Learning-based coronal spine alignment prediction using smartphone-acquired scoliosis radiograph images

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Introduction: Current digital alignment assessment tools

Manual alignment analysis product
- Surgimap, X-Align, Integrated Global Alignment, etc.

Automated alignment analysis tools (no product available)
- Conventional imaging process-based methods and disadvantages
  - Heterogeneous patterns of deformities
  - X-rays having high variance
  - Limited accuracy\(^1\)\(^2\) with original high-resolution images

- AI integrated methods and disadvantages
  - Semi-automated\(^3\)
  - Automated (CV convenient but not mimic clinicians)
    - Direct regress CA\(^4\) cannot guarantee what has been learnt
    - Indirect regress CA\(^5\) still without intermediate supervision
    - CNN alignment detections\(^6,\)\(^7\)
    - All used original high-resolution X-rays but often generated low accuracies (~10° errors)

References:
1. R. Kundu, et al, "Cobb angle measurement of scoliosis with reduced variability"  
2. J. Zhang, et al, "Automatic Cobb measurement of scoliosis based on fuzzy Hough transform with vertebral shape prior"  
6. F. Galbusera et al., "Fully automated radiological analysis of spinal disorders and deformities: a deep learning approach"  
Aim and Objectives

Aim

• Provide reliable and easily accessible automated vertebral landmark detection irrespective of image quality.

Objectives

1. Establish a reliable deep learning-based method to accurately detect vertebral landmarks, including endplates and end vertebrae.
2. Eliminate previous restrictions of automatic coronal alignment on curve patterns or imaging quality by training the model using non-original X-rays of various image quality and different curve patterns.
Method: Handy Auto-alignment using a Mobile App

A: Image acquisition

B: Cobb angles and landmarks

C: Clinical relevance of Cobb angles

<table>
<thead>
<tr>
<th>CAs range</th>
<th>Severity and clinical managements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°-20°</td>
<td>Normal - Mild</td>
</tr>
<tr>
<td></td>
<td>No specific interventions required, but for cases with a curve between 10°-20°, follow-ups may be required for every two years.</td>
</tr>
<tr>
<td>21°-40°</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Conservative management would be suggested, with no invasive procedures, including brace wearing and scoliosis specific exercises.</td>
</tr>
<tr>
<td>&gt;41°</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Surgeries maybe required to correct the spine deformity</td>
</tr>
</tbody>
</table>
Method: SpineHRNet

Standardised data acquisition – **Key anatomy landmark detection** – Pattern computation

The AI Server is located at the **Department of Orthopaedics and Traumatology, Hong Kong**

A. **Send to AI server for Auto-analysis**

B. **SpineHRNet** automated landmark detection of the endplates and detection of the end vertebrae with the angles calculated during the inference stage
Results: dataset is not balanced

Figure 1: Frequency of each vertebra to be chosen as an end vertebra

Table 1: Summary of the ground truth CAs

<table>
<thead>
<tr>
<th>Curves</th>
<th>Number of curves</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAC</td>
<td>97</td>
<td>12.95°</td>
<td>67.77°</td>
<td>28.98°</td>
<td>12.78°</td>
</tr>
<tr>
<td>CAT</td>
<td>268</td>
<td>10.73°</td>
<td>82.48°</td>
<td>29.35°</td>
<td>14.45°</td>
</tr>
<tr>
<td>CAL</td>
<td>212</td>
<td>10.08°</td>
<td>75.16°</td>
<td>24.7°</td>
<td>11.66°</td>
</tr>
<tr>
<td>CA total</td>
<td>577</td>
<td>10.08°</td>
<td>82.48°</td>
<td>27.55°</td>
<td>13.41°</td>
</tr>
</tbody>
</table>
Results: landmarks detections are accurate

Green points = the ground truth (GT) landmarks  Blue points = the predicted landmarks
Red lines connecting predicted landmark and corresponding GT landmark

Retrieval rate
99± 0.9 %
L2 error
2.8 pixels
Results: end vertebrae detections are data driven

Figure 1. Examples of end vertebrae detection

Table 1. Evaluation metrics on CA prediction

<table>
<thead>
<tr>
<th>Curves</th>
<th>Recall</th>
<th>Precision</th>
<th>F1-score</th>
<th>Angle error</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAC</td>
<td>0.62</td>
<td>0.78</td>
<td>0.69</td>
<td>4.09°</td>
<td>3.35°</td>
</tr>
<tr>
<td>CAT</td>
<td>0.88</td>
<td>0.88</td>
<td>0.88</td>
<td>4.48°</td>
<td>3.32°</td>
</tr>
<tr>
<td>CAL</td>
<td>0.83</td>
<td>0.80</td>
<td>0.82</td>
<td>3.73°</td>
<td>3.64°</td>
</tr>
<tr>
<td>CA total</td>
<td>0.82</td>
<td>0.83</td>
<td>0.83</td>
<td>4.15°</td>
<td>3.11°</td>
</tr>
</tbody>
</table>

- A: CAC and CAT
- B: CAT and CAL angle
- C: normal with no curves;
- D: CAC and CAT and CAL angle.

For each part
- (1) the ground truth heatmap
- (2) predicted heatmap
- (3) original image merged with predicted heatmap

An interesting false negative in the cervicothoracic region was shown in D.
Results: reliability assessment results are data driven

Figure 1: Regression analysis of the predictions

<table>
<thead>
<tr>
<th>Curves</th>
<th>R²</th>
<th>p value</th>
<th>Slope of the regression line</th>
<th>Standard error of the measurement (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAC</td>
<td>0.787</td>
<td>&lt;0.01</td>
<td>38°</td>
<td>1.742°</td>
</tr>
<tr>
<td>CAT</td>
<td>0.832</td>
<td>&lt;0.01</td>
<td>42°</td>
<td>0.856°</td>
</tr>
<tr>
<td>CAL</td>
<td>0.839</td>
<td>&lt;0.01</td>
<td>42°</td>
<td>0.802°</td>
</tr>
<tr>
<td>CA total</td>
<td>0.833</td>
<td>&lt;0.001</td>
<td>42°</td>
<td>0.558°</td>
</tr>
</tbody>
</table>

Figure 2: Bland-Altman comparing the agreement of CAs between the predictions & GT
Clinical relevance key points

1) SpineHRNet enables fully automated coronal alignment analysis with no limitations of the curve patterns using smartphones.
2) Our free mobile app can be used to provide consistent and fast coronal alignment analysis results for large clinical trials and may facilitate out of hospital consultation.
3) Visualisations of the vertebral landmarks provide interpretable CA predictions and the specialists can thus easily confirm the detection accuracy.