SpinalTracking: An Application to Help Track Spinal Deformities

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Abstract. The human vertebral column (HVC) comprises specialized tissues and structures that allow it to support body weight with an extensive range of movement and protect the spinal cord, which is essential for routine activities. HVC deformities are highly prevalent in individuals over 65, affecting between 32% and 68% of this population, and represent a public health problem with a profound impact on society. Physicians evaluate and monitor HVC deformities in practice by physical examination and analyzing imaging tests. In this context, the SpinalTracking App was developed to enable specialists to manually or automatically measure the Cobb angle in X-ray images of the spine of patients with scoliosis, using image processing and deep learning techniques. The measurements provided by the app are stored so that treatment can be monitored. The application obtained a Pearson correlation of 0.94 and 0.92 for the calculation made with the manual measurement functionalities and an average correlation of 0.74 for the automatic calculation. This demonstrated the potential use of SpinalTracking as a tool for measuring and controlling the evolution of each patient's scoliosis deviation.

Keywords: SpinalTracking · Mobile App · Cobb angle · Scoliosis

1 Introduction

The spine is a critical mechanism for balancing and supporting the body. The three essential functions of the spine are to absorb load, allow movement, and protect the spinal cord. The anatomy of the spine is perfectly adapted to provide these functions. The spine consists of seven cervical vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, five fused sacral vertebrae, and three to four coccygeal segments, also fused. The spine seen from the front, in the frontal plane, is generally straight and symmetrical. In the sagittal plane, there are four physiological curves. These are anteriorly convex curves (lordosis) in the cervical and lumbar regions and posteriorly convex curves (kyphosis) in the thoracic and sacrococcygeal regions. The mechanical explanation for these physiological curves would be that they allow for greater flexibility and an increased capacity

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to absorb loads while the intervertebral joints adequately maintain strength and stability [13].

Scoliosis affects between 2–3% of the population [2]. In scoliotic spine, the number and segmentation of the vertebrae are the same as in the normal spine. However, the column is no longer straight in the frontal plane. Instead, they are lateral curves, typically right convex in the thoracic region and left convex in the thoracolumbar and lumbar region [18]. This postural deviation is diagnosed by checking image exams by measuring the Cobb angle. The curve is measured using the position of the end/transitional vertebrae. The end vertebra are the upper and lowermost vertebrae which are the least displaced from the midline and the most severely tilted. A line is drawn along the superior (top) endplate of the top end vertebra, and a second line is drawn along the inferior (bottom) end plate of the bottom end vertebra. The angle formed by these two lines (or the lines drawn perpendicular to them) is the Cobb angle [17]. Treatment is related to the degree of deviation that the deformity may present in relation to the normal formation of the spine, and can be corrected or mitigated through treatments such as physiotherapy sessions, use of braces or, in more serious cases, surgical correction.

Given the need for health professionals to work in locations with different infrastructures, the creation of applications for mobile devices aimed at the health area can be considered a tool to help specialists carry out examinations and obtain a diagnosis for each patient. Based on this perspective, this study aimed to develop an application to measure the Cobb angle in X-ray spine images. This method is used to measure the magnitude of spinal deformities and monitor the development of the problem.

The app has three functions for measuring Cobb's angle, the first by obtaining the inclination of the smartphone, captured by the phone's accelerometer, a function developed based on analysis of measurements made in works such as [6, 16], the other by manipulating lines in an image provided by the user and the last by automatic calculation using deep learning and image processing techniques. This application stands out because it combines three functions in just one application, allows patients to be registered, and stores the measurement data for each patient, enabling the development of the deformity to be monitored using the stored exams. The application can also be used in Portuguese or English, depending on the language settings of the device used by the user.

2 Related Work

Several applications are designed to calculate the Cobb angle using X-ray images, including Scodiac, Scoliogauge, and Tiltmeter. Scodiac was developed to measure deformities of the spine and trunk, calculate the Cobb angle and vertebral rotation. The Scoliogauge, available on the App Store, was evaluated by [6], comparing the measurement made by the Scoliogauge with that of the standard scoliometer, concluding that the measurements showed corresponding results. The Tiltmeter, also developed for the iPhone and evaluated by [16], collects the inclination of the device using the accelerometer. When the specialist positions the smartphone on the X-ray, the inclination captured calculates the Cobb angle on the upper and lower vertebrae chosen. The assessment carried out on the Tiltmeter depends on the direct intervention of the specialist.

