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ORIGINAL ARTICLE

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Variability of the spine and pelvis location with respect to the gravity line: a three-dimensional stereoradiographic study using a force platform

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Abstract Analyzing standing posture requires a precise measure of the orientation of the various body segments with respect to the gravitational vector. We studied the posture variability of 34 healthy upright standing subjects. Using a force platform combined with a powerful stereoradiographic technique, we acquired the spine and pelvis three-dimensional (3D) geometry and located it with respect to the gravity line. For our data set, the mean 3D distance between the geometrical center of each vertebral body and the gravity line was 28 mm with a standard deviation of 5.6 mm. The vertebrae location variability, defined as plus or minus twice the mean standard deviation, was ±40 mm in the sagittal plane and ±25 mm in the frontal plane. The line connecting the middle of the external acoustic meatus (center of both acoustic meati: CAM) to the middle of the bi-coxofemoral axis (hip axis: HA) was almost vertical. Its mean distance to the gravity line was 30 mm. Our data show a left lateralization, with respect to the gravity line, of the "Head-Spine-Pelvis" segments. The mean distance was 7.6 mm (SD 1.6 mm). This might be due to uneven partitioning of the body mass on each side of the sagittal plane.

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Variabilité du positionnement de la colonne vertébrale et du pelvis par rapport à la ligne de gravité: étude tridimensionnelle par stéréoradiographie et plate-forme de force

Résumé L'étude de la posture nécessite la détermination de l'orientation des différents segments du corps par rapport au vecteur de la gravité. Le but de cette étude était de caractériser de manière tridimensionnelle la variabilité du positionnement de sujets sains par rapport à la ligne de gravité lorsque ces sujets sont placés en station érigée. Pour cela nous avons utilisé de manière combinée une technique de stéréoradiographie et une plate-forme de force. Ce dispositif nous a permis d'acquérir de manière tridimensionnelle et chez des sujets en charge la géométrie du rachis et du pelvis, ainsi que la position de la ligne de gravité du corps entier. La ligne de gravité se situait en moyenne à une distance 3D de 28±5,6 mm des centres géométriques des corps vertébraux. La variabilité de positionnement des vertèbres dans le plan sagittal par rapport à la ligne de gravité était de l'ordre de ±4 cm, et de ±2,5 cm dans le plan frontal. L'axe "Centre des méats acoustiques externes (CAM)—Centre des têtes fémorales (HA)" était sensiblement vertical, mais situé en avant de la ligne de gravité à une distance moyenne de 30 mm. Il existait dans notre série une latéralisation à gauche de l'ensemble "Tête-Rachis-Pelvis" par rapport à la ligne de gravité avec une distance moyenne de 7,6±1,6 mm. L'explication proposée est l'absence de symétrie absolue de répartition de la masse corporelle de part et d'autre du plan sagittal (masse hépatique à droite).

Keywords Posture · Gravity line · Spinopelvic alignment · 3D reconstruction · Stereoradiography

Introduction

Posture can be described as the composition of all body segment positions at a given point in time [38]. The upright standing posture is also the position with the smallest energy expenditure [4]. As in any clinical examination, studying postural abnormalities requires the definition of a reference posture. The gravity line (GL) is the vertical line through the whole body center of mass (COM). For an upright standing subject the reference posture is defined by the relation between the gravity line and the body segments.

The literature about GL location, whatever the method used to acquire the gravitational data, is mostly based on using lateral radiographs to compare the gravitational data with the spine and pelvis projection in the sagittal plane. Very few papers give data for the frontal plane. Some authors, such as Staffel [32], Bonne [6] and Kendall [18], have used a plumb line or a known rectangular grid on radiographic film as the vertical line reference. The missing COM horizontal position is empirically set by defining a point on a sagittal view or by a clinical description. Van Royen et al. [34] showed that using a plumb line leads to highly variable spinopelvic alignment data as a result of differences in knee flexion and hip extension. Braune and Fischer [7] used the inverted pendulum method to express the whole body COM position, or a body segment COM position, as a percentage of the segment length. Duval-Beaupère et al. [13, 21] characterized the upper body (above the hips) COM and the partial COM associated with each vertebral slice using a gamma ray scanner. Though this method yields 3D coordinates for each COM, data acquisition must be performed on subjects in supine position. When correlating the data with the upright standing lateral radiographs, the authors assumed that there is no modification of the body mass of each vertebral slice between the lying down and the standing up position. Finally, other groups have used a force platform to find the whole-body GL [28] or the upper body GL [19]. Force platform sensors deliver localized pressure data for standing subjects. None of these approaches gives 3D personal data for both the global and partial GLs and for the spinopelvic axis.

