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Bipedalism and pelvic floor disorders, an evolutionary medical approach

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ABSTRACT

Evolutionary medicine can help to better understand the basis of pelvic floor disorders. Some evidences of the anthropological literature are reviewed, with emphasis on the paleontological clues and phylogenetic comparison of cephalo-pelvic relations in *Homo* and non-human primates, is undertaken to elucidate the origin of pelvic floor disturbances in humans. Labor difficulties inherent to bipedal gait and the encephalization process could have started several million years ago with *Australopithecus* and appear undeniable since Homo heidelbergensis, the precursor of Neanderthals. The mechanisms involved in modern human delivery with fetal rotation into the birth canal could be exclusive of *Homo sapiens*. Among pre-bipedal non-human primates only squirrel monkey can suffer severe dystocia and spontaneous pelvic organ prolapse. Better understanding of the evolutionary changes regarding the human pelvis and the pelvic floor could help us to better understand pelvic floor disorders and the interventions to avoid this highly prevalent ailment.

1. Evolutionary medicine

Evolutionary medicine, also known as Darwinian medicine, is the application of modern evolutionary theory to better understanding health and disease. Modern biomedical research has been dedicated mainly to understanding the molecular mechanisms of disease, while evolutionary medicine focuses on how evolution has shaped these mechanisms so as to make us prone to ailment. Evolutionary history is the current scientific theory that outlines the major events during the development of life on planet Earth. In this sense, an evolutionary explanation can be based on the phylogeny of a certain trait or on its proposed adaptive significance.

In this sense, the evolutionary approach has driven important advances in the understanding of cancer and other health problems including infectious disease surveillance and gene-by-environment interactions [1,2]. It is very likely that human bipedal gait determines a susceptibility to pelvic floor disorders and female stress urinary incontinence. We evaluate the archeological and phylogenetic evidences to consider female pelvic floor disorders as an evolutionary disease.

2. Bipedal gait and the proportion of fetal head with maternal pelvis

The understanding of the human lineage is complex, but include at least three different genera, *Ardipithecus*, *Australopitecus* and *Homo* and they all share the characteristic of bipedal gait. Divergence from chimpanzee and other non-human primates is estimated to have occurred more than 7 million years ago. It is assumed that two characteristics of human evolution, bipedalism and increased brain size, have taken place after such divergence [3]. Adult brain size and neonatal body mass results from the encephalization process in genus *Homo* for the last 2 million years. Consequently, the pelvic birth canal increased in size and shifted to a gynecoid shape [4].

Different theories have been proposed to explain the reason for human bipedalism, but none seems totally explanatory. Some scientists have suggested that tool making that left the hands free was the initial trigger for standing up on two legs; but this is not correct because the earliest stone artifacts date only from circa 3.3 million years, much long after hominins had become bipedal [5,6]. Other theories that have been proposed include the need to have visual perspective that helps to avoid predators and follow migrant herds, and also to facilitate genital display for sexual attraction and face-to-face coitus [7]. Pre-bipedal primates were terrestrial quadrupeds, probably knuckle-walkers like current chimpanzees, bonobos and gorillas.

All apes have the transitory capacity to adopt a bipedal pose with full extension of the lower limbs. However, we should hypothesize that to acquire permanent bipedalism, deep anatomical changes would be required that would include a humanoid hip, sacral promontory protrusion, strong thigh muscles, and more robust knee and foot structure to transform prehensive feet into propellent heel-supported ones.

Obstetrical dilemma is the theory that proposed bipedalism resulted in the selection for a larger brain, but also led to conflicting pressures on the pelvis that reduce the size of the birth canal. These opposed

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Fig. 1. Lumbo-sacral complex from the same *Homo heidelbergensis* individual, recovered from *Sima de los Huesos* in Sierra de Atapuerca, Spain (SH, Pelvis 1) dated 400.000 years. Museum of Human Evolution, Burgos, Spain.

selective forces bring the evolutionary change in a trait to a halt, thus constraining the adaptation [8]. Besides, human newborns are considered altricial compared with other primates because they are relatively underdeveloped at birth, which could be due both to the obstetrical constraints and to an increased brain plasticity [9].

