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REVIEW

How Evolution of the Human Brain Shaped Women's Sexual and Reproductive Health

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Abstract: The evolution of the large and complex brain was a big advantage to early humans in their social interactions and encounters with unfamiliar habitats. But it was not without a high cost to women's sexual and reproductive health. The developing fetal brain needs and consumes a lot of energy. To meet this need, a more intensely invasive placenta evolved and with it, the risk of excessive bleeding when the placenta separates partially or completely from the uterine wall, a major cause of maternal death. Delivering the large fetal head is an obstetric dilemma, particularly with the relatively narrow and irregular bipedal pelvis. The additional long time needed for the postnatal growth of the brain dictated the necessity for continued paternal investment. To strengthen the pair bond, sex was completely dissociated from reproduction and ovulation was concealed. However women then became vulnerable to sexual violence, sexually transmitted infections, and unwanted pregnancy. Recently, the human brain has been repaying women in the currency of modern science, including making motherhood safer and developing women-controlled contraceptive technologies. Scientific challenges still stand. For example, the modern woman has to cope with the burden of a reproductive system evolved for a hunter gatherer. Women have already fulfilled the divine obligation to replenish the earth, and it is time for science to help women to finally emerge from behind the mother.

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Introduction

The human female carries a big burden for sexual and reproductive health.[1]

Biological insights can shed light on how in the evolution of the *Homo sapiens*, and in particular the human brain, the female of our species had to make many adaptations, at a significant cost to her health and even a risk to her life.

As early humans faced new environmental challenges, encephalization evolved with the progressive development of larger and more complex brains able to process and store much more information. The modern human brain is the largest and most complex of any primate and its development was a big advantage to early humans. However, it was an expensive undertaking. The human brain consumes an outstanding 20% of the total body energy budget despite representing only 2% of total body mass.[2,3]

Apart from its greatly increased complexity, in comparison with other primates, the evolving human brain had three features which shaped the sexual and reproductive health of women during evolution: a greed for energy and nutrients during fetal development, a relatively large size of the brain and fetal head, and the need for a lengthy time to complete its development after birth.[4,5]

The invasive hemochorial placenta

The placenta in mammals has evolved as an extrasomatic fetal organ, designed to draw nourishment from the mother for the growing fetus. Mammalian placentas differ widely in the degree with which they invade the maternal tissue. Three main phenotypes are described.[6] The least invasive is the epitheliochorial placenta, found in ruminants, horses, and swine, in which the fetal chorion simply adheres to the epithelial lining of the uterus. Nutrients are transposed and diffused to the fetus across several layers of maternal tissue. The next phenotype in order of invasiveness is the endotheliochorial placenta, seen in cats and dogs, where the fetal chorion is in contact with the endothelial lining of the maternal blood vessels but not in direct contact with maternal blood. The most invasive phenotype is the hemochorial placenta, seen in rodents and primates. Here, the fetal chorion, with its complex branching villi, is bathed in maternal blood. There are different degrees of invasiveness of the hemochorial placenta. The human placenta is not only among the most invasive, but it embarks on a second wave of invasiveness around the 16th week of pregnancy, in response to the growing fetal needs particularly of the developing human brain.[6]

In the early placenta, most of the fetal trophoblast covers the mesodermal core of the chorionic villi containing the fetal blood vessels. Other trophoblastic cells serve the function of anchoring the placenta to the uterine wall. In the second wave of invasiveness, cells become detached from this anchoring nonvillous trophoblast and migrate deeply in the uterus. They surround the maternal spiral arterioles and initiate a breakdown of their muscular and elastic layer, replacing it with a thick fibrinoid non-contractile layer. Vascular resistance is thus reduced, the diameter of the vessels widens, and they open in a funnel pattern in the maternal blood lake, bathing the fetal chorionic villi. With this second wave of invasion and remodeling of the maternal spiral arterioles, the fetus ensures unrestricted access to the maternal blood flow to satisfy the needs of its growing brain. There is a cost and a risk to the mother. When the placenta separates from the uterine wall, partially or completely, during pregnancy or in the end of labor, severe bleeding may occur. The spiral arterioles, which have lost their muscle layer, cannot contract to close their lumen. The mechanism of shutting the blood flow in the rich arterioles depends on retraction of the uterine muscle, which may fail.