Stereoradiography is a method for spine and pelvis 3D reconstruction and modeling based on two standard lateral and frontal radiographs. Stereoradiography has been developed for several years by several groups [1, 11, 24, 27]. This technique provides the clinician with 3D information on the patient's spine and considerably reduces the irradiating dose compared with CT. However, most of the early developed stereoradiographic 3D reconstruction techniques [2, 9, 11, 15, 23, 27] are based on direct linear transformation (DLT) [1], meaning that they allow for the reconstruction of stereo-corresponding points only, i.e., those points for which the projection on both X-ray films is easily identifiable. A recent technique, developed at LBM (Laboratoire de Biomécanique, ENSAM Paris, headed by Profs. Lavaste and Skalli), in collaboration with LIO (Laboratoire en Imagerie Orthopédique, Montréal, under Prof. De Guise), allows for the 3D reconstruction of stereo-corresponding and non-stereo-corresponding points, i.e., a set of points for which the projection is visible on only one X-ray film. This technique is based on DLT and on the non-stereo-corresponding points (NSCP) algorithm [24, 36] that was tested on non-pathological cervical [36] and lumbar vertebrae [25] as well as on scoliotic vertebrae [26], proving a considerable improvement for the 3D reconstruction of the vertebrae compared with the DLT technique, by using more information contained in the X-ray film, i.e., anatomical landmarks that are seen on only one film. This 3D reconstruction method has recently been combined with force platform data analysis [8, 31].

The aim of the present study was to characterize, for 34 asymptomatic adult subjects, the variability of the head, spine, and pelvis position relative to the whole-body gravity line using stereoradiography combined with force platform data. This combined method yields 3D data for the relationship between the spinopelvic skeleton and the gravity line for upright standing subjects.

Material and methods

Subjects

This study was based on data gathered on 34 (18 women, 16 men) healthy adult volunteers without prior spine surgery or spinal disease, without spinal or pelvic abnormality, and without a history of back or hip pain. All volunteers provided informed consent for the use of their clinical data for research purposes. For the men, the mean age was 29.1 years (SD 8.5, min 19, max 48), the mean height was 1.82 m (SD 0.15, min 1.71, max 1.96) and the mean weight was 71.8 kg (SD 9.9, min 50, max 90). For the women, the mean age was 31.8 years (SD 10.2, min 21, max 53), the mean height was 1.65 m (SD 0.15, min 1.55, max 1.77) and the mean weight was 56.6 kg (SD 7.5, min 47, max 70).

