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REVIEW ARTICLE

Equilibrium of the human body and the gravity line: the basics

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Abstract

Introduction Bipedalism is a distinguishing feature of the human race and is characterised by a narrow base of support and an ergonomically optimal position thanks to the appearance of lumbar and cervical curves.

Materials The pelvis, adapted to bipedalism, may be considered as the pelvic vertebra connecting the spine to the lower limbs. Laterally, the body's line of gravity is situated very slightly behind the femoral heads laterally, and frontally it runs through the middle of the sacrum at a point equidistant from the two femoral heads.

Results Any abnormal change through kyphosis regarding the spinal curves results in compensation, first in the pelvis through rotation and then in the lower limbs via knee flexion. This mechanism maintains the line of gravity within the base of support but is not ergonomic. To analyse sagittal balance, we must thus define the parameters concerned and the relationships between them.

Conclusion These parameters are as follows: for the pelvis: incidence angle, pelvis tilt, sacral slope; for the spine: point of inflexion, apex of lumbar lordosis, lumbar lordosis, spinal tilt at C7; for overall analysis: spino-sacral angle, which is an intrinsic parameter.

Keywords Sagittal balance · Gravity line · Spino-sacral angle · Incidence angle

Introduction

The acquisition of erect, vertical posture and the possibility we acquired to extend simultaneously the trunk, hips, thigh and legs allowed the bipedal locomotion. This represented definitively the main transformation of the history of the Homininae, the one that induced slowly the others, the evolution of the hand and the brain; and that, consecutively, gave rise to the tools and the conscience, the culture and the society [1]. Human beings stand upright and move through a world subject to the laws of gravity [1] (Fig. 1). Their spines are subject to all of the constraints associated with this situation. The relationship between the pelvis and spine is a direct result of this bipedalism. Assumption of an upright position resulted in broadening and verticalisation of the pelvis (Fig. 2) leading to the appearance of man's characteristic sagittal spinal curves (Fig. 3), as well as profound changes in the muscles supporting the spine [2]. Although all members of the *Homo* genus have been solely bipedal, bipedalism is by no means the exclusive preserve of man [3]. Throughout the course of time, there have been numerous bipedal species employing a wide variety of bipedal mechanisms: archosaurs used their tails as a counterbalance; all modern birds are bipedal, as are certain non-human primates such as the mountain gorilla [1, 3]. In quadrupeds, the sacral plateau is vertical, allowing transmission of forward propulsive force from the lower limbs. With the exception of birds, most bipedal species adopt this uncomfortable and tiring upright position only occasionally, for brief periods and over short distances. Chimpanzees use their arms as counterbalances since they have no spinal curvature and are thus in a position of anterior imbalance (Fig. 4). In contrast, human bipedalism is an entirely different affair: it is the sole position of the species, and is stable and ergonomic [3]. In order to understand this

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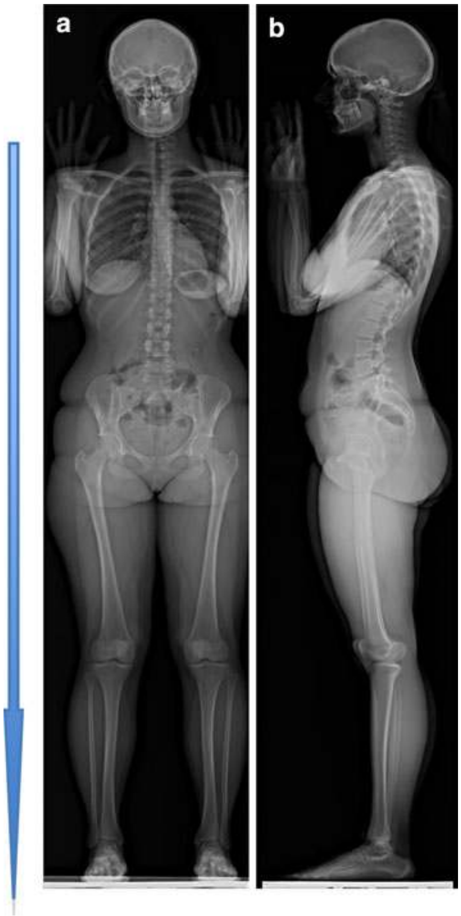


