Enrico Ferrazzi · Claudio Crescini

Anthropological evolution of mechanisms of labor and delivery in humans

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The mechanisms of labor and delivery have evolved significantly from monkeys to bipedal hominids, and even more so in hominids with large brains, such as the Homo sapiens. This three million years evolution raises the question of how our species survived to become dominant among monkeys and apes despite the huge maternal and infant mortality toll caused by the unique mechanisms of childbirth associated with bipedalism, large head and an energy devourer brain.

DELIVERY IN MONKEYS AND APES

Tree-dwelling or terrestrial monkeys and great apes are quadrupeds and can only balance on their hind limbs for short distances. This prevalent locomotion determines a distribution of body weight both on the pelvis and on the shoulder girdle.

Thanks to this balance of weight on four limbs, the pelvic bones do not place mechanical structural limits on the progression of the fetal head and body at birth. The pubic synchondrosis appears, like in all mammals, as a cartilaginous plate with no relation with the fetal head descent at birth (**Figure 1.1**)

This characteristic is associated with the relatively small size of the fetal brain. In the Gorilla, which has a gestation period of the same duration as humans, the brain represents at birth only 3% of the weight of the newborn, more than half the relative percentage of the brain observed in the human fetus. The expulsive period in chimps is therefore much similar to a linear descent of the head down the birth canal (**Figure 1.1**).

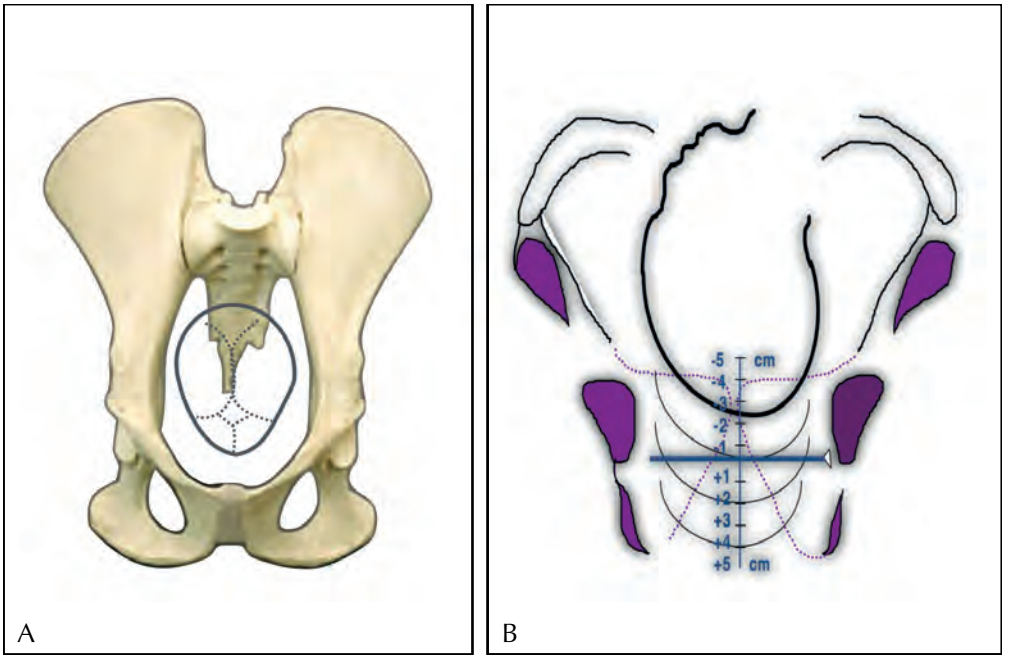

Figure 1.1 A) Ideal measurement of progression measured in cm from the upper brim of the pelvis to the outlet. B) Pelvic bones of a bonobo; the descent of the head is not challenged by the bony pelvis.

Bipedalism and cephalization

Bipedalism and cephalization that accompanied the differentiation of the human species from anthropoid monkeys starting from about three million years ago have radically changed the mechanisms of childbirth. Bipedalism has led the weight of the body to insist only on the lower limbs, the pelvic bones have assumed a more solid structure, and in particular the coxo-femoral joint, on which all the weight of the body rests, has assumed a structure capable of discharging forces, by means of an internal buttress, the ischial spines. Similarly the pubic synchondrosis, the pubis, has progressively assumed a larger size and a typical ogival shape, assuming the role of the anterior wall of the complex human birth canal.