Methods

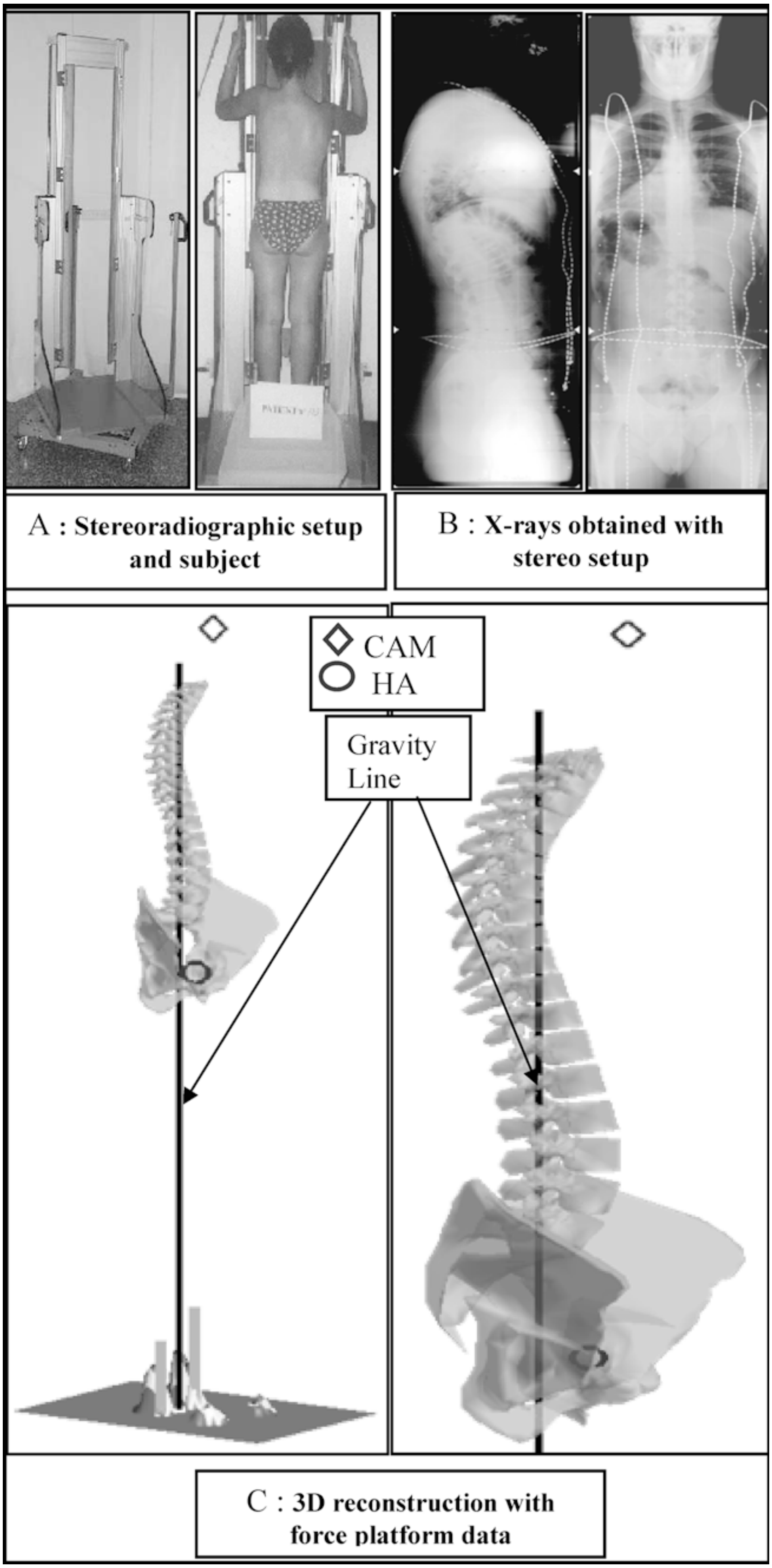
Data acquisition

Data were acquired in the orthopedic surgery department (Prof. J. M. Vital) of the Bordeaux CHU, France, using a specific stereoradiographic calibration setup combined with a force platform.

Radiographs

Two standard 30×90 cm radiographs were taken using orthogonal axes: a left-to-right standing lateral view and a postero-anterior view. With the subject standing in the stereoradiographic setup (Fig. 1A–B) [10], the base platform was rotated by 90° for the second view without the subject modifying his or her posture. The stereoradiographic setup had two vertical bars which let the subjects put their arms in a position showing the thoracic spine on the lateral view (between 30° and 60° forward). The bars contained radio-opaque markers which were projected onto the radiographs. As the 3D positions of the markers were known, we could compute the X-ray source positions and calibrate the radiographic environment. This calibration step is mandatory to compute a valid 3D reconstruction as it yields the scaling factors of the central perspective projection involved in the viewing process. One must also ensure that the two external acoustic meatus, the entire spine and the pelvis, and both hips, are visible on the two views.

Fig. 1A–C Technical reconstruction



Ground forces

During the radiography, we registered the pressure data of the feet using a Zebris® force platform with 32×47 compression sensors, each sensor having a 1 cm^2 area and a 1 N resolution. The force platform was located at the bottom of the stereoradiographic setup; its position relative to the setup base was computed by direct measurement so that we could identify the force platform coordinate system with the setup coordinate system. We checked that the XY plane for the final coordinate system was horizontal using a spirit level.

Radiography processing

The X-ray films were scanned using a Vidar® scanner. Taking as input the scanned radiographs we used specific software to reconstruct the spine and pelvis 3D model together with the hip axis position and the middle of the external acoustic meatus (CAM). The reconstruction software, developed by the LBM/LIO group, used the non-stereo-corresponding point technique (NSCP) [24]. Using this technique, we could not only reconstruct the 3D position of anatomical landmarks visible on both views, but also the 3D position of additional landmarks visible in only one view. On the radiographs the user digitized a landmark position on both views as a stereo pair or as a non-corresponding point in only one view. From that reconstruction an accurate geometric model of the vertebrae and pelvis was obtained. NSCP-based reconstruction accuracy has recently been evaluated by Mitulescu et al. [25, 26]. The difference between the NSCP stereoradiography reconstruction and the 3D reconstruction resulting from a CT scan using 1 mm cuts is 1.1 mm on average for non-deformed vertebrae.

Force platform data processing

The force platform output was used to find the pressure center position. The GL position was therefore the vertical line containing the pressure center. The GL position was expressed in the same 3D coordinate system as the one describing the vertebral positions, the hip axis (HA) and CAM, with an accuracy of ±5 mm [8].

Data analysis

A qualitative analysis could be performed on the 3D representation of the spinopelvic axis combined with the current GL. This 3D model could be viewed from any point in space (Fig. 1C). For each vertebra, for HA and for CAM, the spine position variability relative to the GL was numerically expressed by:

(1) The X and Y coordinates of the geometric center of each vertebra expressed in the following normalized coordinate system. Its origin was the center of pressure, its Z-axis was the upward-oriented GL, its Y-axis was parallel to the vertical plane containing the anterior superior iliac spines and right-to-left oriented, and its X-axis was orthogonal to the two other axes and back-to-front oriented (Fig. 2).

(2) The object center 3D distance to the GL defined as the shortest distance from the center of any reconstructed object (each vertebra or CAM or HA) to the GL and $D_{GL}=\sqrt{x_i^2+y_i^2}$.

Statistical processing was done with Statview® version 5.0 (SAS Institute, Cary, N.C.).

