Sagittal spine posture assessment: Feasibility of a protocol based on intersegmental moments

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Accepted: 8 December 2011

KEYWORDS  
Postural balance; Spine; Intersegmental moments; Biomechanics

Summary  
Evaluation of spinal posture has recently benefited from the contribution of three-dimensional reconstruction technologies that have helped improve our understanding of this dynamic balance. The aim of this study was to present the preliminary results of a three-dimensional protocol to analyze postural balance. This analytical method is not limited by certain constraints of the radiological approach and evaluates postural balance using a new approach taking into account the net efforts of different intersegmental centers. These preliminary results show the technical feasibility of the protocol. Its future development and clinical use could provide a better understanding of postural balance disorders, and help evaluate the impact of surgical correction on spinal balance.

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Introduction

The role and importance of sagittal alignment of the spine have been extensively described in the literature. The key parameters are numerous and include both pelvic and spinal reference points [1]. These analyses of sagittal alignment have shown the close relationship between spinopelvic parameters which constitute a chain of relationships between the lower limbs and the spine, centered in the pelvis, defined by Dubousset as a veritable pelvic vertebra [2], and the regulator of sagittal balance. In asymptomatic subjects, this chain of relationships corresponds to a balanced position in which the vertical axis at C7 passes above the pelvis, with harmonious sagittal curves and lordosis proportional to pelvic incidence. On the other hand, during aging process, this balance may become disturbed resulting in lumbar lordosis (which is no longer proportional to pelvic incidence) causing anterior tilting of the trunk.
This increase in thoracic kyphosis generates compensatory mechanisms in the form of pelvic retroversion (increase in pelvic tilt) to try to return the sagittal vertical axis of C7 above the pelvis [3]. A comparable situation can be found in patients with sagittal malalignment in whom the increase in anterior tilt and the loss in potential hip extension (pelvic retroversion) will result in a progressive handicap.

Nevertheless, these studies have usually been performed with standard two-dimensional X-rays and the recent development of imaging systems allowing three-dimensional reconstructions of the entire spine [4,5] has improved understanding of these complex postural mechanisms. Significant differences in results have been reported in the literature between 2D and 3D analyses with a force platform [6,7]. Nevertheless, there are certain limitations inherent in these evaluations. First, sagittal balance and postural balance are dynamic elements which involve numerous permanent reciprocal interactions, and X-ray views must comply with several parameters to obtain a high-quality image.

Thus, to obtain a lateral X-ray in certain patients, in particular as they age (Fig. 1), they must be placed in a specific position which involves a significant change in their customary posture. As a result, analysis of the image obtained does not correspond to the natural postural balance, which is specific for each patient [8]. This is particularly true in subjects presenting with degenerative kyphosis which places the subject in maximum lordosis when the image is taken or in childhood high-grade spondylolisthesis in which there is an overall forward tilt of the trunk [9].

The usual gold standard when quantifying postural balance is solely based on two-dimensional angular and linear measurements [3,10,11]. Nevertheless, evaluation of postural balance can be imagined using other parameters correlated to data from stereoradiographic sequences combined with a force platform and those provided by motion analysis laboratories during a freestanding posture. With the help of optoelectronic markers and a force platform, this new approach could quantify the force of external efforts in the different intersegmental centers. It would then be possible to characterize postural balance in terms of effort, and analyze the variability over time as well as describe any possible differences between natural posture and that imposed to obtain X-rays.

The aim of this study was to present the feasibility of a protocol analysis to characterize three-dimensional postural balance in a patient in a freestanding posture.

**Materials and methods**

This pilot study was performed in a healthy 30-year-old male subject (1m80, 80 kg) at the Laboratoire d’Évaluation du Mouvement (Movement Evaluation Laboratory) at our institution. All measurements were obtained using an optoelectronic system Vicon (Vicon, Oxford, UK) with six high-resolution cameras with infrared light and a sampling frequency of 100Hz which recorded the position of passive retroreflective markers and two force platforms (AKTI, USA). This protocol included all the markers necessary to obtain parameters of a standing posture and to calculate the force of external efforts in the different intersegmental centers. The choice was based on the studies by Dumas et al. [12] and Wu et al. [13,14] drafted from the recommendations of the International society of biomechanics.