At the same time, cephalization, that is, the increase in brain volume, has determined the fact that paradoxically the average circumference of the head of the human fetus is greater than the average circumference of the birth canal.[1]

This is why the head of the fetus can engage and enter the upper part of the birth canal only by presenting its smaller circumference (sub-occipito-bregmatic) on the oblique diameter of the upper strait, or more rarely in an asynclitic transverse position. The progression into the pelvic canal is even more complex with subsequent mechanical movements, that make this short trial in the pelvic canal possibly the riskiest journey ever for the *sapiens sapiens* (**Figure 1.2**).

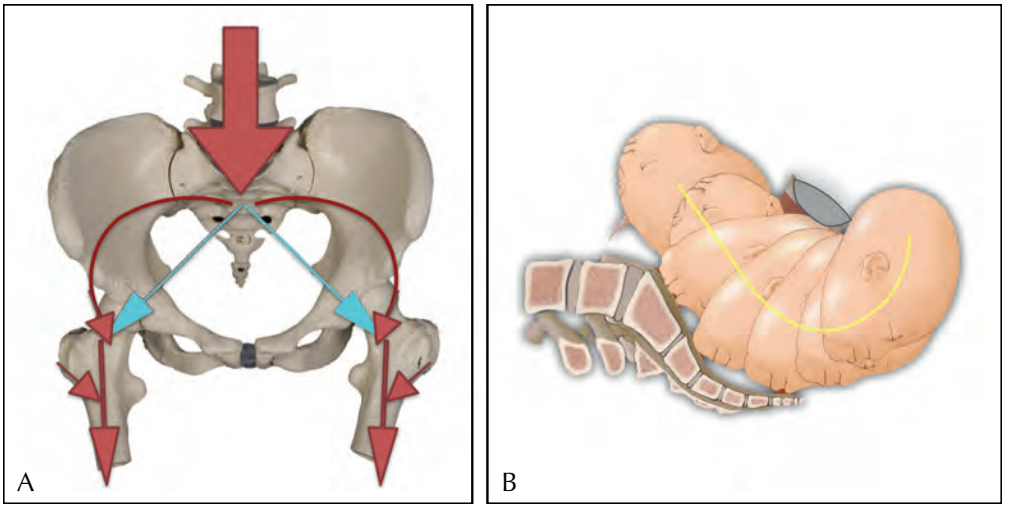

Figure 1.2 A) The head is bigger than in apes. It must engage the upper brim of the pelvis along its oblique diameter only by extreme flexion. At midpelvis after a short descent downward the head must rotate on its anteroposterior diameter to match the narrow mid pelvic strait. After such rotation is successful the direction is now frontward until the occipital bone is below the lower brim of the pubis, now maternal forces on the asymmetrical leverage of the fetal spine on atlantal foramen of the skull, makes the head to deflect and start its final upward trial to crowning. See chapter 3 and 7 for NMR and U/S imaging. B) Pelvic bones became stronger, the ischiatic spines are there like buttress to help support the weight of the whole body, the synchondrosis has now a perfect ogival shape.

ALTRICIALITY AND THE DEATH TOLL OF GIVING BIRTH IN HUMANS

Cephalization also means a metabolically "expensive" brain mass, such that it has been estimated that maternal cardiac output, even if normally adapted to pregnancy, would not be able to maintain the growth of the fetal brain until its maturity estimated at 56 weeks.[2] Indeed, in approximately 15% of pregnant women at term we can measure echocardiographic indices of right heart failure and observe signs and symptoms of this impending failure: shortness of breath, lower limb oedema, nycturia.[3]

The bony limits of the pelvis, the size and the metabolic cost of the fetal brain are considered the cause of two important phenomena of the human species. The first phenomena is that our species is characterized by altriciality, that is, the human fetus is born prematurely (relative to the maturity of the fetuses of anthropoid monkeys and apes, and in general of quadruped mammals). The second phenomena were the high mortality and morbidity of childbirth, both maternal and feto-neonatal, that has characterized our species for thousands of years, and that unfortunately still characterizes vast areas in countries with low health resources. The rate of childbirth deaths around the 14th century, during periods of high agricultural production, estimated through the analysis of burial sites, was up to one in 300, while in times of food shortages and war the count was as high as one in five as during the American Civil War in states swept by armies and battles. Without erring to the extremes, until 1926 in USA maternal mortality was one every 150 deliveries, not much different than other European countries such as England and Wales where that death toll was as high as one every 250 deliveries.[4]