Results

Database

This clinical study provided 3D reference values for spine and pelvis localization relative to the GL. It also allowed us to compute many of the standard posture parameters adapted to our 3D model. These 3D parameters came from the 2D posture parameters described in the literature [5, 12, 13, 14, 16, 17, 20, 33]. We have computed values for 3D versions of: the spinal sagittal curvatures (kyphosis and lordosis), the anatomical pelvic parameters (pelvic incidence and thickness), and the spinopelvic alignment positional parameters (sacral slope, overhang, sacrofemoral tilting). In the present study, we focused only on the results for the vertebrae and the CAM-HA axis position relative to the GL. The 3D values of different spinal and pelvic parameters will be presented and discussed elsewhere.

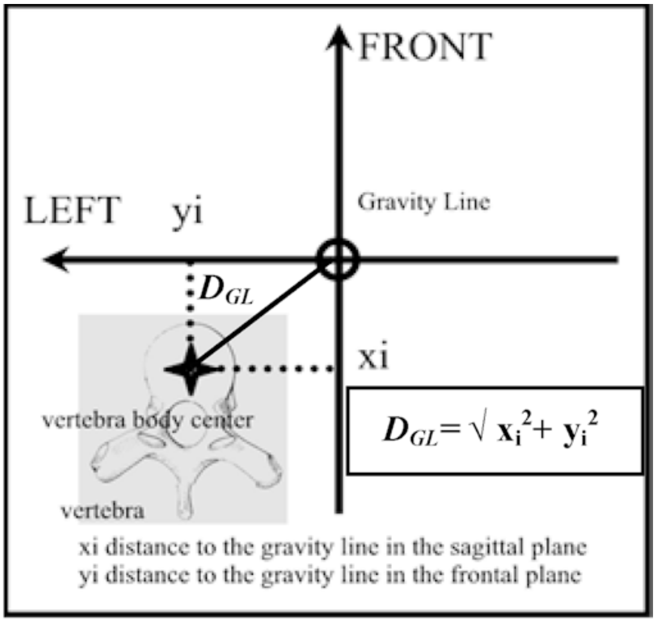


Fig. 2 Vertebral coordinates relative to the gravity line (GL). The origin is the center of pressure, the Z-axis is the upward-oriented GL, the Y-axis is right-to-left oriented, the X-axis is back-to-front oriented. A vertebra with a positive (or negative) xi coordinate is in front of (or behind) the GL. A vertebra with a positive (or negative) yi coordinate is to the left (or right) of the GL

Reconstructed vertebrae

All radiographs were processed and we were able to reconstruct most vertebrae for all subjects. On the sagittal views, T2 and T3 were often invisible because of the projection of the shoulders (Table 1). On the frontal views, the mandible projection prevented identification of C3 to C6.

Variability of the position of the head, spine, pelvis and hips relative to the GL

Table 1 contains the main numerical results for the 34 subjects. Fig. 3a shows the mean position of the vertebral geometric centers, of HA, and of CAM relative to

Table 1 Position of the vertebral body geometric centers, center of both acuoustic meatus (*CAM*), hip axis (*HA*) relative to the gravity line (*GL*). Main data for the 34 subjects. All values are in millimeters. The origin is the center of pressure, the Z-axis is the upward-oriented GL, theY-axis is right-to-left oriented, the X-axis is back-to-front oriented. The 3D distance is the length of the segment connecting the object geometric center to its orthogonal projection on the GL. Vertebrae with a positive (or negative) x_i coordinate are in front of (or behind) the GL. Vertebrae with a positive (or negative) y_i coordinate are to the left (or right) of the GL

Anatomic objects	No.of reconstructed objects	3D distance to the GL (D_{GL})				x_i: distance to the GL in the sagittal plane				y_i: distance to the GL in the frontal plane			
		Mean	SD	Max.	Min.	Mean	SD	Max.	Min.	Mean	SD	Max.	Min.
CAM	27	36	24	90	4	28	30	90	−20	9	13	33	−25
C7	32	27	17	70	6	13	27	69	−38	7	11	22	−29
T1	20	26	15	60	3	4	27	59	−43	6	12	22	−28
T2	8	24	14	48	2	−6	23	21	−48	10	13	31	−8
T3	14	29	13	56	5	−13	25	34	−56	12	11	33	−5
T4	26	31	17	67	3	−20	25	23	−65	10	13	33	−32
T5	29	33	19	77	6	−26	24	16	−76	8	12	31	−34
T6	33	34	20	83	3	−29	23	11	−82	7	12	30	−35
T7	34	35	20	88	1	−30	23	10	−87	7	12	29	−36
T8	34	34	20	87	1	−29	22	13	−86	8	12	28	−36
T9	34	32	18	81	3	−26	22	19	−81	8	12	29	−35
T10	34	29	17	72	4	−21	21	23	−72	8	12	29	−35
T11	34	26	14	62	2	−16	20	30	−62	8	12	30	−35
T12	34	23	11	50	7	−9	20	37	−50	8	12	32	−34
L1	34	21	10	43	3	1	18	42	−38	8	12	33	−35
L2	34	22	10	50	7	10	17	49	−26	7	13	34	−38
L3	34	26	11	53	12	18	16	53	−15	7	13	34	−40
L4	34	26	11	51	7	20	16	51	−14	7	12	34	−41
L5	34	21	10	42	8	13	15	41	−22	5	12	35	−39
S	34	17	10	39	4	6	15	33	−31	5	11	33	−38
HA	34	31	12	57	14	28	14	57	−13	6	11	32	−35

the GL. Fig. 3b is a 2D diagram showing the mean coordinates x_i and y_i for each vertebra, for CAM, and for HA. Fig. 4 shows the mean and SD for the D_{GL} of each reconstructed object.

