

# Center of Body Mass and the Evolution of Female Body Shape

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**ABSTRACT** Among primates, the genus *Homo* has a unique sexual dimorphism in general body shape. The stenotypic female “hourglass figure” has often been attributed to sexual selection. Sexual dimorphism both in shape and in position of the center of body mass (CoM) emerges during puberty and is related to hormonal influences. These are only the proximal and not the ultimate causes of this feature. This article explores the hypothesis that the evolutionary (i.e., ultimate) reason for female body shape and male preference for a lower waist-to-hip ratio (WHR) is due to the acquisition of bipedal locomotion and different biomechanical constraints on each sex. The demands of pregnancy and subsequently carrying infants may have more tightly constrained CoM in females than in males. A lower-position of CoM relative to height ( $RCoM = (CoM/height) \times 100\%$ ) would contribute to better stability during pregnancy and infant carrying. Using body measurements from 119 female students, we show that RCoM correlates negatively with only maximal thigh circumference and positively with only WHR and shoulder width. The relationship between RCoM and traits that best characterize female body shape seems to confirm a hypothesis of biomechanical selection pressure that may have acted on *Homo* female morphology, thus contributing to sexual dimorphism. *Am. J. Hum. Biol.* 15:144–150, 2003. © 2003 Wiley-Liss, Inc.

Human sexual dimorphism in body shape is quite unusual among primates (Schultz, 1969). Apart from some parts of skeleton (e.g., pelvis) and musculature, the difference between adult men and women is largely in the distribution of fat. It is well known that the sex hormones specifically affect fat distribution and regulate fat utilization (Leibel et al., 1989). This mechanism is only the proximal reason for sexual dimorphism in morphology. Body shape is also characterized in women by relatively narrow shoulders, permanent breasts composed of fatty tissue, a narrow waist, and gluteofemoral fat deposits.

It has been hypothesized that the ultimate (evolutionary) reason for human female body shape is sexual selection (e.g., Barber, 1985; Morris, 1967). It is also hypothesized that body fat in the breasts and buttocks could serve as a reserve for metabolic demands and protection against famine during pregnancy or lactation (Symons, 1979). This is questionable in the light of rather ineffective lipolysis and poor utilization of fat from buttocks (Pond and Mattacks, 1987). Moreover, some authors emphasize the reproductive energy balance of women and the reproductive adaptations of adipose tissue for energy storage, and thus claim that sexual dimorphism in fat distribution most likely evolved under sexual selection (Pond, 1992).

It is also possible that the primary causes of this sexual dimorphism may be related to the necessities of bipedal locomotion and different constraints imposed on each sex (Pawłowski, 2001). Since bipedalism imposes specific requirements on morphology, its emergence in early hominids probably had associated biomechanical and energy-balance constraints. With fully extended hips and knees, and with minimal supporting surface area, the center of body mass (CoM) should lie on the frontal plane approximately above the rotational axis of the hip joints (Janusson, 1991). In order to maintain balance, any weight in front of the plane (with gravity pulling downwards) would be counterbalanced by an equivalent weight behind. Otherwise, bipedalism would be energetically costly because of the energy needed to prevent bending or falling forwards. Thus, in the evolution of normal bipedal posture, the center of gravity shifted down and back. Raising the center of gravity forces musculoskeletal and neurological systems to exert more effort in order to maintain stability

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Received 26 March 2002; Revision received 17 September 2002; Accepted 30 September 2002

Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/ajhb.10136

(Kuo and Zajac, 1993). It is no wonder then that this mode of locomotion is so rare and that among living primates it is unique to the genus *Homo*. One difference between the sexes, however, may have made bipedalism more costly for females than for males. In advanced pregnancy and during lactation, when the infant is being carried, a bipedal female has to contend with a substantial increase in the anterior load above the center of gravity (Pawłowski, 2001). In traditional societies and perhaps more so in earlier stages of human evolution, pregnancy and infant-carrying while nursing were a temporary but nonetheless common difficulty during adult life of women. To prevent the center of gravity, or CoM, from moving upwards and forwards, as well as to facilitate walking and foraging during pregnancy and lactation, evolution may have favored fat deposits in the buttocks and thighs of early *Homo* females (Fig. 1) (Pawłowski, 2001). To keep CoM from moving upwards, it would be expected that the female body would have relatively small diameters (e.g., shoulder width) and circumfer-

ences (e.g., waist width) above the CoM. If this is the case, it might be expected that males prefer a female body shape with a relatively lower CoM and perceive it as more attractive. Many studies have shown that a lower waist-to-hip ratio (WHR) in females is perceived as more attractive than a higher ratio (Furnham et al., 1997; Heness, 1995, 2000; Singh, 1993a,b). The WHR is of course related both to waist and hip girth. The proximal causes of sexual dimorphism in the WHR, which appears during puberty, are hormonal (Björntrop, 1991). In several studies (Björntrop, 1988; DeRidder et al., 1990; Wass et al., 1997; Zaadstra et al., 1993; Pawłowski and Dunbar, submitted) the biological relevance of a preference for lower WHR has been illustrated. Women with lower WHR appeared to be healthier, had higher chances of fertilization, had higher level of estrogens and earlier maturation and gave birth to relatively heavier newborns.

Why does not the same hold true for other female primates? The evolutionary reason for human sexual dimorphism in shape may lie in some characteristic that is unique to the evolutionary lineage, i.e., bipedal locomotion. It is possible that the biomechanical advantage of lower WHR in females was another biological reason for male preference of females with a lower WHR.

This article considers morphological traits in females which influence the relative position of the center of gravity (RCoM) and suggests that the evolution of some features of women's body shape that are now perceived as more attractive (e.g., low WHR) may have been primarily related to such ultimate causes as efficient bipedal locomotion and foraging when a woman is pregnant or carrying an infant.

## MATERIALS AND METHODS

Measurements were taken from 119 female students, 19–25 years of age, from the University of Physical Education in Wrocław in southwestern Poland in September 2000. Thirteen measurements were taken: height (H), body mass (W), position of body center above the base (CoM = center of body mass), height to suprasternale (sst), symphysis height (sy) as an estimate of leg length, length of trunk (sst-sy), width of shoulders (biacromial), width of the pelvis (biiliacristal), circumferences of the chest (xiphoid level), waist, hip, maximal, and mid-thigh. All the measurements were made according to anthropometric

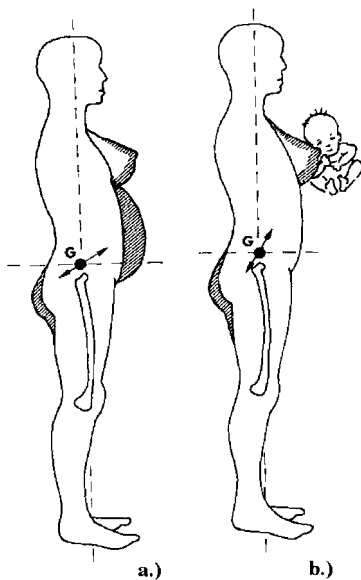


Fig. 1. Schematic drawings showing the posterior fat deposits and the additional anterior and superior weight in a pregnant (a) and superior weight in lactating (b) human female (dashed areas and a baby). "G" is the center of gravity and the arrows show the influence of both anterior and posterior additional female weight for the gravity center (after Pawłowski, 2001).

protocol by Martin and Saller (1958). Three indices were calculated: relative body center (RCoM = (CoM/H)\*100%), WHR, and body mass index (BMI = W/H<sup>2</sup> in kg/m<sup>2</sup>).