3. Pelvic floor disturbance as an evolutionary disease

Animal observation and experimentation have greatly contributed to understanding the mechanism of disease, although their real value bit to predict intervention and etiologic assessment remain controversial [10]. Evolution conceived as the change in the genetic makeup of a population over successive generations producing mutation and recombination is truly important for the adaptation of a variation in functional trait. Therefore, selection increases the ability to survive and reproduce. So, the trouble caused by the fact that bipedal gait led to obstetrical dilemma is a very interesting phenomenon to understand the diversity of living individuals, and to understand the process of evolution regarding the adaptability of individuals, populations and other biological systems such as socio-sanitary structures, to secure human health.

Applied evolutionary biology has the potential ability to serve society by addressing the basic evolutionary principles that govern life [11]. Also, behavioral and genomic variations in human populations make us differentially susceptible to different diseases that range from obesity to the antibiotic resistance to infections [12]. As with obesity, female urinary incontinence and pelvic floor disorders represent a combination of culture based, behavior changes and predisposition linked to an evolutionary perspective.

Sometimes it is not that disease itself is an evolutionary process, but traits that leave bodies vulnerable to disease have evolutionary explanations. This could be the case of pelvic floor disorders and female genuine incontinence. Medical research tries to explain why some individuals fall ill while others do not. However, it is equally important to understand why all members of a species are vulnerable to disease. These are evolutionary questions whose answers require tracing phylogenies and reconstructing the forces of evolution and selection that explain the underlying responsible traits [13,14].

Human childbirth is more difficult than that of most other primate species, owing primarily to a tight close match between the fetal head and maternal birth canal. Small variations of maternal and fetal dimensions, that are likely to occur in populations, often lead to a considerable rate of disproportion that produces obstructive labor. Cephalopelvic disproportion is a leading cause of maternal morbidity and mortality where cesarean section is not available. Short- and long-term complications of difficult labor include uterine rupture, vesicovaginal fistulae and urine incontinence. However, the topic is more complex than previously considered because most studies were based on European individuals and did not take into account the wide range of variation showed by our species as a whole. Also, the rotation movements required by the fetus to negotiate the twisting passage tends to be reported following the average Caucasian experience. Given the geographical differences in canal shape among modern populations, a wider range of variation in childbirth might be expected in modern multi-ethnic societies [15,16]. Generally speaking, anatomical traits are subject to long-standing natural selection for several million years and thereof the question of why is the human fetus so tightly matched to the maternal birth canal and so prone to birth complications is very compelling.

4. The paleontological evidence

There are very few well preserved pelvic remains of non-modern human fossils. The most complete one is an almost complete pelvis, found associated with fragmented femora and also with a complete lumbosacral complex from the same individual, recovered from *Sima de los Huesos* in *Sierra de Atapuerca*, Spain (SH, Pelvis 1) dated 400.000 years. This unique nearly complete and non-distorted Middle Pleistocene fossil offers a very special glimpse into the anatomy and life of *Homo heidelbergensis*, and it is probably the first archeological evidence favoring obstetrical dilemma leading to increased risk of complicated deliveries in an early human fossil that has been classified as an ancestor of Neanderthals [17] (Fig. 1). *Homo heidelbergensis* developed more than 600.000 years ago in Africa and lived at least until 200.000 years (Middle Pleistocene).

A detailed evaluation of SH Pelvis 1 has confirmed a primitive pattern within genus Homo and suggests a less pronounced sagittal spinal curvature that will be adopted by Neanderthals compared to Homo sapiens [18]. It is a remarkably elliptical, broad, tall, robust and expanded pelvis, with many differences if compared to that of modern