THE POWER OF BIPEDALISM AND HOW NATURE INVENTED THE MECHANISM OF ALTRICIALITY IN HUMANS

Two questions arise in the face of this "massacre" of females of our species in competition with other anthropoid species. What was the competitive advantage of hominids living on the hind-legs, and what is the mechanism that allowed these bipeds with the "narrow" pelvis, the "large" head and the cardiometabolic limits, to be born prematurely to allow for the limits associate with bipedalism and cephalization?

There is significant evidence that the energy consumption of walking, running, jumping on two legs is much less expensive than on four legs, such as the foot- knuckle walking of apes.[5] Two millions years ago as well as 300 thousands years ago, food was not stored in the fridge, or, for the less careful, in the supermarket nearby, but the result of foraging, or finding the leftovers of prays of carnivorous, or less frequently of hunting. Two legs walking, for the same weight, could cost six times less than in quadrupeds (**Figure 1.3**).

The quest for energy is still to-day moving the competition between states. Consuming less energy for the same tasks was then the "ownership of oil fields". Similarly, there is evidence that punching in the upright position develop a stronger impact than punching with the same forearm in the quadruped position. These two combined factors do represent a highly significant competitive pressure that favoured hominids vs. chimps.

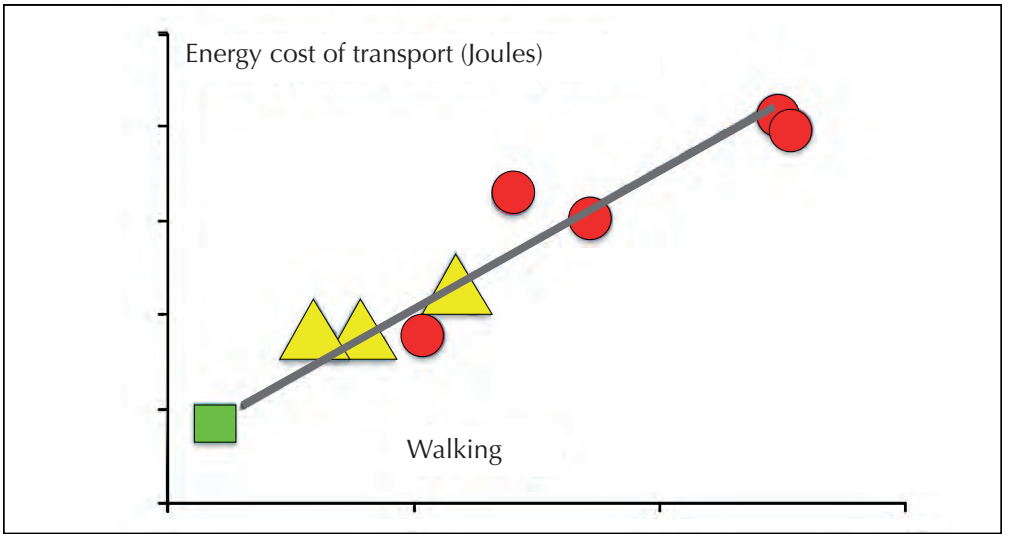

Figure 1.3 Green dot: humans; yellow: bipedal chimpanzees walking; red circles: knuckle foot walking of chimpanzees. The mass-specific net cost of transport (COT) is significantly lower in bipedal hominids.[5]

The first "failed" attempt to deliver large heads in strong pelvis is probably represented by the australopitecus AL 288-1, commonly known as Lucy, who lived 3.2 million years ago. The mechanical "solution" to deliver a big head in a small pelvis was to "enlarge" the bi-acetabular width and let the head engage and progress down the pelvis in a transverse position (**Figure 1.4**).[6] However, this "model" was not enough competitive. A large pelvis comes with a waddling gait with an enormous cost of muscular work to keep the kinetic of walking in due balance.