The height of the CoM was measured with a one-sided lever, which consisted of a board placed on two supports, one of which was placed on the balance. The distance between the supports was 2 m. The feet of the subject were placed in line with the second support. To obtain the value of reaction force (R), the subjects were weighed lying down on the lever. The absolute value of CoM was calculated from R and body mass (W) using the equation: R\*200/W. This method is reasonably exact and objective (Donski, 1963; Bober, 1966). The RCoM adjusts the CoM for differences in body height. All the measurements were made by one of the authors (MG) to avoid interobserver errors.

Correlation and multiple regression analysis was used to identify variables which influence RCoM. All analyses were carried out using STATISTICA 5.5A PL (StatSoft, Tulsa, OK).

RESULTS

Means, standard deviations, and ranges of variability for all variables, including age, are shown in Table 1. The majority of subjects (more than 90%) did not practice any sport (half of them studied physiotherapy) and the means of anthropometric measurements are similar to the means for the female polish students of the same age from the University of Łódź (e.g., height = 164.6, biiliocrystal = 27.5 BMI = 21.2) (Roślak, 1997) and from the University of Kielce (n = 1,191, mean age = 19.7 SD = 0.76, e.g., shoulder width = 35.04 cm, lower limb length = 84.4, BMI = 21.45; data recently collected by Jopkiewicz, not published). This means that our sample is not selected in terms of the subjects' physique.

Since the height of the CoM is related to height (r = 0.93), height was controlled in all further analyses by only using RCoM. Given the high positive correlations between some

TABLE 1. Descriptive statistics of variables used in analysis

	Mean	Std. deviation	Min.	Max.
Age (yr)	21.1	1.05	19.0	25.0
Height (cm)	166.3	6.20	151.3	183.3
Body mass (kg)	58.7	7.17	42.0	78.2
SST (cm)	135.4	5.60	122.8	154.2
Lower limb length (cm)	86.7	4.19	76.7	98.5
Trunk length (cm)	48.7	2.74	42.8	56.3
Shoulder width (cm)	35.9	1.67	32.3	40.8
Hip width (cm)	27.5	1.61	23.8	32.0
Chest circum. (cm)	75.7	4.53	67.0	90.0
Waist circum. (cm)	69.0	4.97	57.5	85.5
Hip circum. (cm)	95.2	5.06	85.0	108.4
Max. thigh circum. (cm)	55.3	3.87	47.0	66.0
Mid thigh circum. (cm)	49.3	3.56	41.0	58.5
Height of body mass center (cm)	95.1	3.81	86.0	105.9
RCoM (%)	57.2	.86	55.3	60.1
WHR	72.5	3.44	66.1	83.9
BMI	21.2	2.12	16.8	26.9

variables, e.g., as suprasternale height is highly correlated with the length of lower limbs (r = 0.88), chest circumference is highly correlated with waist girth (r = 0.89), and mid-thigh circumference is correlated with maximal thigh circumference (r = 0.88), they were excluded from the analysis.

Correlations between RCoM and other variables indicate that only two are significantly correlated with RCoM (Table 2). Since some variables are correlated with each other, multiple regression analysis was used to show which variables had the strongest effect on RCoM. As independent variables, all variables that were correlated with RCoM and two other variables that correlated with RCoM at P < 0.2 (shoulder width and hip girth) were included. Of these six variables, only three are significantly related to RCoM: WHR (Fig. 2), maximal thigh circumference (Fig. 3), and shoulder width (Table 3).

DISCUSSION

RCoM is sexually dimorphic in *Homo sapiens*, specifically from puberty on

TABLE 2. Simple correlations (r) and their significances (p) between RCoM and other variables

	Lower limb length	Trunk length	Shoulder width	Hip width	Waist circum.	Hip circum.	Max thigh circum.	Body mass	WHR
Correlation (r)	.064	-.027	.14	-.010	.070	-.15	-.21	-.09	.28
P (significance)	0.49	0.77	0.14	0.92	0.45	0.11	0.02	0.35	0.002