Many studies have been conducted to calculate Cobb's angle automatically by providing the X-ray image and obtaining the angles found. In [7], the vertebrae were located, and then the landmarks were detected, consisting of passing the X-ray to the vertebrae detection network and then calculating the landmarks using a DenseNet, followed by the calculation of the angles. The work in [4] details the steps involved in segmenting the X-ray image, recognizing the corners of each vertebra, and then calculating the Cobb angle.

A three-step method was proposed in [8]. The first finds the centroids of each vertebra using Centroid-Net, the second applies M-net to find the inclination of each vertebra, and finally, the Cobb angle is calculated. In [5] two networks were used. The first focused on segmenting the spine, and the second was developed to extract the center line of the spine using the results of the first network, with post-processing to estimate the Cobb angles. The method developed in [11] was used as the basis for the automatic calculation functionality developed in the App proposed in this study.

In summary, SpinalTracking stands out from other available applications as it combines three methods for calculating the Cobb angle in a single app: through accelerometer data, manual line marking, and automatic measurement. Additionally, it enables the storage of examination results, allowing professionals to track the progression of each patient's deformity.

3 Materials and Method

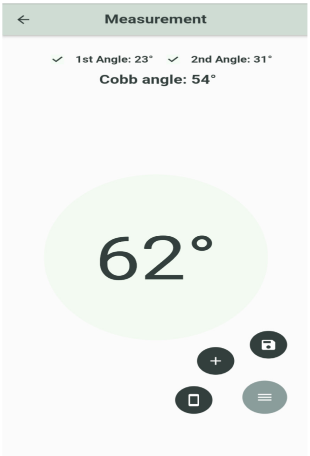
The specialist usually measures the Cobb angle using an X-ray of the spine, choosing the vertebrae that delimit the curvature to be measured and drawing two lines, one passing through the upper limit of the upper vertebra and the other through the lower limit of the lower vertebra. A goniometer is usually used to calculate the angle formed by the lines and thus obtain the Cobb angle. The result of this measurement is used to monitor the progression or containment of the deformity. However, it is only sometimes convenient to keep the X-rays for analysis by a specialist, as the examination may deteriorate or be lost over time. As a result, the use of applications that make it possible to store the image of the examinations carried out is becoming increasingly indispensable.

The SpinalTracking app was developed to provide specialists with a more practical way of measuring Cobb's angle, which has three measurement functions: by tilting the cell phone positioned on the x-ray (function 1), by marking the upper and lower vertebrae on the scan provided to the App (function 2) and automatic marking (function 3). All measurements are stored in the App, so it is possible to track each patient's history.

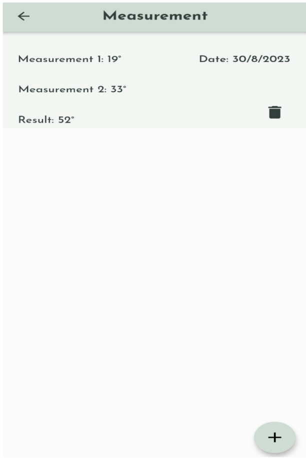
Functionalities 1 and 2 were developed based on the traditional examination method, requiring the specialist to analyze and choose the vertebrae to be used for the measurement. For functionality 3, simply sending the x-ray to the application is enough to calculate the angles.

3.1 Measurement by Tilting the Cell Phone on the X-Ray Image

Considering the conventional measurement, functionality 1 simulates the marking of lines by positioning the handset on the vertebrae selected in the x-ray examination. This mode allows the calculation to be based on the inclination of the cell phone about the x-ray. The data obtained from the accelerometer integrated within the phone is utilized to attain the measurement, and the Cobb angle is calculated by utilizing the inclinations obtained. Figure 1 shows the screens for measuring and checking the saved result.



