statistically significant predictor of bi-spinous diameter. In terms of obstetrics, one can conclude from the statistical analysis that neither the height nor the weight of a woman is useful in accurately predicting the most critical dimension of the birth canal, the bi-spinous diameter. Knowing a woman's weight or height is of little value in predicting the degree of difficulty she will have with vaginal childbirth.

For forensic anthropology, it seems that these particular skeletal measurements do not help in understanding the live body weight of an individual. Knowing the bi-spinous diameter does not provide useful information about the individuals body size (height or weight), nor does it indicate reproductive patterns.

VI. Conclusion

This study was executed in an attempt to better understand the relationship between certain skeletal measurements and overall body size of females. Contrary to the previous study (Walrath and Glantz 1996), it was found that there is no significant correlation between the variables measured in this study (bi-spinous diameter and femoral head diameter) and a woman's body weight. Neither bi-spinous diameter nor femoral head diameter can be used as a predictor variable for body weight. Therefore, these measurements are of limited use in predicting body weight from skeletal remains. Similarly, knowing the body weight of an individual female does not help one to assume correctly the individual woman's bi-spinous diameter for obstetric or other purposes.

A more promising result came from the significant correlation between body height and bi-spinous diameter, a relationship that, with further study, may prove to be useful in predicting height from the BSD, or vice versa. The fit of the regression in this particular study is not very good, however, and error variation is high. Perhaps replicating this study using a different sample population will yield better results.

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APPENDIX

RAW DATA

OBS	SPEC	AGE	RACE	HT	WT	RT3WT	BSD	FH	FHSQ	FH3
1	152	70	b	1600	150	5.3	86.6	42.3	1789.3	75687.0
2	269	25	w	1600	110	4.8	102.4	42.6	1814.8	77308.8
3	324	43	w	1524	150	5.3	99.6	39.9	1592.0	63521.2
4	442	40	b	1574	160	5.4	90.4	42.2	1780.8	75151.5
5	495	25	b	1676	140	5.2	94.8	42.4	1797.8	76225.0
6	514	30	w	1600	140	5.2	102.3	40.4	1632.2	65939.3
7	520	45	b	1676	112	4.8	98.7	41.0	1681.0	68921.0
8	529	34	b	1600	128	5.0	103.5	42.3	1789.3	75687.0
9	530	45	b	1638	140	5.2	97.1	41.5	1722.3	71473.4
10	603	35	w	1651	164	5.5	108.7	43.7	1909.7	83453.5
11	657	40	b	1507	134	5.1	91.0	40.8	1664.7	67917.3
12	675	27	w	1547	130	5.1	88.2	41.2	1697.4	69934.5
13	704	29	b	1604	150	5.3	112.0	42.9	1840.4	78953.6
14	1103	29	b	1610	108	4.7	100.8	38.7	1497.7	57960.6
15	1124	40	b	1568	92	4.5	99.0	38.3	1466.9	56181.9
16	1161	24	b	1643	101	4.7	100.2	41.2	1697.4	69934.5
17	1208	23	b	1585	103	4.7	111.2	41.2	1697.4	69934.5
18	1214	32	b	1504	126	5.0	91.2	36.7	1346.9	49430.9
19	1215	31	b	1728	120	4.9	104.2	48.0	2304.0	110592.0
20	1275	50	b	1597	129	5.1	109.4	41.1	1689.2	69426.5
21	1333	89	b	1654	148	5.3	98.0	44.2	1953.6	86350.9
22	1345	39	b	1754	135	5.1	111.8	46.5	2162.3	100544.6
23	1516	37	b	1736	160	5.4	110.7	42.1	1772.4	74618.5
24	1534	45	b	1751	131	5.1	100.4	42.7	1823.3	77854.5
25	1539	26	b	1684	118	4.9	92.1	43.1	1857.6	80063.0
26	1551	60	b	1564	125	5.0	93.9	42.2	1780.8	75151.4
27	1580	31	b	1709	180	5.6	116.2	42.9	1840.4	78953.6
28	1600	28	b	1604	120	4.9	98.2	40.1	1608.0	64481.2
29	1709	25	b	1654	120	4.9	89.0	39.6	1568.2	62099.1
30	1747	34	w	1536	120	4.9	107.0	45.5	2070.3	94196.4
31	1748	44	b	1659	135	5.1	76.0	41.0	1681.0	68921.0
32	1749	42	b	1629	115	4.9	102.0	40.0	1600.0	64000.0
33	1752	48	w	1570	130	5.1	102.0	46.0	2116.0	97336.0
34	1771	54	w	1509	100	4.6	88.5	40.2	1616.0	64964.8
35	1785	32	b	1630	120	4.9	107.0	41.1	1689.2	69426.5
36	1786	45	b	1651	125	5.0	102.3	42.9	1840.4	78953.6
37	1793	52	b	1639	120	4.9	112.8	40.8	1664.6	67917.3
38	1825	76	w	1573	146	5.3	83.3	40.9	1672.8	68417.9
39	1846	53	w	1643	125	5.0	97.2	44.3	1962.5	86938.3
40	1856	45	b	1737	120	4.0	99.6	43.8	1918.4	84027.7
41	1899	30	b	1722	125	5.0	99.1	41.1	1689.2	69426.5
42	1911	30	b	1724	110	4.8	102.1	45.1	2034.0	91733.9
43	1912	60	b	1662	108	4.8	88.0	42.8	1831.8	78402.8
44	1961	28	b	1740	125	5.0	90.6	42.3	1789.3	75687.0
45	1973	24	b	1573	138	5.2	98.0	39.2	1536.6	60236.3
46	1988	70	b	1578	130	5.1	100.3	41.0	1681.0	68921.0
47	2041	25	b	1800	125	5.0	115.0	45.0	2025.0	91125.0
48	2048	52	w	1486	125	5.0	108.7	40.8	1664.6	67917.3
49	2053	45	b	1611	120	4.9	105.2	42.7	1823.3	77854.5
50	2082	42	w	1684	143	5.2	116.8	43.1	1857.6	80063.0
51	2120	43	b	1638	105	4.7	100.7	44.6	1989.2	88716.5