The location of markers was chosen to characterize the centres of mass of the body segments based on easily palpable anatomical landmarks. This group of markers was used to define a model with ten body segments (head, thorax, abdomen, pelvis as well as both thighs, legs and feet) then net effort exerted at the different intersegmental centers was calculated. Markers were placed by an operator who was experienced in identifying the cutaneous landmarks defined as follows (Fig. 2):

- on the cephalic segment: vertex, sellion and the two tragi;
- on the thoracic segment: right and left acromia, manubrium sterni and the anterior side of the xiphoid process. On the spine the markers were positioned on the spinous processes of C7, T8 and T12, as well as the so-called mid-thoracic marker on T6 which was used to characterize the thoracic curve;
- on the lumbar segment: the lumbar segment was characterized by placing markers on segments above and below (T12 and S1), thus defining the thoracolumbar (T12-L1 center) and lumbosacral junctions (L5–S1 center). An additional so-called mid-lumbar marker was placed on L3 to define the lumbar curve;
- for the pelvis: a sacral marker (in the middle of the segment connecting the two posterior superior iliac spines) and a marker on each of the anterior superior iliac spines;
- on the “thigh” segments: the greater trochanter and the lateral and medial femoral condyles on each of the legs;
- on the “leg” segments: the head of the fibula, the anterior tibial tubercle and the lateral and medial malleolus on each of the legs;
• on the "foot" segment: calcaneum and the heads of the 1st and 5th metatarsals on each side.

Once the markers had been positioned the subject was told to stand freely, with no restraint or external support. The subject was standing with his arms along his body, looking forward, with both feet on the force platform. A series of four sequences of several seconds were recorded without changing the position of the markers and with a break of several minutes between each, during which the subject was told to walk freely around the laboratory.

Based on the 3D reconstruction from the coordinates of the markers, the net effort of the intersegmental centers could be obtained for each joining moment of the sequence. The calculations could be broken down into five steps which are briefly described below (Fig. 3):

• determination of intersegmental centers based on marker coordinates, according to the protocol described by Dumas et al. [12];
• determination of segment lengths based on the distances between the intersegmental centers;
• calculation of masses, coordinates of the centers of mass and body segment inertial parameters based on the weight and height of the subject as well as mean general anthropomorphic data according to Dumas et al. [12];
• calculation of segment reference points according to the protocol described by Wu et al. [13, 14];
• calculation of the net effort between each body segment based on effort measured on the ground by force plates (one for each foot). This calculation was obtained using an ascending method for the intersegmental centers representing the ankles, knees, hips as well as for the lumbar (L5–S1 center), thoracolumbar (T12–L1 center) and cervicothoracic (C7–T1 center) junctions; a descending method was used for the C7–T1 junction (which only takes into account the weight of the head from anthropomorphic data).

In this preliminary study because of the importance of the sagittal plane as described in the literature, only data characterizing sagittal alignment were taken into account.

Results

The clinical feasibility of the new protocol was considered satisfactory with 15 minutes to equip the subject with all the markers. The mean intersegmental moments for 1 sec of recording for the four trials of the healthy volunteer showed:
Table 1 Summary of the calculated moments (in N.m) based on the analysis on the volunteer.

<table>
<thead>
<tr>
<th></th>
<th>CT</th>
<th>TL</th>
<th>LS</th>
<th>LH</th>
<th>LK</th>
<th>LA</th>
<th>RH</th>
<th>RK</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>-0.39</td>
<td>-6.34</td>
<td>-0.59</td>
<td>14.56</td>
<td>-5.43</td>
<td>-9.44</td>
<td>11.82</td>
<td>-3.44</td>
<td>-10.04</td>
</tr>
<tr>
<td>Trial 2</td>
<td>-0.61</td>
<td>-10.56</td>
<td>-0.73</td>
<td>11.21</td>
<td>-3.64</td>
<td>-10.88</td>
<td>12.83</td>
<td>-6.05</td>
<td>-9.52</td>
</tr>
<tr>
<td>Trial 3</td>
<td>-0.66</td>
<td>-6.04</td>
<td>-0.47</td>
<td>17.65</td>
<td>-3.25</td>
<td>-8.57</td>
<td>14.56</td>
<td>-3.01</td>
<td>-10.04</td>
</tr>
<tr>
<td>Trial 4</td>
<td>-0.56</td>
<td>-4.83</td>
<td>-1.35</td>
<td>16.80</td>
<td>-8.27</td>
<td>-10.46</td>
<td>13.23</td>
<td>-5.73</td>
<td>-12.31</td>
</tr>
</tbody>
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- a mean intersegmental moment of $-9.8 \text{ N.m}$ for the left ankle (LA) and $-10.5 \text{ N.m}$ for the right ankle (RA);
- a mean intersegmental moment of $-5.2 \text{ N.m}$ for the left knee (LK) and $-4.6 \text{ N.m}$ for the right knee (RK);
- a mean intersegmental moment of $15.1 \text{ N.m}$ for the left hip (LH) and $13.1 \text{ N.m}$ for the right hip (RH);
- the mean intersegmental moments for the spine were $-0.78 \text{ N.m}$ at the lumbosacral junction (LS), $-6.9 \text{ N.m}$ at the thoracolumbar junction (TL) and $-0.55 \text{ N.m}$ at the cervicothoracic junction (CT).