On the other side, if this second wave of placental invasion fails to adequately remodel the spiral arterioles, the vessels retain their endothelial linings and muscular walls, and remain relatively narrow-bore, high-resistance vessels. The condition of placental insufficiency may prevail, and can be a factor in the development of the potentially serious or fatal condition of pre-eclampsia and eclampsia.[7–9]

The Obstetric Dilemma of the Large Fetal Head in a Bipedal Pelvis

In our fellow primates, the size of the fetal head at the time of birth is such that it can be easily accommodated in the pelvis of the mother and can move smoothly through the straight birth canal driven by uterine contractions and a final bearing down push. In the female *H. sapiens*, evolution of the human brain and the consequent large head, came several million years after evolution of bipedalism. The bipedal

pelvis has evolved to support upright locomotion. With bipedalism already established, there was not much room for concession to allow for an easier birth of the large head. The pelvis can stretch only a little through relaxation of ligaments of its joints at the end of pregnancy. A large head requires a large pelvis while bipedal locomotion needs a narrow pelvis. If the pelvis were to be too large, a woman would waddle when she walked.[10–13]

The fetal head can undergo a certain degree of molding. The plates of bone of the vault of the large skull are not fused until sometime after birth. For this molding to take place slowly without damaging the brain, the head must come down first. In cases of breech presentation, where the body comes down first, this causes a problem.

The human fetus has to make certain "gymnastic" movements to negotiate its course along the curved, rather narrow and irregular birth canal. These are what obstetricians call the cardinal movements of the normal mechanism of labor. Increased flexion allows the head to pass with a smaller circumference. Internal rotation must take place in the middle of the pelvis as the head moves from the wider transverse or oblique diameter of the inlet of the pelvis to the wider anteroposterior diameter of the pelvic outlet. As the head emerges, the increased flexion and the internal rotation are corrected by extension and restitution. The human fetus has large shoulders that have to also undergo rotation as they descend in the birth canal, shown as external rotation of the head after it emerges from the pelvis. Any difficulty in the completion of these cardinal movements can lead to obstructed labor.

Different from our fellow primates, the fetal head of a full-term fetus just fits snugly in the pelvis. If it remains impacted there for a long time, the soft pelvic tissues between the head and the bony pelvis can undergo such compression that they can become necrotic, slough, and result in the dreadful complication of a fistulous opening between the vagina and the urinary bladder or rectum.

Even when such tissue damage does not occur, overstretching of the ligaments supporting the pelvic organs can take place. In the biped female, different from our quadruped relatives, the pelvic organs are not lying horizontally. They are subject to the pull of gravity if their supporting mechanisms, which have been strengthened through evolution, are damaged or weakened during childbirth. This can result in different degrees and manifestations of pelvic organ prolapse, including urinary stress incontinence.

The birth of midwifery

Human birth, at its best is long, uncomfortable, painful, and uncertain. The human female is the only mammal or primate who needs assistance during childbirth. Birth is not the private business as of our fellow mammals and primates, where the female seeks a secluded place to give birth, probably also not to be exposed to predators at this vulnerable time. The human female needs not only the moral and emotional support and encouragement of other females, she requires actual assistance. Because of the large size of the fetal head and the configuration of the bipedal pelvis, the head is normally delivered with the occiput anterior and the newborn baby facing the back of the mother. In non-human primates, the head emerges with the face of the newborn to the front of the mother, allowing her, from her squatting position, to extend her hand and ease the head out.[14] If the human female tries to catch the baby's head herself, and to ease it out, she may break its neck. This is why midwifery may have been the oldest human profession. Birth attendance, however, carried the risk of infection in the days before asepsis, anti-sepsis, and antibiotics. When the concept of help evolved into the establishment of hospitals, the contagiousness of childbed fever did cost many women their lives.[15]

Altriciality

Infant development, across species, can be described as precocial or altricial.[16] Precocial infants are those that are well developed at birth, with motor skills that enable them to follow or cling to their mothers. Altricial infants are helpless at birth, and must be left in nests or carried by their mothers. Human infants are born with a degree of helplessness not seen in most members of the primate order.[17]

From a biological perspective, it can be stated that all human newborn babies are born prematurely. They had to be delivered "half done." The human brain, because of its complexity, needs time to develop. However, there is a limit to how long it can be left to develop in utero. If pregnancy was allowed to continue, the size of the head would be too large to pass

through the pelvis. The newborn brain is only about a quarter of the way through its growth trajectory at the time of birth. Additional time is needed for the postnatal growth of the brain, which in humans reaches its full adult size only by about the time of puberty.

It has been proposed that the brain serves as a pacemaker for the growth of other body systems. In primate species, relative brain mass scales with the time after birth required to reach maturity, implying that the development of larger brains requires more time.[5]

Altriciality and the need for paternal investment

Altriciality dictates the need for extended maternal investment over long periods of time that go well beyond the period of lactation, and until the child can go on in life on its own.[5]

For this, the mother needs and will benefit from prolonged sustained joint parental investment. The concept of paternal investment is not completely novel in evolutionary history. It is seen, in different degrees in some other species.[18] In our nearest relatives, the primates, the concept of paternity has been out of use in the polygamous promiscuous society, where the paternal investment is limited to the minimal effort of the act of copulation.[5] To achieve and sustain parental investment, the female *H. sapiens* had, through evolution, to develop mechanisms to strengthen the pair bond. Sex was the tool in the hands of evolution.