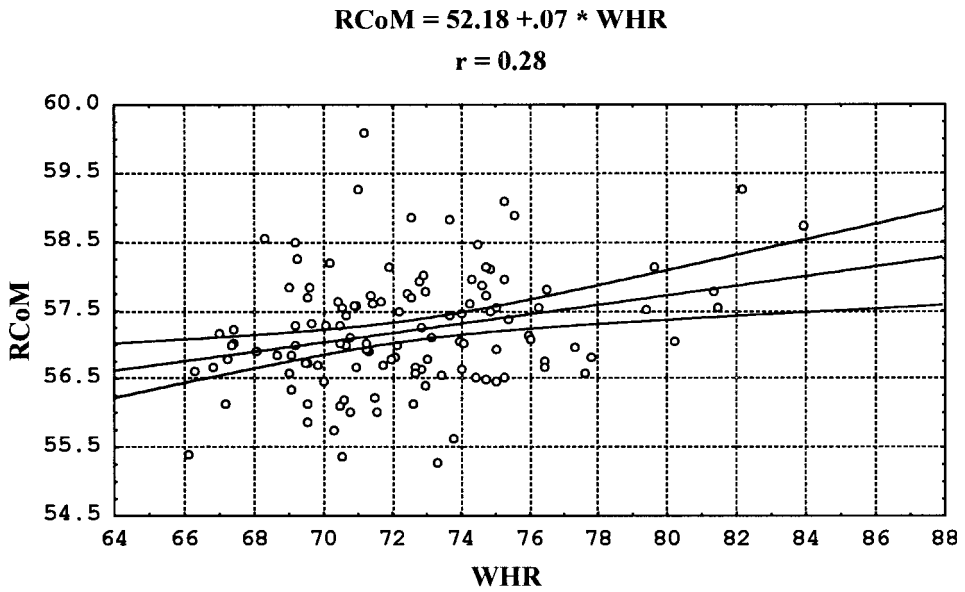


Fig. 2. Relationship between relative position of CoM and WHR.

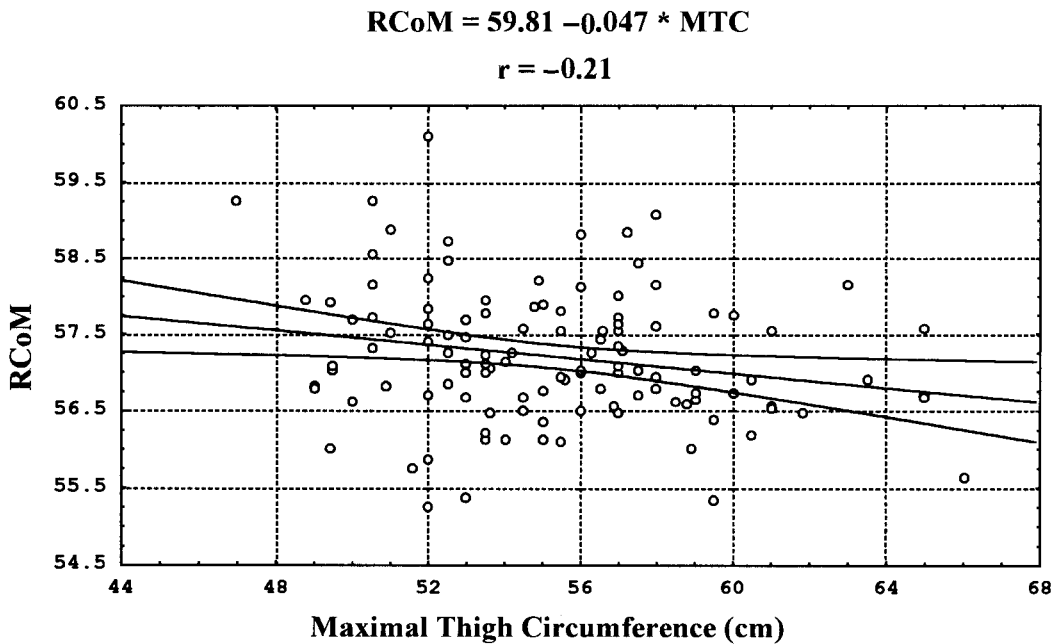


Fig. 3. Relationship between relative position CoM and maximal thigh circumference (MTC).

