Innovative Spine Posture Analysis for Low Back Pain Diagnosis

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Purpose

Low back pain (LBP) is a major cause of disability among the working population of the industrial world for many reasons: about 80% will be affected, it’s 2nd common reason for seeing a family physician [1] [2], it’s responsible for most lost workdays and disability claims [3], and consequently has a significant socioeconomic impact. At present at most third of individuals with chronic LBP have diagnosis (pain due to specific causes) [4]; most cases are non-specific, which complicates considerably decision making regarding precocious steps (including surgery) and appropriate treatment. Although spine curvature and posture are accepted by many clinicians as important to sustain healthy back [5], spine curvature is difficult to measure and most methods are insufficiently accurate to be reliable, making curvature analysis and its connection to LBP enigmatic.

Posture Analysis Techniques

![Posture Analysis Techniques Diagram](image)

**Fig. 1:** Evaluation of sagittal spinal curvature in 2D images. (a) Modified Cobb method; (b) Ishihara index; (c) Polynomial angle; (d) TRALL method; (e) Posterior tangents;

**References:** - Aviel/IL

Several manual and automated techniques are available for quantitative analysis of spine curvature, most of them using spine imaging such as X-ray imaging, CT or MRI. The Cobb technique #[6] is the most established method for quantifying spinal curvature. But the Cobb technique is known to have poor sensitivity and large inter and intra observer variability, making it insensitive small posture deviations, and acceptable for detection.
of large deviations. Over the years new methods (fig. 1) for measuring the degree of spinal deformity were proposed, e.g. [8], [9] (see [7] for review of spinal curvature evaluation methods). But most posture analysis methods, Cobb method among them, suffers from few fundamental limitations: they are 2D measurements relying on a 2D plane, ignorant to the 3D structure and susceptible to problems of the 2D plane definition; the measurements are derived from bone features making them prone to errors due to bone variations (e.g. osteophytes); the definitions of feature elements are based on bony structures which are prone to variations (e.g. curvy end plate for Cobb angle, osteoporosis) causing significant variability in feature identification, resulting in large inter and intra observer variability and increased measurement error; measurements result are one or few characteristics, oversimplifying the curvature structure, and missing important deviations. Few 3D curve analysis methods exist (e.g. [10]), but these methods are simple extension of 2D measurements to 3D (e.g. computing Cobb angle on 2 planes). To date, we don't know of a spine curve analysis method that is capable to discover 3D curve deviation and of both large scale (e.g. lumbar) and small scale (e.g. single vertebra). Clinicians would also desire such method to be fast, requiring minimal user interaction (preferably automated), and as sensitive as the current methods.

Purpose

To establish a reliable method for analyzing spine curvature in 3D, and detection its deviations from the norm, using CT imaging.

To overcome current methods drawbacks, spine curvature analysis method should be: capable to discover deviation of the curve of both large scale (at least over several vertebrae - few cm) and small scale (span of single vertebra or disk - few mm); as sensitive as the current methods (Cobb angle measurement); preferably an automated method requiring minimal user interaction, and preferably fast to allow seamless workflow.

Methodological approach

The proposed method is based on two innovative concepts:

- spine curvature analysis is derived from centerline of the spinal canal.
- posture evaluation is based on comparison of the curve against a statistical model of individuals without spine problems.
**Fig. 1:** Evaluation of sagittal spinal curvature in 2D images. (a) Modified Cobb method; (b) Ishihara index; (c) Polynomial angle; (d) TRALL method; (e) Posterior tangents;
Methods and Materials

Spine Curve Analysis

To satisfy the requirements presented above, our method applies few original concepts: the spine curvature analysis is based on the centerline of the spinal canal extracted using a new automated algorithm, and individual's curve evaluation is performed by comparison of the curve against a statistical curve model (model curve and its variability) based on curves of individuals without spine problems.

Fig. 2: The spine curve assessment framework steps The framework steps shown from left to right: steps 1-3 (colored blue) are spinal canal segmentation algorithms parts; Step 4 (purple) is curve extraction; Next, step 5, building curve model (light green); Final step 6 - patient (scan) specific curve evaluation (dark green).

References: - Aviel/IL

Curve extraction has two steps: (1) Automatic segmentation of spine canal - an original two step segmentation process (coarse and fast morphological region growing followed by accurate 3D active surface segmentation) for fast and accurate segmentation (2) Curve extraction - using centerline calculation of spinal canal by minimal path algorithm the segmented canal.

For curve evaluation we created statistical population model (divided to gender and age cohorts) from healthy individuals (no LBP history) curves extracted as described. The mean model curve, its percentiles, and standard deviation were calculated. Evaluation is performed by comparing individual's curve to the model curve using distance
measurement. Curve’s distance is compared to model statistics, so if curve deviates from the model’s 95% percentile, is defined as abnormal.

**Validation**

We did both algorithmically and clinically validation for this assessment method. The algorithms (segmentation and curve extraction) were validated against manual canal and curve extraction using 24 scans showing small error compared to manual results, in terms of intra observer error. As clinical validation we compared diagnosis to Cobb angle measurement of the 33 individuals (20 normal and 13 with scoliosis), showing sensitivity of 100% for a test group of individuals with scoliosis.