Sex and the pair bond

In mammals and non-human primates, sex is only a tool for reproduction. The female will only be receptive, proceptive, and attractive to the male when she is ovulating and ready to conceive.[19] Receptivity is defined in terms of female responses necessary and sufficient for the male's success in achieving intravaginal ejaculation. Proceptivity connotes various reactions by the female toward the male which constitute her assumption of initiative in establishing or maintaining sexual interaction. Receptivity and proceptivity are behavioral traits mediated by the hormonal changes associated with ovulation. Attractivity refers to the female's stimulus value in evoking sexual responses by the male. Attractiveness may be visual or olfactory. A most exaggerated model of visual attractiveness is seen in the sexual swellings of the external genitalia of the baboon, where the female moves around widely advertising the fact that she is ovulating and ready for sex and conception. Olfactory messages are mediated by phermones secreted by the female around the time of ovulation, a distinctive feminine perfume that is difficult for the male to resist. It can be sniffed by the male, and when secreted in the urine, it can leave a track for the lover male to follow.

To maintain the pair bond and continued paternal investment, sex in the human female was dissociated from reproduction. All external evidence or clues to ovulation were completely suppressed. Feminine beauty was put on permanent display. Non-reproductive sex became a norm, not an exception.

Concealment of ovulation

Ovulation is a well-kept human secret. It is such because it is not only hidden from the prospective male partner or other females, but also from the woman herself. Ovulation is under hormonal control. Although much research has attempted to look into the question of whether in our species, males and/or females show behavioral clues of female receptivity and proceptivity around the time of ovulation, the evidence, if any, is only minimal, not consistent, and subject to alternative interpretations.[20] It has been suggested that because of our obsession with cleanliness and clothing, our phermones lost their ability to indicate the time of ovulation. However, a study in a primitive community to test this hypothesis did not confirm any change in sexual behavior around the time of ovulation.[21]

Not only is ovulation concealed, but it evolved to take place monthly, irrespective of any opportunity for conception or even sexual intercourse. The uterus is prepared every month to welcome a pregnancy through endometrial decidualization. In most mammals, decidualization does not occur until there is an embryonic signal. The decidua will be useful if there is a pregnancy, but otherwise it had to be shed by the monthly menstruation.[22]

Feminine beauty on permanent display

Rather than being attractive to the male only around the time of ovulation, the human female put her feminine charms on permanent display. The female breast is unusual among mammals and primates, where it is

only an organ for milk production.[23] In other primates, the breast only becomes prominent during pregnancy and lactation. In the human female, it is an organ of sexual adornment, made up of fat and connective tissue. The buttocks also store more fat, resulting in rounded female buttocks and an attractive hour glass figure.

Non-reproductive sex

Although non-reproductive sex has been observed in some other mammals and primates, it is the exception rather than the rule. It is possible that our primitive human ancestors did not conceive the relation between the sexual act and pregnancy until they observed it in domesticated animals. To ensure and strengthen the pair bond, the female had to make herself available for sex at all times, even when pregnant or already past the time for childbearing. Sex changed from being a reproductive duty to a pleasure and a tool for human bonding. The euphemism "to make love" is a true statement.

In one of our closest primate relatives, the Bonobos (*Pan paniscus*), non-reproductive sex is the norm. However, it is not used for pair bonding. Our promiscuous relative uses sex to reduce tension, in a sense making love, not war, or using pleasure for peace.[24,25]

A price to pay

With concealment of ovulation, and making sex available all the time, the human female succeeded through this evolution to establish the pair bond and increase and maintain paternal interest and investment in the offspring. There was, however, a price to pay. Concealing of ovulation from the woman herself made it almost impossible for her to avoid an unwanted pregnancy. Women throughout history have had to struggle, through unsafe abortion, to terminate unwanted pregnancies.

Putting her feminine attractions on display all the time meant that she could be exposed to or forced to have unwanted sex. Sexual violence encompasses acts that range from verbal harassment to forced penetration as well as an array of coercion types, from social pressure and intimidation to physical force.[26]

Sex provided a good medium for microbial transmission. More than 30 bacterial, viral, and parasitic pathogens are transmissible sexually.[27] The World Health Organization (WHO) estimates that more than 340 million new cases of curable sexually transmitted infections (not including viral infections) occur every year throughout the world in men and women aged 15–49 years.[27] Most women are acquiring the infection (including HIV) not because of their own sexual behaviors but because their partners engage in unsafe behaviors. For a mix of biological, social, and medical reasons, the burden of sexually transmitted infections falls disproportionately on women.[1] Women are more likely to be infected, are less likely to show signs of infection, and are at greater risk for severe disease sequelae, including pelvic inflammatory disease and cancer of uterine cervix caused by human papillomavirus infection.