(Janusz et al., 1984). Men have a relatively higher CoM than do women. The results of the present analysis indicate that a smaller WHR, a greater maximal thigh girth, and a

narrower shoulder width contribute to a lower RCoM in adult women. However, the correlations are not as high as one would expect. This may reflect the limited variability

TABLE 3. Multiple regression analysis with RCoM as dependent variable (multiple  $R = 0.44$ )  
 $F(4,114) = 7.04$ ,  $P < 0.000$

	$\beta$	Std. error of $\beta$	B	Std. error B	t(114)	P
Intercept			50.6	2.30	22.06	.000
<b>Shoulder width</b>	<b>0.21</b>	<b>0.096</b>	<b>0.11</b>	<b>0.049</b>	<b>2.20</b>	<b>0.03</b>
Hip circumference	0.23	0.19	0.04	0.032	1.21	0.23
<b>Max thigh circum.</b>	<b>-0.54</b>	<b>0.18</b>	<b>-0.12</b>	<b>0.041</b>	<b>-2.95</b>	<b>0.004</b>
<b>WHR</b>	<b>0.32</b>	<b>0.09</b>	<b>0.08</b>	<b>0.022</b>	<b>3.62</b>	<b>0.000</b>

of some dimensions and indices in the sample. The coefficient of variation for WHR in the sample was only 4.7%, whereas, for example, in a sample of 562 polish women from Wrocław (mean age 26.8, SD 5.3) it was 8% (Pawłowski and Uliaszek, in prep.). The variability of other variables was also relatively small. More variability would probably produce higher correlations and might strengthen the results and their evolutionary interpretation. Yet since selection must have acted mainly on young primiparous females, the sample may be suitable for such evolutionary analysis.

Because of pregnancy and carrying of infants, bipedal females in the course of human evolution faced different constraints in the biomechanics of locomotion than did males. The different constraints could have appeared with the evolution of *Homo*, among whom females gave birth to relatively larger newborns and therefore were weighed down by a heavier burden during late pregnancy and when carrying infants (Pawłowski, 2001). The distance of the CoM above the base is negatively related with general stability (Kuo and Zajac, 1993). Since efficacy of foraging and proper locomotion may have been a strong selection pressure on *Homo* females, one can assume that selection favored skeletal morphology and a distribution of body fat that would permit better body stability during riskier periods (e.g., by reducing the risk of predation and improving foraging efficacy).

Sexual dimorphism in human body shape is often explained in terms of sexual selection. If this was the form of selection, it is surprising that no other primates exhibit a similar kind of sexual dimorphism. Our results support a hypothesis of the evolutionary emergence of gluteofemoral fat deposits in *Homo* females and the biological relevance of male preference for females with a lower WHR. High correlation between hip and thigh circumference ( $r = 0.88$ ) and the posi-

tive relationship between WHR and RCoM may indicate that gluteofemoral fat deposits and slim waist emerged as one complex female trait. This could have been the evolutionary response to biomechanical constraints during pregnancy and when carrying babies in their first months of life (when they had to be carried anteriorly). Hip circumference itself appeared to be not related to RCoM. Hip circumference (or hip width) is very close to the CoM plane, so its influence on the CoM vertical shift is very limited. On the other hand, those measurements which are farther from CoM horizontal plane, e.g., shoulder width or thigh circumference, are much stronger factors influencing CoM.