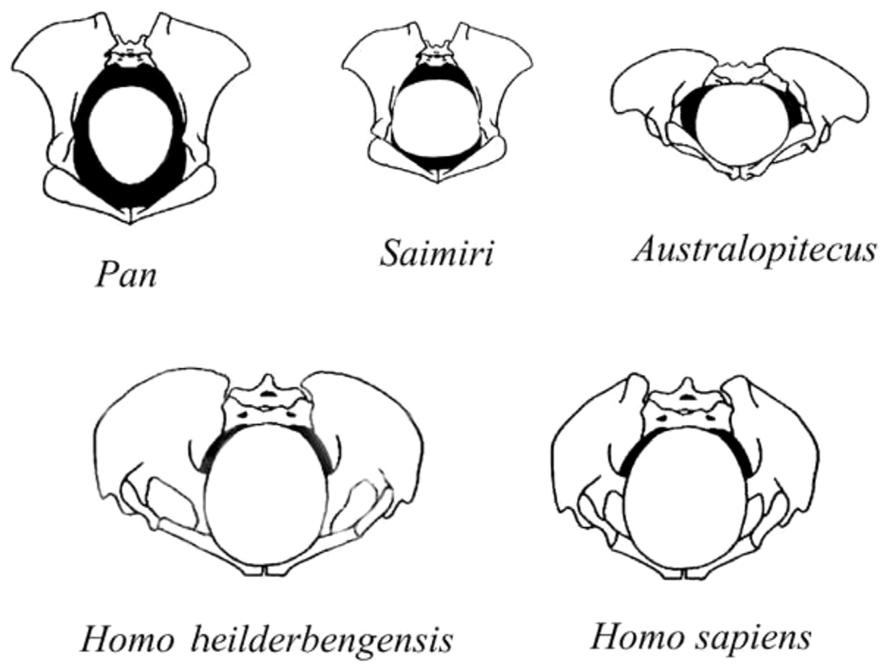

Fig. 2. Non-human primates may suffer dystocia caused by cephalopelvic disproportion, but that happens rarely in *Pan sp.* like the chimpanzee. However, squirrel monkey is particularly prone to suffer dystocia, in consonance with the relatively large infant brain in this species. Differences in the relative proportion of fetal head with maternal pelvis, between non-human primates (*Pan* and *Saimiri*), and also between different paleontological registries of bipedal species in human evolution (*Australopithecus*, *H. heidelbergensis* and *H. sapiens*).

humans. It likely represents the plesiomorphic condition for the genus *Homo* [19]. The cranial capacity of several different specimens recovered from the same archeological site is around 1.250 cc; smaller than in modern humans. It appears then that the obstetric dilemma may have even worsened in modern humans. There is no evidence to evaluate whether the phenomenon has been involved in Neanderthal extinction. Partial fossils recovered from Tabun in Mount Carmel (Israel) have allowed the reconstruction of birth canal. Neanderthal childbirth seems about as difficult as in present-day humans [20]. However, there are substantial differences based on a more primitive birth mechanism without rotation of the fetus inside the birth canal, the most important adaptations in modern humans to avoid obstetrical dilemma.

It seems reasonable to accept that a significant shift in childbirth happened quite late in human evolution, probably for the last few hundred thousand years; and also, that a divergent evolutionary trajectory appeared even later between Neanderthals and the lineage leading to present-day humans. However, we must be cautious because the archeological record is very incomplete to fully understand the evolution of human labor from a paleontological perspective, as there are very few non-modern human pelvic fossils from around the world. They include the less complete pelvises from Hadar (*Australopithecus afarensis*), Sterkfontein (*Australopithecus africanus*) and Kebara (*Homo neanderthalensis*); and some isolated pelvic bone remains from East Turkana, Olduvai, Jinniushan and Arago (lower and middle Pleistocene).

5. The animal model evidence

Studying pelvic evolution is difficult for several reasons. Besides the already mentioned fragmentation and scarce representation in the paleontological record, the pelvis is an integrated multi-structural organ in which the transformation of one part may lead to secondary changes to preserve the functional integrity of the global structure. It is undeniable that pelvic changes produced by the transition to bipedalism have determined a specific birth canal, and the relative brain size increase of genus *Homo*, known as encephalization, and also of the global fetus size have affected not only the pelvic size but also delivery passage. Generally speaking, birth related pelvic changes in human lineage led to progressive anterior-posterior broadening of the birth canal to compensate the obstetrical dilemma.