Fig. 1 Simultaneous AP and lateral radiographic view of the full body in standing position with the low-dose EOS system (Biospace, Paris, France). **a** AP view and **b** lateral view of the spine and pelvis

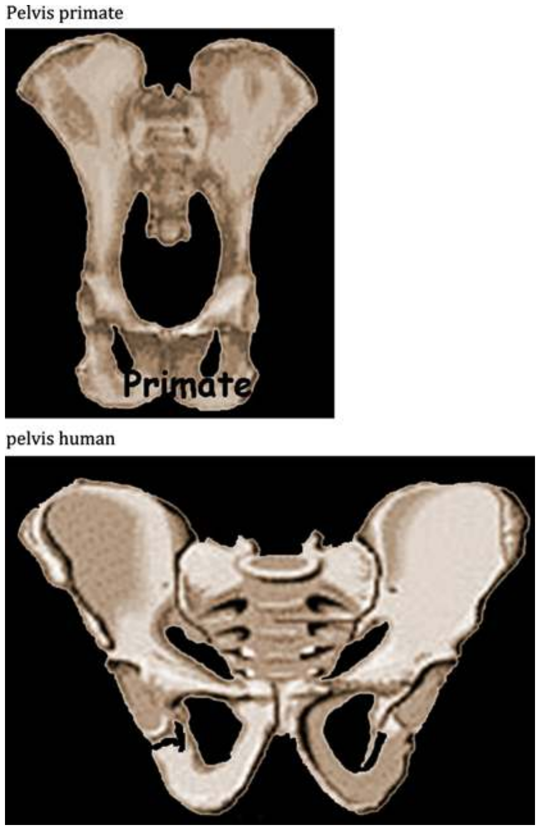


Fig. 2 Lateral view: **a** pelvis shape of primate and **b** human. Enlargement and verticalisation of the pelvis

adaptation to the upright state, we shall examine each element individually before defining the parameters that allow analysis of the human clinical picture.

Bipedalism offers a number of advantages, which we shall briefly discuss, but it entails a number of constraints that must be managed by the musculoskeletal system [1]. An upright posture results in complete liberty of the upper limbs, which are now free to perform tasks or carry things. The lower limbs become the sole point of contact with the ground. We have thus gone from a highly stable quadruped position to an eminently unstable biped position [3]. However, stability in the upright position is preserved despite a smaller base of support between the two feet. Nevertheless, although upright, humans can carry loads and are able to run. The upright position of humans also allows completely vertical position to be combined with a fixed unstable horizontal line of sight, in which it is essential for effective positioning of the semicircular canals and thus good balance [1]. Finally, human bipedalism is ergonomic [2]. In order to allow such an upright position to be assumed, the hips and knees form a straight line. The femoral bone is lengthy and vertical (Fig. 1), the femoral trochlea is hollow to ensure stabilisation of the patella during walking, and the proximal end of the tibia broadens at the plateau. The foot, which has lost its prehensile function, serves to propel the body [1]. The arch of the foot, which is clearly present, helps absorb shocks during walking and provides additional impetus while walking or running.

The pelvis, the point at which the two lower limbs join with the spine, may be considered “the first vertebra or pelvic vertebra” as proposed by Dubousset [4]. The upright position of man has in fact resulted in the pelvis becoming an essential structure within the human motor apparatus, and its evolution required a compromise between two contradictory functions [3]: supporting the trunk and spine—for which a small, rigid, solid pelvis is needed—and allowing the passage during childbirth of a foetus whose head has considerably changed over time, and requiring a broader pelvis with maximum flexibility. In order to resolve this dilemma, the pelvis became vertical and broader. Vertical position: rather than being horizontal, as seen in quadrupeds (Fig. 2), in which it simply joins together the trunk and the posterior limbs, it became vertical. The sacral plateau became a pedestal, a base for the