(a) Measurement screen

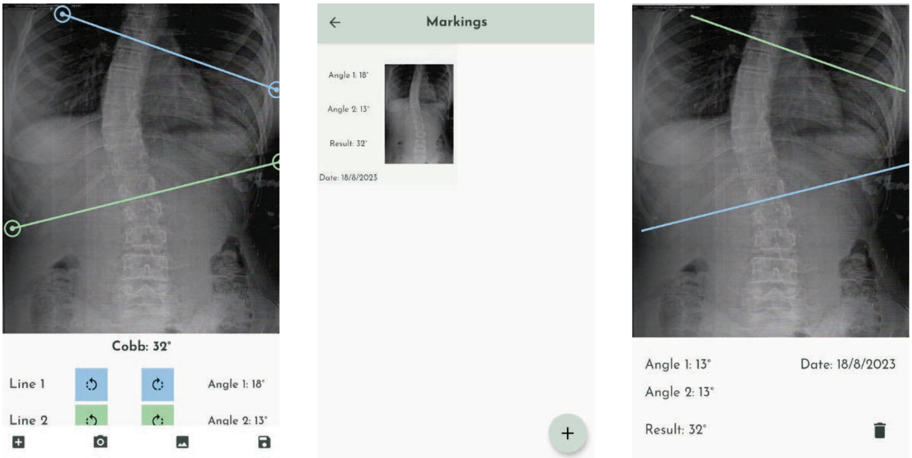


(b) Result preview screen

Fig. 1. Screens for measuring the Cobb angle by capturing the inclination of the cell phone in relation to the X-ray.

3.2 Measurement Through the Vertebrae Markings on the X-Ray

This method has the same procedure as traditional measurement: the professional makes the markings on the x-ray image provided to the application, and the calculation is made by the application using the Cobb method, followed by the storage of both the image and the measurement result. Figure 2a shows the marking made with the lines on the exam provided, Fig. 2b shows the saved exam in reduced form, and Fig. 2c shows the saved exam expanded.



(a) Measurement screen (b) List of exams (c) Result preview screen

Fig. 2. Cobb angle measurement screens by demarcating the vertebrae in the X-ray provided to the application.

3.3 Automated Measurement

The development of the automatic measurement was divided into two stages: searching for automatic calculation methods and creating the API that processes the X-ray.

Firstly, some methods developed to estimate Cobb angles were analyzed. The method proposed in [11] was used as a basis among the works found. This method was chosen because it is feasible to implement in the API and has good results for the estimated angles.

The method uses image processing and deep learning techniques to calculate Cobb angles, consisting of:

Segmentation: A network based on the U-net [14] was used to segment the spine's vertebrae. The network takes a 128×256 resized x-ray image as input and uses 3×3 convolution layers with an ELU [3] activation function and dropout. Four hundred eighty-one images from the [19] database were used for training, with augmentation being performed for 200 epochs, using Tversky loss [15] as the loss function. Figure 3 shows the network architecture and operations.

Post-processing: The mask resulting from the segmentation goes through the noise removal process. At this stage, morphological transformations were used to remove some noise. The Watershed [1] method was used to delimit the structures present in the mask, followed by calculating the areas of these elements to check and remove components that had an area smaller than the threshold used.