**Clinical Data**

The research is based on data of individual that underwent abdominal CT scans (covering the entire lumbar spine and sacrum), all conducted at the radiology department of Carmel Medical Center. The research has received Helsinki approval of Carmel Medical Center committee. The exclusion criteria (to assure no clinical findings that may directly or indirectly affect their posture): trauma to the abdomen or pelvis, posture problems (e.g. scoliosis), osteoporosis, metabolic problems, diabetes, and cancer or autoimmune diseases.

The CT data used was scanned on a Philips Brilliance 64 slice CT scanner using abdominal protocols. For all scans used the patients were laying on the back in supine position, without a pillow underneath the knees. Scan parameters: voxel size in-plane 0.5-1.0mm, slice increment 0.9-1.5mm, and slice thickness of 0.9-3.0mm. All scans had image plane of 512x512 voxels with varying number of slices (250-700).

The posture analysis was conducted using 211 CT scan of the abdomen of 211 individuals. The participants were split into two groups (Table 1): A-symptomatic (158 individuals) - individuals that didn’t report LBP lasting more than 3 months; and Symptomatic (53 individuals) - individuals reported to had LBP in the past 6 months with non-specific cause, and no other clinical condition that could impact the analysis.

**Control group - Individuals without Back Problems**

The control group includes 158 individuals with average age of 42.2±14.9. The group consisted of 81 males and 77 females (divided by gender), 82 young individuals (age less than 40 years old) and 76 old individuals (divided by age cohort).
Study group - Individuals with Non Specific Low Back Pain

The study group consisted of 53 individuals which had low back pain without any known cause. The group average age was 57.6± 14.3, where the youngest individual was 21 years old and the oldest 76 years old. The study group consisted of 30 males and 23 females (divided by gender), or 20 young individuals (age less than 40 years old) and 33 old individuals (divided by age cohort).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Group</th>
<th>Low Back Pain Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>N=158</td>
<td>N=53</td>
</tr>
<tr>
<td>Age (years)</td>
<td>21-84</td>
<td>21-76</td>
</tr>
<tr>
<td>Male</td>
<td>N=81</td>
<td>N=30</td>
</tr>
<tr>
<td>Female</td>
<td>N=77</td>
<td>N=23</td>
</tr>
</tbody>
</table>

**Table 1:** Study and Control groups

Images for this section:

![Image of spine curve assessment framework steps](image)

**Fig. 2:** The spine curve assessment framework steps The framework steps shown from left to right: steps 1-3 (colored blue) are spinal canal segmentation algorithms parts; Step 4 (purple) is curve extraction; Next, step 5, building curve model (light green); Final step 6 - patient (scan) specific curve evaluation (dark green).
Results

As described above, the lumbar spine curve of each individual was extracted from the CT scan data and assessed against the model of the same age group and gender. The comparison is set of distance measurements between same points along the individual and model curves. These distance measurement values are compared to the model statistics (population percentiles of distance statistics). Curves are defined as abnormal or deviating from the norm if one or more distance measure is greater than the 95% percentile. We describe the results for the population without back problems compared to the population with non-specific low back pain.

Population without Back Problems

We compared each curve of the healthy population to the model using "leave one out" method (i.e. for each curve assessed, it was excluded from the model). Results of curve deviations are given in Table 2, as well as the number and percentage of individuals exhibiting spine curve deviation per sub group.

<table>
<thead>
<tr>
<th>Group Type</th>
<th>Males &lt;= 40 age</th>
<th>Males &gt; 40 age</th>
<th>Females &lt;= 40 age</th>
<th>Females &gt; 40 age</th>
<th>All Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individuals</td>
<td>43</td>
<td>38</td>
<td>39</td>
<td>38</td>
<td>158</td>
</tr>
<tr>
<td>Curve Deviations</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Percentage</td>
<td>9.3%</td>
<td>7.9%</td>
<td>5.3%</td>
<td>7.9%</td>
<td>7.6%</td>
</tr>
</tbody>
</table>

Table 2: Prevalence of deviated spinal curve among the non-LBP population, by age and gender

Population with Non Specific Low Back Pain

We compared each curve of the LBP group to the appropriate model, taking into account the gender and age of the individual. We then checked if there were any deviations of the curve from the 95 percentiles of the general population model. We present three examples of spinal curves deviations found among individuals with LBP: mild scoliosis (Figure 3), hyper lordosis (Figure 4), and flat back (Figure 5).
Fig. 3: Spinal lumbar curve of LBP patient showing slight scoliosis Spinal lumbar curve of a male age 53 with non-specific LBP, shown in coronal plane. The individual’s curve is shown in pink and the appropriate models’ curve in black with 50, 75 and 95 percentiles lines in dashed red, blue and green respectively. The graphs are shown using 1:1 scale (left) as well as unscaled (right) to emphasize the differences. This individual’s curve shows slight scoliosis.