3D distance between the vertebral centers and the GL (Table 1, Fig. 4)

The mean 3D distance between a vertebral geometric center and the GL, D_{GL}, equaled 28 mm (SD 5.6). The mean position variability for all vertebrae could be approximated by plus or minus twice the mean standard deviation: ±30 mm for our data. The sacral plate center appeared to be closest to the GL (mean 17 mm, SD 10). The head and the vertebrae at the top of the thoracic curvature had the largest variability.

Sagittal plane distance between the vertebral centers and the GL

The variability of the vertebrae geometric center position in the sagittal plane with respect to the GL increased in the caudo-cranial direction (Table 1). It could be approximated by plus or minus twice the mean standard deviation: ±40 mm for our data. On Fig. 3b, the x_i coordinates show the spine curvatures in the sagittal plane. L1 was closest to the GL in the sagittal plane, L4 was the most anterior, T7 was the most posterior, and T9 vertebral body center was 26 mm (SD 22) back to the GL. Over all objects, including CAM and HA, the mean sagittal coordinate was 4 mm (SD 20).

Frontal plane distance between the vertebral centers and the GL

The variability of the vertebral geometric center position in the frontal plane with respect to the GL was almost constant in the caudo-cranial direction (Table 1). It could be approximated by plus or minus twice the mean standard deviation: ±25 mm for our data. On Fig. 3b, the y_i coordinates show the spine curvatures in the frontal plane. There was a slight thoracic curvature centered on T3 and T4. In our data, the spine and the pelvis were not aligned with the GL in the frontal plane. The vertebrae, CAM and HA, were lateralized to the left of the GL with a mean frontal distance of 7.6 mm (SD 1.6). This lateralization increased in the caudo-cranial direction. T3 was the most left-lateralized vertebra; L5 and the sacral plate were the least left-lateralized objects.

CAM-HA axis

In the sagittal plane, the GL lay behind the middle of the femoral heads, at a mean distance of 28 mm (SD 14) (Fig. 3b). For the 27 subjects whose external acoustic