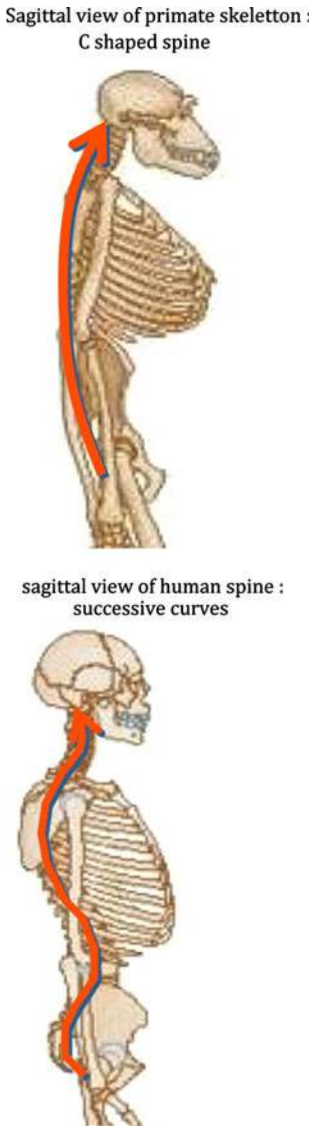


Fig. 3 **a** Primates have no lordosis. Sagittal view of primate skeletton: C shaped spine. **b** Humans have lumbar lordosis, thoracic kyphosis and cervical lordosis. Sagittal view of human spine: successive curves

spine. The position or spatial orientation of this base, which is more or less inclined forwards, dictates the position of fixation of the lumbar spine, and consequently of the entire vertebral column. The pelvis and iliac wings broadened to allow the insertion of long muscles with a considerable lever effect. However, the pelvis was broadened only enough to allow childbirth, and this pelvic broadening and upward turning required a considerable increase in the strength of the gluteal muscles [5]: the median gluteal muscle to ensure lateral stabilisation during walking and the major gluteal muscle to maintain the pelvis upright.

Fig. 4 Primates have a horizontal pelvis and no lordosis, and they use their upper limbs as counterbalances

Since the pelvis sits balanced on the hips, it is easy to see how the respective morphology and position of the hips, pelvis and trunk play a key role in the posture of the human body [6]. The frontal spinal position of the spine and pelvis is straightforward: the normal spine is vertical with a median axis that passes through the middle of the sacrum and the pubic symphysis (Fig. 5). The normal pelvis is horizontal, with symmetrical points at the same height. However, the geometry of the sagittal pelvic position is more complex.

To better understand sagittal balance, we must examine the position of the centre of gravity and of the line of gravity (Fig. 6). The line of gravity and the centre of gravity have been exhaustively studied by several authors [6–8] using a platform of force to generate a line representing the line of gravity and projected onto radiographic images comprising full-spine X-rays. This line of gravity is

Fig. 5 Projection of the gravity line on AP view is exactly between the two femoral heads

located frontally along a vertical line passing through the middle of the sacrum and perpendicular to the ground, and laterally through a vertical line situated slightly to the rear of the femoral heads [8]. In healthy asymptomatic subjects, this line of gravity is a result of a reaction between the ground and an ideal dynamic chain between the trunk, pelvis and lower limbs [7, 8] (Fig. 7). In most pathological settings, the centre of gravity is too far forward with a mechanical axis located in front of the femoral heads (Fig. 8). This type of situation is commonly seen in the event of abdominal hypertrophy, pregnancy, marked thoracic kyphosis (osteoporosis) not compensated by adequate lordosis, and above all, in major degenerative lumbar disc disease in elderly subjects [9]. Posterior imbalance is generally well tolerated since it is in part compensated by underlying thoracic kyphosis.