The Human Brain is Repaying Women in the Currency of Science

Women made major sacrifices of their sexual and reproductive health to allow the spectacular human brain to develop in utero, to be delivered safely, and to be nurtured until complete development. It was high time for this same human brain to repay women in the currency of science, and to ease their sexual and reproductive health burden. And it has.

Making motherhood safer

The WHO estimates that where nothing is done to avert maternal death, "natural mortality" is around 1000–1500 per 100,000 births.[28] If women were still experiencing "natural" maternal mortality rates today, the maternal death toll would be four times its current size. Three quarters of these deaths are currently avoided throughout the world: nearly all the "natural" maternal mortality in developed countries, but only one third to two thirds in developing country regions. The blame for avoidable maternal mortality in the world today is not on science. Science has already provided the knowledge and the tools.

Skilled birth attendance, the availability of blood transfusion, and the resort to Caesarean section are products of our human brains to ease the burden of the obstetric dilemma on women. Abdominal delivery, originally only performed on a dead mother to get the baby out, and later only when vaginal delivery would put the baby's or mother's life or health at risk, is now a relatively safe procedure available on request, even when there is no medical indication for it.[29,30]

Fertility regulation and control

Women throughout human history have tried desperately to have control on their fertility. With ovulation concealed, it was difficult. Men, on the other hand, had a simple means to spill their seed on the ground. The human brain came to help. Thanks to a contraceptive technology revolution, for the first time in human history, women had access to reliable, safe and reversible contraceptive methods that they could use on a daily basis, or as long acting methods: every month, every two or three months, every 3 years, every five years, or for 10 years.[31] Contraception has been moved outside of the bedroom. Women had methods of contraception which they can use without the need for cooperation of their male partners. In the world today, more than 60% of married women of reproductive age are using contraception.[32] Contraception has become a way of life. The contraceptive technology revolution still has an unfinished agenda.[33–35] A sustained research effort is needed if men are to have broader contraceptive choices to enable them to share effectively in the responsibility for fertility regulation. Women still need back up methods to reduce the need for abortion.[36] More than 40 million unintended pregnancies are terminated each year, an estimated 20 million of which are unsafe.[1] Women also still lack woman-controlled methods which they can use to avoid contracting a sexually transmitted infection from their partner.[37]

Challenges Still Stand

Women can feel happy that the human brain which they nursed and for which they sacrificed, is finally rewarding them back. Challenges, however, still stand.

From the hunter gatherer to the modern woman

The modern woman in the post-industrial society has to cope with her new life while burdened with a reproductive system that has evolved to serve well the survival and reproductive success in her life in a hunter-gatherer society.[16] A female in a hunter-gatherer society will get her first pregnancy soon after puberty, will lactate for three or four years, then will have other successive pregnancies and breastfeeding periods. During her reproductive life span, she will probably have no more than 50 menstrual cycles. The woman of today will reach puberty earlier, will delay the time for first childbearing, will breastfeed for only brief periods or not at all, and will have fewer pregnancies. She will also survive for a much longer time after cessation of ovarian function. The female reproductive system of the hunter gatherer has become a burden to the modern women. The system continues to be exposed to the hormonal menstrual cycles, without fulfilling the potential functions of reproduction. Susceptibility of women to reproductive cancers can be seen in this evolutionary context.[38] Evidence has been accumulating to implicate incessant ovulation, without intervening periods of pregnancy and lactation, in the causation of ovarian neoplasia.[39] Our ovulation competitor, in this regard, is the domesticated egg laying hen, and it is no co-incidence that it is the recognized animal model for ovarian cancer.[40] Significant duration-dependent reductions of ovarian cancer incidence in the general population are associated with oral contraceptive use which suppress ovulation.[41]

The female breast, serving now mostly an adornment function, is the seat of the commonest female cancer. It is more common when there is a long period between puberty and the first pregnancy, in women who had no or fewer pregnancies and did not lactate at all or only for short periods.[38] Suboptimal breast feeding is associated with a higher risk for breast cancer and other diseases.[42] In other mammals, breast tumors are common in domesticated cats and dogs, whose reproductive function we limit and control.[43]

Emergence of the woman from behind the mother

At a great cost to their health and life, women have already fulfilled the divine obligation to replenish the earth. Reproduction has now become a function of women, not the function of women. Women now spend only a relatively shorter time of their life in childbearing and child rearing. Women became producers, not only reproducers. In modern human life, production does not need the muscle of the hunter gatherer. It needs brain rather than brawn. A women-centered medical and social research agenda is needed to help the woman to finally emerge from behind the mother.[44–46]

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