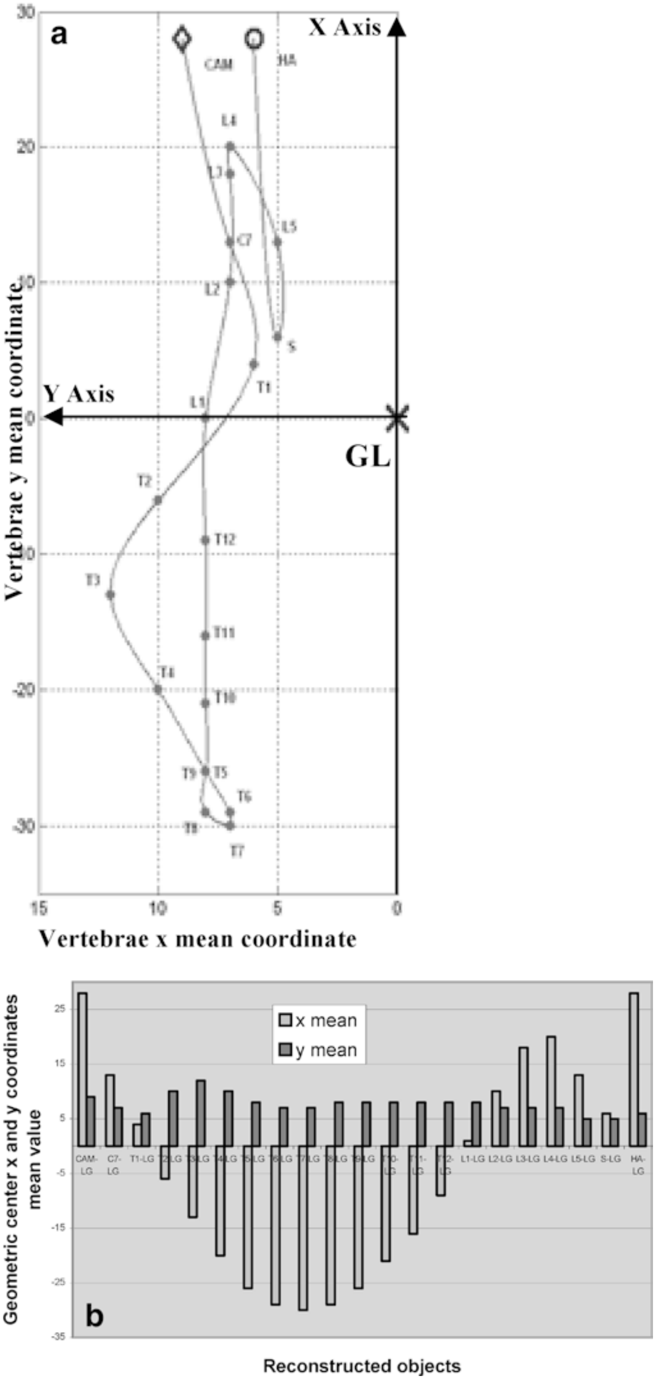


Fig. 3a,b **a** Mean position of the vertebral body geometric centers relative to the GL. Values are in millimeters. The origin is the center of pressure, the Z-axis is the upward-oriented GL, the Y-axis is right-to-left oriented, the X-axis is back-to-front oriented. A vertebra with a positive (or negative) xi coordinate is in front of (or behind) the GL. A vertebra with a positive (or negative) yi coordinate is to the left (or right) of the GL. **b** Sagittal curvatures and spine and pelvis lateralization. Values are in millimeters. A vertebra with a positive (or negative) xi coordinate is in front of (or behind) the GL. A vertebra with a positive (or negative) yi coordinate is to the left (or right) of the GL

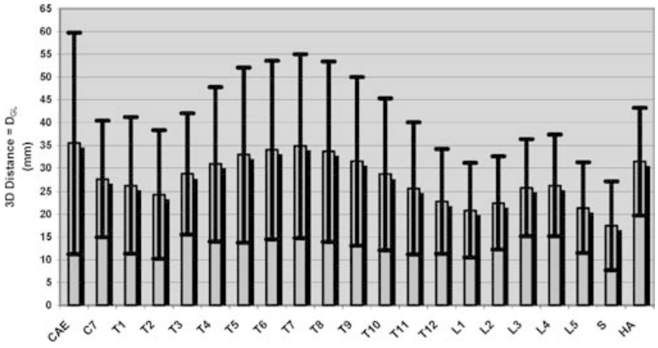


Fig. 4 Three-dimensional distances between the vertebral body geometric centers, center of both acoustic meati (CAM), hip axis (HA) and the GL. Mean and SD values (mm) for 34 subjects

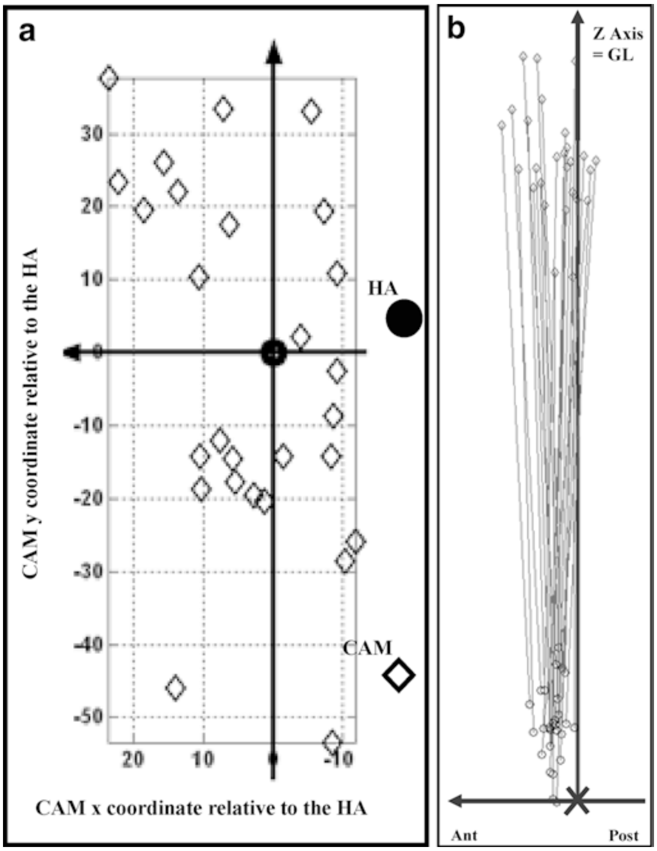


Fig. 5a,b **a** CAM position relative to the HA for all subjects. Values are in millimeters. We use the main coordinate system translated to the HA, the Y-axis is right-to-left oriented, the X-axis is back-to-front oriented. A CAM with a positive (or negative) x coordinate is in front of (or behind) the HA. A CAM with a positive (or negative) y coordinate is to the left (or right) of the HA. **b** Global sagittal view of CAM-HA lines in the normalized coordinate system. Left side view. *Diamonds* correspond to CAM; *circles* correspond to HA

meatus could be digitized, Fig. 5a and b show the distribution of CAM relative to HA. The CAM-HA axis was almost always in front of the GL with a mean sagittal distance of 30 mm. This axis was slightly slanted, either down and forward or down and backward.