In practice, the position of the line of gravity is of major interest to the clinician, with the exact centre of gravity being of less concern. The centre of gravity in fact varies according to the position of the arms and of flexion of the trunk, and under normal circumstances, it is situated slightly in front of the sacrum [2], but the line of gravity represents the area of reaction with the ground and allows analysis of balance to be made [7, 8]. In order to resolve problems of spinal imbalance, particularly in the sagittal plane, it is essential to determine the position of the line of gravity. For a subject in equilibrium in an ergonomic position, this line must fall within the base of support as

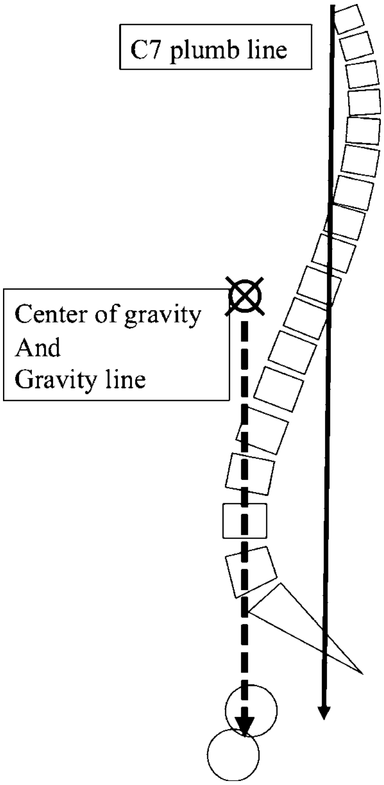


Fig. 6 The centre of gravity lies in front of the spine while the gravity line is vertical and passes through the femoral head. in a balanced spine C7 plumb line is always behind the gravity line

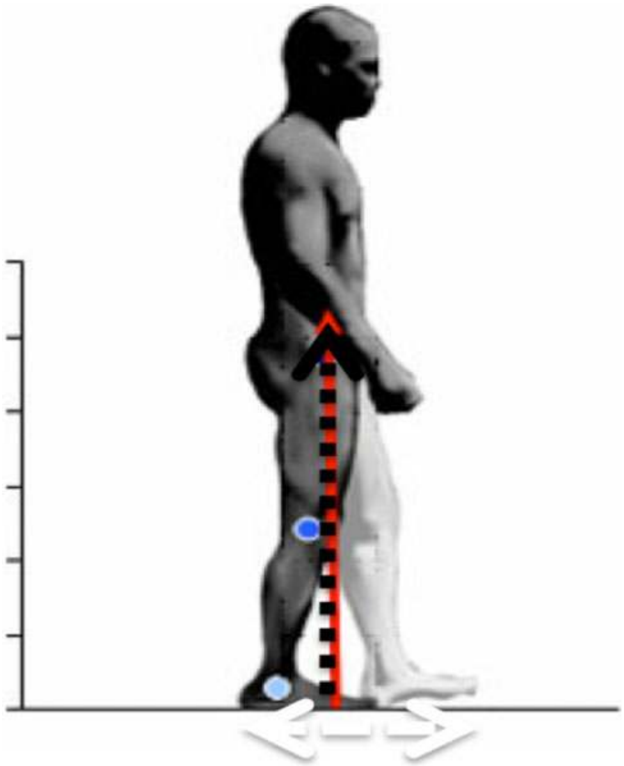
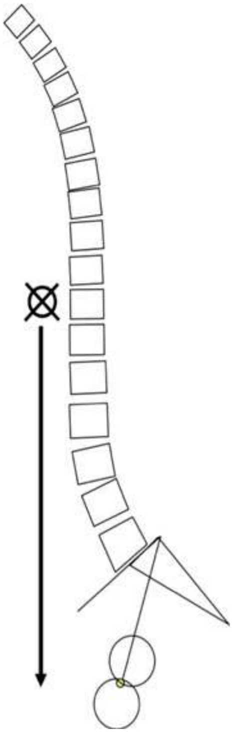


Fig. 7 The gravity line passes through the base of support if balance is adequate

Fig. 8 In pathological situation: the gravity falls in front of the femoral heads: this is an imbalance situation that will induce body reactions