To-day, we can still measure this cost in women according to their bi-acetabular diameter. **Figure 1.5** proves how the larger this diameter the higher the metabolic cost of walking.[7]

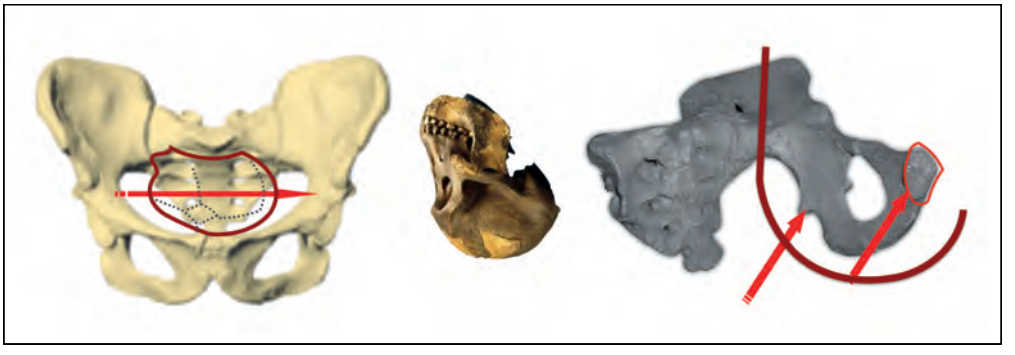

Figure 1.4 The large bi-acetabular diameter of "Lucy" allowed for the head to engage and progressing from downward to front ward to up ward to expulsion in a transverse position with the parietal bones articulated along the pubis, now already enlarged and ogival in shape.

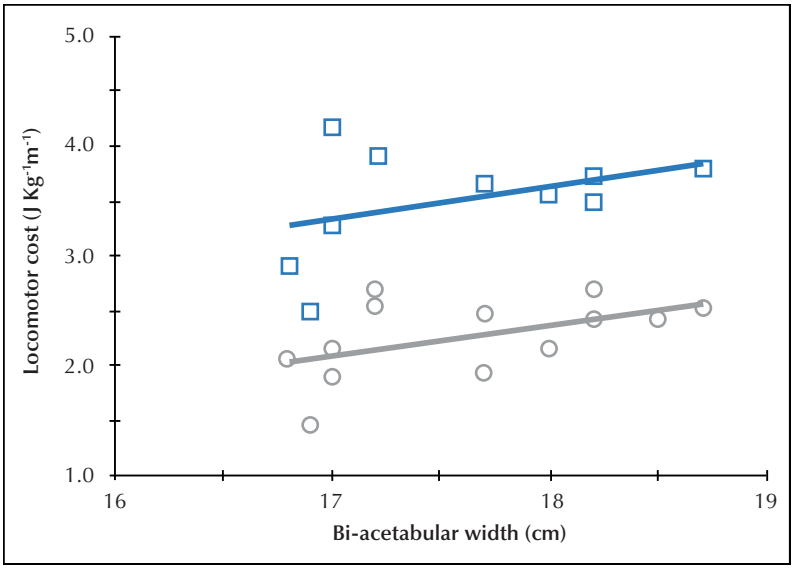

Figure 1.5 The larger bi-acetabular diameter the higher the cost of running (square) and walking (circles) in 10 and 13 contemporary women.[7]

The second question to be answered is how nature "invented" the mechanism of altriciality in humans to allow for a negotiation between the factors we have analysed above. In all quadruped mammals, and in anthropoid monkeys included, at near term the placenta reduces the production of progesterone, the hormone that keep the myometrium quiet. We, humans, are the only known species in whom the progesterone remain in a steady state production all along term. We "simply" produce on the myometrium decoy receptors for progesterone (progesterone receptors type A, instead of the standard type B), as such blocking its quiescent effect to leave the oestrogens activate a cascade that will eventually produce oxytocin receptors and activate labor.[8] Who is the master of the production of decoy receptors? This master is the metabolic stress of the growing fetus who do not receive the needed amount of nutrients and oxygen to grow further on in uterus. It is the fetal inflammasome due to "unexpected" metabolic restriction that ignites the mechanisms of being delivered into a hopefully more favourable nutritional environment.