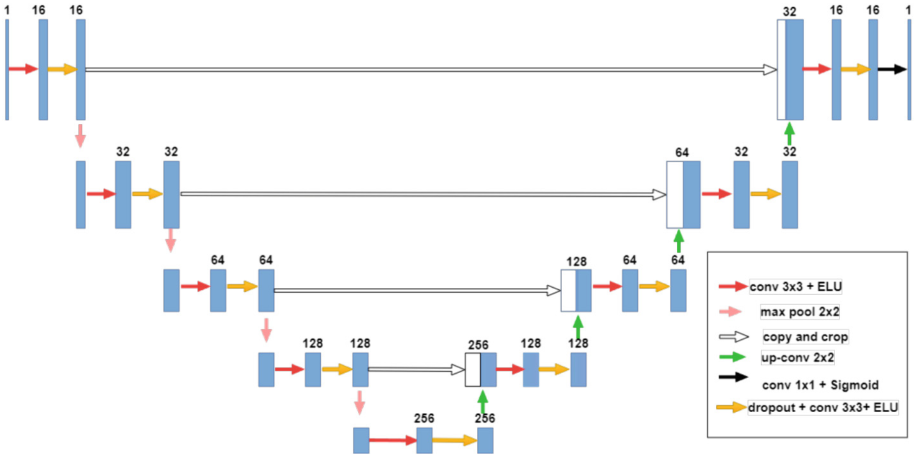


Fig. 3. Modified U-net network architecture

Calculation of Cobb's Angle: To calculate the Cobb angle, the centroids of each vertebra are found with regionprops algorithm through the centroids property, then the contours finding perimeter and fit minimum bounding rectangle, and finally, the four corners of each vertebra, extracting points on the top and bottom endplates. The four corners of each vertebra in the post-processed mask (endplates) and the centroids are used as input for the Cobb angle calculation algorithm. Finally, the result is three angles, corresponding to the PT (proximal thoracic), MT (main thoracic), and TL/L (thoracolumbar or lumbar) regions, the vertebrae that are the apex and the location of the angles.

To calculate each of the angles, the inclinations found for the selected upper and lower vertebrae are used, employing the following calculation:

$$|arctan(slopesup) - arctan(slopeinf)| \tag{1}$$

For the post-processing and Cobb angle calculation steps, the scripts were initially implemented in Matlab [12] and transcribed into Python using the necessary libraries for later implementation in the API. The steps described are shown in Fig. 4.

The method is designed to interpret standing anteroposterior radiographs and is available at [10].

The API was developed to process and analyze the image the App will send in the automatic calculation exam. The application performs the following sequence of actions: it receives the x-ray image sent by the App, processes it, and returns to the application the segmented image with the markings of the vertebrae selected by the method, as well as the value of each angle calculated. The process in question is shown in Fig. 5.

The screens corresponding to sending the x-ray and storing the markings and angles obtained as a result of the automatic calculation are shown in Fig. 6.

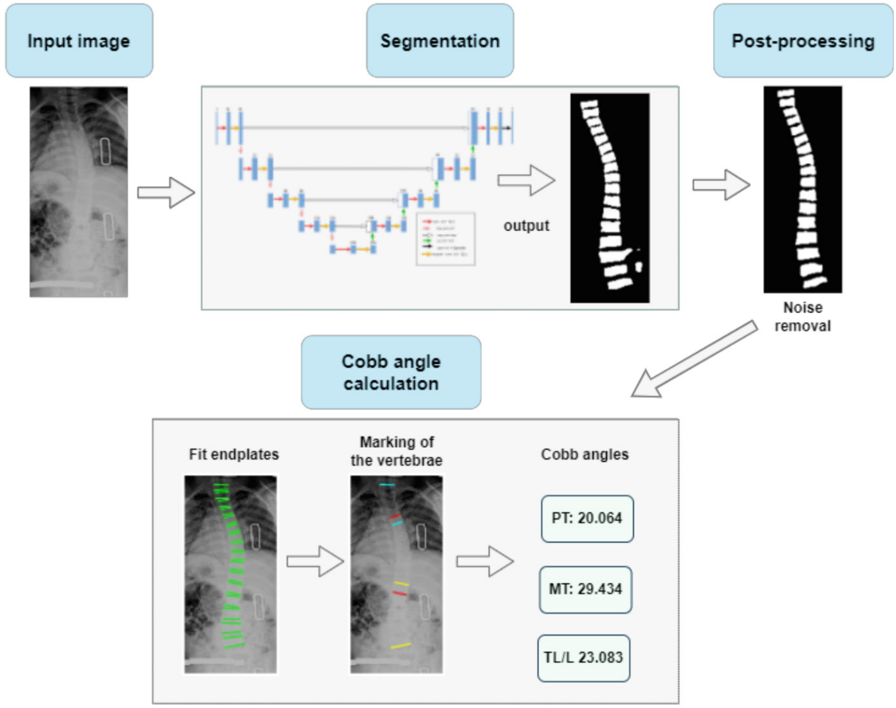


Fig. 4. Steps of the automatic calculation method.