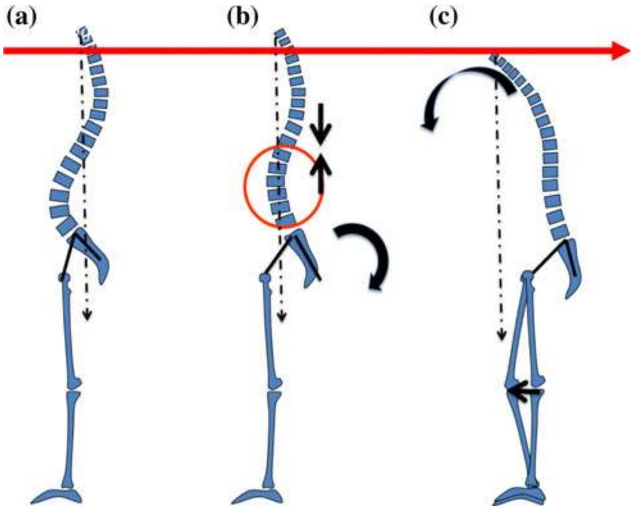


Fig. 9 Effect of aging or degenerative process on the sagittal balance of the spine from left to right side: **a** well balance spine, economical: C7 plumb line through S1 plateau **b** there is a progressive loss of disc height from **a** to **b**: inducing Compensation by retroversion of the pelvis (*arrow backtilt*) and post muscle contraction (*post arrow*) allow to keep the balance (C7 plumb line behind femoral head) until a certain limit. **c** If kyphosis is progressing, the pelvic retroversion has a limit and the patient flexes the knees to keep his balance (C7 plumb line passing through the base of support). This is not economical because he has to control quadriceps contraction, posterior spine muscles contractiion

defined by the position of the two feet on the ground (Fig. 7). When the line of gravity falls outside this base, compensation is required, and various mechanisms may come into play to correct any tendency towards forward imbalance:

- contraction of the posterior spinal muscles lifts the trunk vertically, requiring painful abnormal effort from the spinal muscles to prevent falling forwards (Fig. 9). Such pain may also be caused by excessive pressure on the posterior facets;
- retroversion of the pelvis around the femoral heads;
- hyperextension of the hips nevertheless has a limit known as the extension reserve, which is generally 10°;
- flexion of the knees in severe forms; controlled by the quadriceps.

Imaging systems are only rarely coupled with force platforms, and consequently the location of the line of gravity is not known when analysing X-rays, even those taken with the patient upright. CT scans and magnetic resonance imaging (MRI) images are obtained with the patient supine, with loss of information that may be provided by imaging systems in which the patient is in a vertical position. It thus appears essential to define parameters for indirect measurement of sagittal balance that allows detection of situations of pathological imbalance through analysis of X-rays of upright patients [8]. If we accept that the lower limbs must be laterally perpendicular to the knees, we must thus characterise the form and spatial orientation of the pelvis, which is the key area for transfer of load from the trunk [10]. Similarly, the spine, which forms the backbone of the trunk, must be analysed and characterised using parameters readily measurable on X-ray. It will then be necessary to establish a correlation first between these spinal and pelvic parameters and then between these parameters and the line of gravity [11–13].

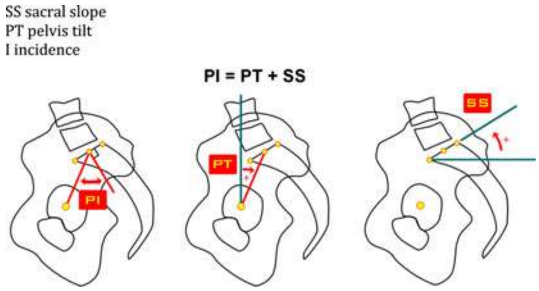


Fig. 10 Pelvic parameters: pelvis tilt, sacral slope, incidence angle. *SS* sacral slop, *PT* pelvis tilt and *I* incidence

Conclusion

All of the foregoing represents analysis of sagittal spinal balance. The principal parameters are as follows [14]:

- for the pelvis: incidence angle, pelvic tilt, sacral slope [5] (Fig. 10);
- for the spine: point of inflexion, apex of lumbar lordosis, lumbar lordosis, spinal tilt at C7, back type [15];
- for overall analysis: the spino-sacral angle (SSA), which is an intrinsic parameter [16].

Conflict of interest None.

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