The mechanics of childbirth in human vs. chimps

The differences here above described are the results of millions of years of trials and errors to negotiate the power of our species with the critical mechanisms of delivery.

A common social trait of surviving neolithic tribes is that labor and delivery is assisted by peers or older "experienced" women (see chapter 4). Chimps' females deliver alone with no assistance by peers. In humans, the progression of the fetal head in the pelvis is not like the "descent of a ball in a tube", where its progression can be properly measured centimetre by centimetre. The progression of the fetal head can only be achieved if complex mechanical movements occur in constant sequences according to the position of the head, with the shoulders (or the head in breech presentation) following suit with the same complex cardinal movements of human delivery, flexion and engagement, progression in

the upper pelvis, internal rotation at midpelvis, extension of the head under the pubis and expulsion. This very strict dynamic relationship between head and pelvis, which include also the adaptation of the latter to pregnancy, is the cause of obstructed labor that for millennials had claimed maternal and fetal mortality and morbidity.

Childbirth today in high- and low-income countries

Assistance by peers or wise elders, the development of midwifery and of specialized medical disciplines, the development of prenatal care, and hospital delivery after the 2nd world war, are all here to testify the inner risks of delivery and the need to protect mothers and fetuses from unwanted outcome. In high income countries (HIC), where prenatal care is totally covered by the NHS, mortality is down to 1 in 15.000-18.000 deliveries. This is not the case of low-income countries where major disparities still exist, and the mortality and morbidity cost of pregnancy and delivery are still unbearable high.

Indeed, new problems are arising in HIC. Advanced maternal age, obesity epidemics, air pollution, overprocessed food, poor physical activity is adding new challenges to prenatal care. One important underestimated effect of advanced maternal age at first pregnancy is the effect of pregnancy itself on the pelvic biometry. Pregnancy in young women is typically causing an enlargement of both the anterior and posterior width of the pelvis of about 2.5 cm.[9] These changes are less pronounced, and less frequent after 30-35 years of age.[10] This lesser enlargement is reducing both the bi-spinal ischiatic diameter at mid-pelvis and a narrower subpubic angle. The consequence of the latter narrow sub-pubic angle is the need of a more downward progression of the head to articulate its occipital bone under the lower brim of the pubis (**Figure 1.6**).[11]

This possible additional limitation of advanced maternal age is associated with overstretching of the fibromuscular pelvic floor and subsequent pelvic floor dysfunctions, with possible lifelong consequences on the quality of life of women (see chapter 10).

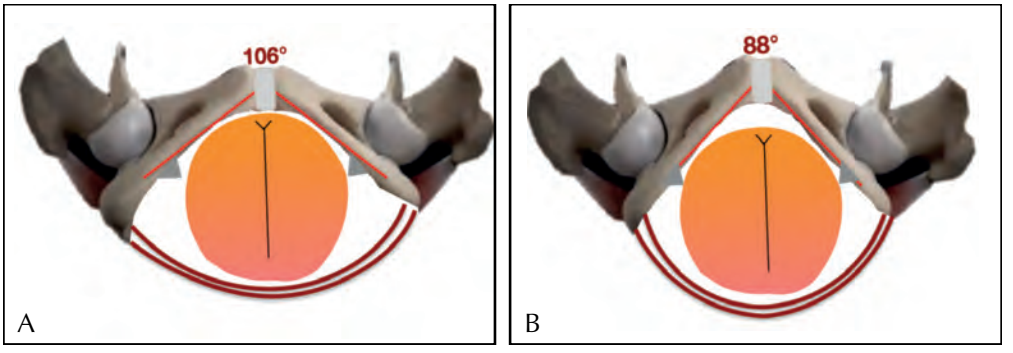

Figure 1.6 A) Normal subpubic angle: typical female pelvis: the fetal head change its down-ward direction when it articulates its occiput point of flexion under the symphysis pubis. B) Narrow subpubic angle, this anterior shape is associated with critical limitations to head progression: in an android pelvis with narrow subpubic angle and narrow ischiatic spines, even when the internal rotation is feasible, the head must progress more down-ward to articulate its flexion point under the pubic branches and progress front-ward and then up-ward, this occurs at the cost of a longer second stage and overstretching of the pelvic floor.

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