The positive correlation of female shoulder width with RCoM might suggest that this trait was also under biomechanical selection pressure. Irrespective of foraging strategy and risk of predation, broader shoulders and stronger arms should have been advantageous for females. Therefore, it is likely that there was some counterselection. It is postulated that the advantage of having lower RCoM was greater for females than broad shoulders and stronger upper arms. This might also have contributed to the sexual division of labor in human evolution. A comparable example of two opposing selection pressures in the evolution of *Homo* female morphology is apparent in the compromise between birth canal diameter and mechanical costs of bipedal locomotion (see Lovejoy, 1988). If the birth canal diameter was just 2 cm wider, there would be no obstetric problems during labor in humans (highly adaptive condition), but such an increase, however slight, must have been strongly counterbalanced by the mechanical and energy constraints of bipedalism. The mean difference in RCoM between the sexes is not large (e.g., at 14 years it is  $(60-57.9)/57.9 = 3.6\%$ ; Janusz et al., 1984), but in the evolutionary past its functional



consequence for *Homo* females when pregnant or carrying an infant could have been important.

The increase of anterior weight during pregnancy causes the increase of lumbar lordosis. To some extent this is counterbalanced by changing the head position more posteriorly (Franklin and ConnerKerr, 1998). However, the gluteofemoral fat deposits can be considered as a more effective morphological counterbalance to the anterior weight increase (including breast size increase) during pregnancy.

The proposed mechanism for the evolution of female body shape could have been related mainly to later pregnancy. As Pawłowski (2001) suggests, this period could have been a survival "bottleneck" for bipedal *Homo* females. It is because at that time inefficient walking and foraging could have put females at much greater risk of starvation and predation. The critical period, however, could be extended also to the first months of a baby's life when mothers had to carry babies in front of them. Today babies are carried first in front carriers and only when a baby can sit up well can it be carried on the hip or in a backpack. One should remember that the hypothesis presented here refers to our evolutionary past and so to the time when there were no baby carriers. It is also worth noting that in contemporary Western and other societies there are no selection pressures on foraging efficacy during late pregnancy, there is no predation risk during late pregnancy, there is no need to carry an infant constantly, and there are fewer pregnancies. The selection pressure for a lower RCoM in females in these societies probably does not exist any more.

It is possible that during human evolution some features of female body shape came to be perceived as sexually attractive. This, however, could have emerged as a reflection of the higher reproductive success of males who preferred a female body shape with a lower RCoM. It is well known that the "hourglass" female figure is molded by hormonal influences during puberty, but this is just a proximal cause. The proposed hypothesis does not undermine the idea that sexually reproducing organisms generally choose mates that display traits indicative of high genotypic quality (Symons, 1979; Buss, 1989). It only suggests why the widely preferred "hourglass" figure was originally associated with relatively higher genotypic

quality. What is more, the hypothesis of selection for lower CoM in *Homo* females is not exclusive to the hypothesis of energy reserves in gluteofemoral fat.

The hypothesis which we have tried to verify here seems to have a few advantages over the other concepts of the evolutionary emergence of the human female body shape which includes gluteofemoral fat deposits:

1. It is based on such hominin peculiarities as i) bipedal locomotion, which created new selection pressures on many other traits in *Homininae*, and ii) the *Homo*-specific neonatal body size increase. The concepts explaining the gluteofemoral fat deposits or general female body shape on the basis of sexual selection or energy reserves could also be applied to other primates. Therefore, if we accept the presented hypothesis we do not need to explain why such selection took place only in *Homo* evolutionary lineage.
2. It explains not only the selection pressure for the evolution of gluteofemoral fat deposits in the human female, but the selection for the whole female body shape (including narrow waist and shoulders). This parsimonious approach to the selective pressures should be given higher credit than hypotheses explaining some related traits by different or multiple factors.
3. It does not exclude other secondary adaptations of gluteofemoral fat depots (e.g., energy reserves) and it also explains the sexual preference for some characteristics of female morphology (e.g., low WHR) and therefore allows the action of sexual selection in this respect.

## ACKNOWLEDGMENTS

We thank Prof. Robert M. Malina from Michigan State University, Peter Frost from Université Laval, Sainte-Foy (Québec), and Robert Kruszynski from the Natural History Museum, London, for suggestions and help in English. We also thank Prof. Andrzej Jopkiewicz for access to the unpublished (recently collected) data on students from Kielce.

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