All of the data are summarized in Fig. 4 and Table 1.

Clinical interpretation of the results obtained for each of the intersegmental centers shows a movement of dorsal flexion in the ankles, flexion in the knee and pelvic retroversion in the hip-pelvic complex while flexion movements are found in the different spinal junctions (Fig. 5).

Discussion

At present, evaluation of sagittal alignment of the spine is usually obtained by two-dimensional radiographs which provide measurement of the main spinopelvic parameters. Thus, description of sagittal alignment is based on geometric values which translate angular or linear measurements between bone reference points. The approach of this new protocol analysis for spinal balance, based on parameters other than traditional parameters of sagittal alignment, has been shown to be feasible in a Movement Evaluation Laboratory using a group of markers and information from force platforms. The preliminary results are encouraging because the moments from the intersegmental centers of the lower limbs and the spinal junctions can be calculated automatically. It is therefore possible to visualize the moments of the different intersegmental centers that are necessary to maintain postural balance. These results show the efforts necessary during standing, with overall flexion of all intersegmental moments counterbalanced by muscular action in the hip-pelvic complex as the key element, creating plantar flexion in the ankle, extension of the knee, pelvic anteverision and extension of the trunk by erector spinae muscles that pull the body back to maintain the center of gravity above the support polygon.

Nevertheless, there are inherent limitations to the use of these cutaneous markers that may be some distance from reference bones in particular in the case of voluminous subcutaneous tissue which may cause measurement errors [15]. Additional studies are necessary to develop and validate this method. First, a precise evaluation of intrinsic error and measurement variability will be determined using the methodology by Schwartz et al. [16]. During this essential step, markers will be placed on two healthy volunteers and
the standing posture will be analyzed by three different operators in three different sessions over time.

After validation, healthy volunteers could be studied to define normal net effort values in the different intersegmental centers and physiologically tolerable moments for each body segment. These in vivo measurements in a population of volunteers could illustrate the dynamic character of postural balance and the presence of reciprocal compensation among the body segments resulting in transitory modifications in the efforts made. It will also be possible to evaluate any changes and compensatory postural mechanisms in pre- and post-operative sequences after management of different spinal disorders.

At the same time we are also developing a more clinical version of this approach by associating a simultaneous stereoradiographic EOS® sequence (markers in place) associated with recording of ground reaction forces generated by a plantar pressure sensor. Comparison of these data will provide various elements: first, it will be possible to radiologically confirm correct placement of the markers on the subject, but especially, significant differences between the “radiologically imposed posture” and a free-standing posture can be investigated in relation to moments in the intersegmental centers.

The long-term goals also seem promising. In fact, in vivo characterization of postural balance in terms of the effort of different intersegmental centers has different clinical applications. For example analysis of strains adjacent to a long spinal fusion, the consequences of a discl lumbo sacral arthroplasty or an analysis of reciprocal reactions between the spine and the legs on one hand and the “pelvic vertebrae” on the other would then be possible. In the same way, knowledge of intersegmental efforts allows indirect analysis of all the different groups of muscles involved in maintaining posture.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgements

This study was possible thanks to the financial support of the principle investigator by the Société Francaise de Chirurgie Orthopédique et Traumatologique (SOFCOT).

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