Discussion

Measurement setup limitations

The subject position in the stereoradiography setup was as close as possible to physiological posture. However, because of the 90° rotation implied by the two views, we modified the standard arm position to limit the space used by the arms in the setup while making sure the thoracic spine remained visible on the lateral view. The reference upright standing posture for lateral radiographs, as described by Stagnara et al. [33], positions the subject's arms in front of the pubis with the hands lying on a stand. Vedantam et al. [35] have shown that, for symptomatic patients with no previous spinal fusion, there is no difference between positioning the arms at 90° versus 30° when measuring the sagittal vertical alignment with a plumb line. Therefore, we think that the difference between the position used in this study and the reference position has a very small influence on the parameter values. Moreover, to avoid subtracting any pressure from the force platform the subjects were instructed to avoid leaning their forearms on the vertical poles.

Our analysis is static. First, we assumed that the subject position remained unchanged between the two views. As this was not strictly true in practice, the 3D reconstruction obtained in this study mixed 2D information coming from the two radiographs. Second, the pressure measurement was static, and we could therefore use the fact that the center of pressure on the force platform is the projection of the center of mass [40].

Nevertheless, the quantitative results of previous studies showed that the NSCP-based 3D reconstruction technique allowed a considerable improvement in accuracy of stereoradiographic reconstruction compared with techniques based only on stereo corresponding points, i.e., for non-deformed vertebrae mean error equaled 1.1 mm [25] for the NSCP-based reconstructions versus 2.6 mm [3] and 2.4 mm [25] for the DLT-based reconstructions, while for scoliotic vertebrae mean error equaled 1.5 mm [26]. Similar results (mean error 1.1 mm) were obtained by Dumas et al. [10], who used a slightly modified protocol, i.e., the calibration object was different from that used by Aubin et al. and by Mitulescu et al. For the present study we used the same X-ray acquisition and calibration protocol as the one described by Dumas et al. We therefore consider that the accuracy of our reconstructions is comparable to the one obtained in their study.

Variability analysis

Our results show a large variability of the spine configuration with respect to the gravity line (Fig. 6a–c). We

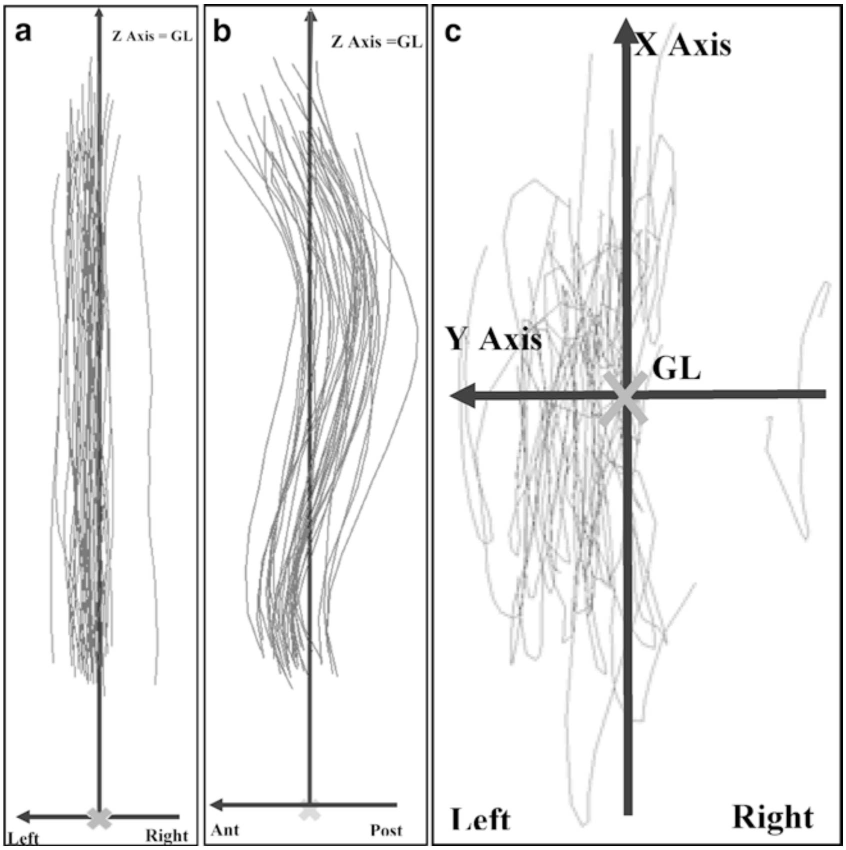


Fig. 6a–c **a** Global frontal view of spinal lines in the normalized coordinate system. Back-to-front view. **b** Global sagittal view of spinal lines in the normalized coordinate system. Left side view. **c** Global axial view of spinal lines in the normalized coordinate system. Top view

did not find any 3D values in the literature; however, our results for the sagittal and frontal values agree with the published results. The gravity line was slightly more posterior than the plumb-line-based clinical descriptions done by Staffel [32], Bonne [6] and Kendall [18]. Likewise, Roussouly et al. [29], using a force platform, located the GL at 8 mm (SD 13.5) behind the bi-femoral head axis with a front maximum of 37 mm and a back maximum of 21 mm. Our results indicate a more posterior position; only one subject had a GL in front of the femoral heads.