References: - Aviel/IL
Fig. 4: Spinal lumbar curve of LBP patient showing hyper lordosis. Spinal lumbar curve of a male age 59 with LBP with no specific cause, shown in sagittal plane. The individual's curve is shown in pink and the appropriate models' curve in black. The graphs are shown using correct scale (left) as well as unscaled (right) to emphasize the differences. This individual's curve shows hyper lordosis.

References: - Aviel/IL
Fig. 5: Spinal lumbar curve of LBP patient showing flat back. Spinal lumbar curve of a female age 23 with low back pain with no specific cause, shown in sagittal plane. The individual's curve is shown in pink and the appropriate models curve in black. The graphs are shown using correct scale (left) as well as unscaled (right) to emphasize the differences. This individual's curve shows flat back.

References: - Aviel/IL

The results of number of individuals with curve deviations found by the curve analysis method are given in Table 3. For this non-specific LBP group spine curve deviations were exhibited in almost 1/3 of the individuals (32.1%). There was higher percentage of deviations in the older population than the younger population (25% vs. above 33%), but no significant difference between gender.

<table>
<thead>
<tr>
<th>Group Type</th>
<th>Males &lt;= 40 age</th>
<th>Males &gt; 40 age</th>
<th>Females &lt;= 40 age</th>
<th>Females &gt; 40 age</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individuals</td>
<td>12</td>
<td>18</td>
<td>8</td>
<td>15</td>
<td>53</td>
</tr>
<tr>
<td>Curve Deviations</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>percentage</td>
<td>25.0%</td>
<td>38.9%</td>
<td>25.0%</td>
<td>33.3%</td>
<td>32.1%</td>
</tr>
</tbody>
</table>
Table 3: Prevalence of deviated spinal curve among the LBP population, by age and gender.

Deviation Comparison

Significant association (\#2=19.972, df=1, p<0.001) was found between non-specific low back pain and spinal deformity (Table 4). While among the non-specific LBP group, almost one third of the individuals manifested deformed spine (of one type or another), among the healthy population, about 7.5% of the individuals had a curve deviating from the norm.

<table>
<thead>
<tr>
<th>group</th>
<th>LBP</th>
<th>Abnormal curve</th>
<th>Normal curve</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>17</td>
<td>36</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>% within group</td>
<td>32.1%</td>
<td>67.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>% within deform</td>
<td>58.6%</td>
<td>19.8%</td>
<td>25.1%</td>
</tr>
<tr>
<td>Control</td>
<td>Count</td>
<td>12</td>
<td>146</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>% within group</td>
<td>7.6%</td>
<td>92.4%</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>% within deform</td>
<td>41.4%</td>
<td>80.2%</td>
<td>74.9%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>29</td>
<td>182</td>
<td>211</td>
</tr>
<tr>
<td></td>
<td>% within group</td>
<td>13.7%</td>
<td>86.3%</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>% within deform</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

P value: P< 0.001

Table 4: Association between LBP and spinal deformation

Images for this section:
Fig. 3: Spinal lumbar curve of LBP patient showing slight scoliosis. Spinal lumbar curve of a male age 53 with non-specific LBP, shown in coronal plane. The individual's curve is shown in pink and the appropriate models' curve in black with 50, 75 and 95 percentiles lines in dashed red, blue and green respectively. The graphs are shown using 1:1 scale (left) as well as unscaled (right) to emphasize the differences. This individual's curve shows slight scoliosis.
Fig. 4: Spinal lumbar curve of LBP patient showing hyper lordosis. Spinal lumbar curve of a male age 59 with LBP with no specific cause, shown in sagittal plane. The individual's curve is shown in pink and the appropriate models' curve in black. The graphs are shown using correct scale (left) as well as unscaled (right) to emphasize the differences. This individual's curve shows hyper lordosis.
Fig. 5: Spinal lumbar curve of LBP patient showing flat back Spinal lumbar curve of a female age 23 with low back pain with no specific cause, shown in sagittal plane. The individual's curve is shown in pink and the appropriate models curve in black. The graphs are shown using correct scale (left) as well as unscaled (right) to emphasize the differences. This individual's curve shows flat back.
Conclusion

In the current study we present a new method for assessing spines' curve. Furthermore, we demonstrate its usefulness for spine analysis and LBP diagnosis, as we show statistically significant association between LBP and spinal curve deviations, which we believe can improve LBP diagnosis and treatment.

Our New spine posture analysis method overcomes many of the drawbacks of previous curve assessment methods as it employs several new concepts: the analysis is 3 dimensional; it examines the entire curve (and not curve characteristics); the curve is computed using the spinal canal and not bone features, and the assessment is carried out against a statistical model derived from the general population (gender and age are taken into consideration).

The comparison of individuals without LBP and with non-specific LBP shows statistically significant association between LBP and spinal curve deviations, which we believe can improve LBP diagnosis and treatment. Using our new spine curve analysis method, we have found that among the non-specific LBP group, almost one third (32.1%) of the individuals, manifested deformed spine (of one type or another). Furthermore, the analysis also provides the exact location of the deviation and the type of deviation (e.g. hyper-lordosis, mild scoliosis). This information can significantly improve the diagnosis of low back pain and allow treatment to patients with non-specific LBP.

References


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