OBS	SPEC	AGE	RACE	HT	WT	RT3WT	BSD	FH	FHSQ	FH3
52	2138	50	w	1677	130	5.1	108.8	46.4	2153.0	99897.3
53	2140	40	b	1630	115	4.9	83.7	41.6	1730.6	71991.3
54	2169	24	b	1695	135	5.1	100.6	45.3	2052.1	92959.7
55	2188	75	w	1546	102	4.7	95.4	42.7	1823.3	77854.5
56	2190	41	b	1626	140	5.2	106.1	45.5	2070.3	94196.4
57	2199	37	w	1573	120	4.9	102.6	42.4	1797.8	76225.0
58	2242	40	b	1594	130	5.1	99.0	42.0	1764.0	74088.0
59	2284	39	b	1580	98	4.6	96.4	40.0	1600.0	64000.0
60	2332	50	b	1649	135	5.1	106.9	42.3	1789.3	75687.0
61	2354	45	w	1732	117	4.9	93.1	42.3	1789.3	75687.0
62	2414	47	w	1477	129	5.0	5.0	105.4	38.9	1513.2
63	2437	45	w	1673	120	4.9	102.6	45.1	2034.0	91733.9
64	2505	47	b	1523	152	5.3	106.1	38.6	1490.0	57512.5
65	2516	31	b	1604	100	4.6	96.7	43.3	1874.9	81182.7
66	2561	35	b	1663	153	5.3	100.4	42.5	1806.3	76765.6
67	2567	32	b	1712	102	4.7	106.0	42.7	1823.3	77854.5
68	2595	48	b	1720	133	5.1	113.7	42.6	1764.0	77308.8
69	2612	39	b	1555	106	4.7	101.9	39.4	1552.4	61163.0
70	2708	38	b	1632	162	5.5	82.9	43.6	1901.0	82881.9
71	2853	38	b	1628	138	5.2	108.0	42.4	1797.8	76225.0
72	3391	53	b	1605	129	5.1	101.1	43.3	1874.9	81182.7

VITA

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