Some authors have provided results for the upper body gravitational parameters. Even if we assume that the lower limbs are symmetrical with respect to the sagittal plane, we cannot conclude that the projection of the whole-body center of mass is the same as the projection of the center of mass for the body above the hips. The published results, available only for the sagittal plane, and our study show that these two projections are very close to each other. Duval-Beaupère et al. [13] and Legaye et al. [21], using a baricentremeter, positioned the center of mass supported by the hip joints (GF) in front of T9 in most cases. They reported a (GF–anterior side of T9 vertebra) mean sagittal distance of 15 mm (SD 10.9, max 31, min 0). In our case, the whole-body GL was at the same position in front of T9. Furthermore the whole-body GL position with respect to HA found by our study was the same as the upper-body position reported by these authors (mean 35 mm, SD 10.87).

Legaye et al. [21] studied the momentum of the gravitational forces for the lumbar vertebrae. The projection of the partial center of mass was always behind the lumbar vertebrae bodies. Therefore, balance is reached with a small contraction of the anterior muscles. The posterior position of the partial GL, correlated with electromyographic data [13], agrees with an economic standing posture.

Klausen and Rasmussen [19] characterized the upper body GL with subjects immersed up to the hips using X-rays and a force platform. When there was no action potential in the rectus abdominis and erector spinae muscles, the upper body GL was located 30 mm to the back of the L4-L5 disk center. Without considering the electromyographic data, the GL was located 15 mm to the back of the L4-L5 disk center. This last value is close to the one we found, even though we have characterized the whole body GL (Table 1).

CAM-HA axis

In the literature, the CAM-HA axis is used to describe the body balance axis, mostly for sagittal plane studies. Marnay [22] reported studies by Strasse and Fick which describe a vertical reference axis containing: the femoral heads, the L5-S1 disk center, the upper body center of mass, the C7-D1 disk center, and the external acoustic meati. Marnay [22] preferred to define an "antero-posterior equilibrium physiological space" defined on sagittal X-rays by two verticals, one through S2 and the other through the HA. Vital [37] positioned the head COM above and slightly in front of the external acoustic meatus projection in the sagittal plane. Characterizing the CAM-HA axis is therefore the same as localizing the head COM with respect to the HA. In our study, the CAM-HA axis was not exactly vertical and almost always in front of the whole-body GL at a sagittal mean distance of 30 mm. We conclude that, though the CAM-HA axis is a good candidate for the clinical and radiological evaluation of the sagittal balance, it does not coincide with the GL.

Spine and pelvis axis lateralization

Our results show a left lateralization, relative to the GL, of the head, spine and pelvis segments (Fig. 6a). Duval-Beaupère et al. [13] found no lateralization but Klausen and Rasmussen [19], characterizing the upper body GL, found a lateralization with a value close to our results: the L4-L5 disk center is to the left of the upper body GL, at a mean distance of 6.5 mm (SD 1.5). In our study, the force platform data analysis shows an asymmetric repartitioning of the ground pressure which is higher for the left plantar contact. This result agrees with posturographic studies for asymptomatic teenagers [30, 39]. In our opinion, the presence of the hepatic mass on the right side of the body could explain the left lateralization we found. Given the measurement precision for the GL, it seems that the lack of absolute symmetry with respect to the sagittal plane for the body mass generates a posture with a slight left lateralization of the head, spine and pelvis axis relative to the GL. Everything happens as though the subject modifies his or her posture in order to center the hepatic mass above his or her positional base.

Clinical application

The spinal curvatures are currently analyzed in routine clinics, especially when dealing with kyphotic and scoliotic deformities. Means of analysis are currently limited to standard plane radiographs. Nevertheless, new technologies such as stereoradiography develop very fast and will probably allow 3D reconstruction of the spine on a regular basis in the near future. Efficient interpretation of 3D analyses of spinal curvatures as well as any other 3D spinal and/or pelvic parameters will require a database of physiological 3D values for healthy subjects. Also, the GL in the frontal plane, which is one of the issues addressed in the present study, has been described only very briefly in the literature. In this context, we consider that the results of studies such as the present one will be of paramount importance in clinical applications on a routine basis when dealing with spinal pathologies altering balance and posture.

Conclusion

Stereoradiography combined with force platform data can be used for 3D posture characterization, allowing for the description of body segments orientation with respect to the gravity vector. In this study we have given reference values for asymptomatic adults. The head, vertebral, and pelvis locations show a large 3D variability. The results show a left lateralization, relative to the gravity line, of the head, spine and pelvis segments. Future work will investigate the correlation between the head, spine and pelvic 3D locations and the anatomical and positional spinopelvic parameters.

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