However, the advantages gained by increased pelvic width seem to be outweighed by the disadvantage caused by bipedal gait. Primates and humans tend to be born in a very early developmental form, and this altricial status partially compensates the risk of cephalopelvic disproportion and obstructed labor in humans. Gestational length, neonatal rotation and delivery assistance by other humans are additional protective mechanisms [21]. More recently, it has also been recognized that humans have evolved a complex link between pelvis shape, stature, and head circumference; i.e., females with a large head, who are also likely to give birth to large-headed neonates, have birth canals that are shaped to better accommodate megacephalic neonates [22].

Pelvic floor musculature in quadruped mammals is a vertical muscle structure that serves for moving the tail. In humans, the muscles of the pelvic diaphragm have a very different anatomical orientation and form a horizontal pelvic "floor" that supports the abdominopelvic organs and facilitates control of the anal and urinary sphincter. Primates occupy an intermediate position between tailed mammals and *Homo sapiens*. However, among non-human primates, squirrel monkey (*Saimiri* genus) is a very peculiar model for research on women's pelvic floor disorders because its intrapelvic musculature is very similar to that of humans [23]. In squirrel monkey the *levator ani* muscle consists of the pubocaudal and iliocaudal muscles, analogous to pubococcygeus and iliococcygeus muscles in humans. Besides, the endopelvic fascia in squirrel monkey has connective tissue condensations that are very similar to uterosacral and cardinal ligaments in females. Loss of muscle contraction and damage to the connective tissue and ligaments is associated to occurrence of pelvic organ prolapse (POP). Squirrel monkeys are dolichopelvic, and their pelvis have an oval cranial portion and are flattened laterally. High perinatal mortality has impaired the reproductive performance of female squirrel monkeys in captivity and narrow pelvic outlets were consistently observed in females that delivered stillborn infants [24].

Although the pelvic bone morphology of women and squirrel monkeys differ, their pelvic floor structures are very similar and also the impact of fetal size and its passage through the birth canal during delivery is very similar. *Saimiri sp.* is therefore very useful in human obstetrical research. Non-human primates may suffer dystocia caused by cephalopelvic disproportion, but that happens rarely in *Pan sp*. like the chimpanzee. However, squirrel monkey is particularly prone to suffer dystocia, in consonance with the relatively large infant brain in this species. Differences in the relative proportion of fetal head with maternal pelvis, regarding the transverse and antero-posterior diameters of the pelvic inlet, can be compared between non-human primates, and also between different paleontological registries of bipedal species in human evolution (Fig. 2).

The conclusion is that squirrel monkey and *Homo sp.* have striking similarities to suffer dystocia. Squirrel monkeys have developed several adaptations to compensate for this exaggerated obstetrical difficulty. The cranium of squirrel monkey has a unique dolichocephalic shape to accommodate its maximum cranial breadth to the birth canal. Also, it has been observed that squirrel monkey is able to pull itself out of the birth canal once the shoulders have been liberated [25]. Still though, more than 10% of female squirrel monkeys in captivity experience dystocia, mostly primiparous ones. Practically, any other presentation different to the longitudinal one leads to fetal death. The adaptations developed by humans to avoid dystocia are fetal rotation during pelvic passage and assistance at birth. However, it remains to be demonstrated whether assistance during childbirth, including cesarean section, will bring a decrease in pelvic floor disorders.

Several animal models in rats and sheep have been used to study the pathophysiology of POP. In some of them there are measurable effects of pregnancy, delivery and iatrogenic menopause, but there is not a single uniform pattern. Only squirrel monkeys and humans develop clinical POP spontaneously [26]. In women prolonged births have also been identified as one of the major risk factors to develop prolapse, together with aging and menopause.

6. Conclusion

There is accumulated evidence to consider pelvic floor disturbances as part of an evolutionary phenomenon, linked to bipedal gait and the encephalization process that imply secondary labor difficulties. Obstetric dilemma affects not only modern humans. There is paleontological evidence that it has been present at least since pre-neanderthal biology, with *Homo heidelbergensis* around 600.000 years ago; but could have started 4.2 million years ago with Australopithecus. Among pre-bipedal non-human primates only squirrel monkey can suffer severe dystocia and spontaneous POP. Better understanding of this condition and the factors involved could facilitate interventions to avoid this highly prevalent disease.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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