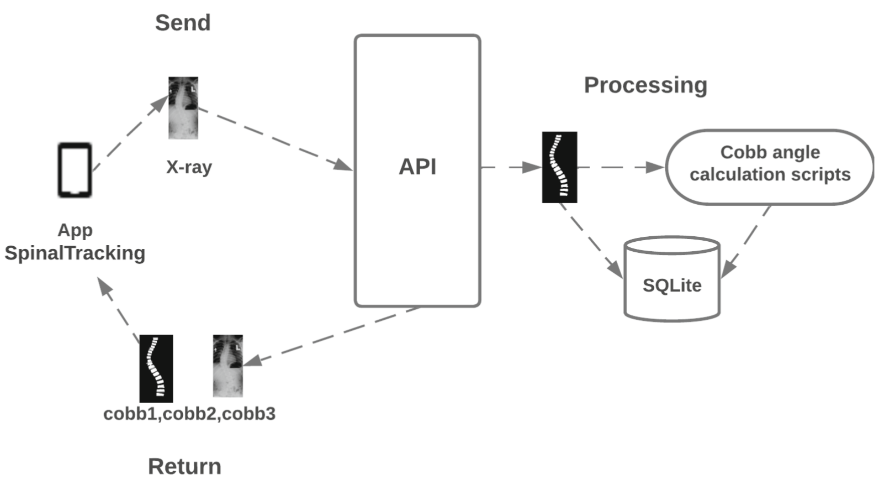
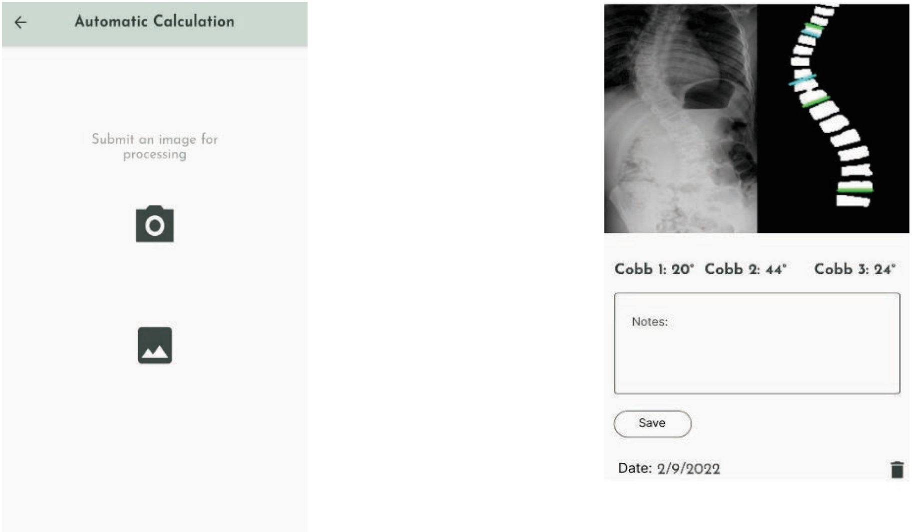


Fig. 5. Steps for sending, processing and returning the X-ray image via the API.



(a) Measurement screen (b) Result preview screen

Fig. 6. Cobb angle measurement screens by demarcating the vertebrae in the X-ray provided to the application.

4 Results and Discussion

Tests were conducted to assess the efficacy of each function. The accelerometer data and line markings were measured using images with the vertebrae marked and the Cobb angle calculated by an expert. The tests carried out at this stage were done with few images due to the low availability of marked images, and with the Cobb angle calculated to compare the real and the predicted. In this way, the application made the measurement based on the expert's markings, only comparing the calculated angles. About the automatic calculation, 128 images from the [19] database used for testing were used by submitting the X-ray to the application to compare the predicted angle with the real one.

Table 1 shows the comparison between the measurement made by the expert and that made by the application for the measurement functionality, using the tilt of the cell phone in relation to the X-ray image. The Application column shows the result of the measurement made by the App, the Manual column shows the value of the angle calculated by the expert. The Difference column shows the degree of difference between the measurements.

Figure 7 shows the scatter plot, constructed using the results from Table 1. An R^2 of 0.9 and a Pearson correlation of 0.94 were achieved.

According to the study by [18], the difference between the two exams is clinically significant when the measurements exceed 5º. The results presented indicate that, of the nine images analyzed, five are within the acceptable variation

Table 1. Comparison between app and expert measurement using mobile phone tilt.

Images	Application	Manual	Difference
Image 1	41º	49º	8°
Image 2	41º	48º	7°
Image 3	36º	32º	4°
Image 4	83º	80º	3°
Image 5	72º	70º	2°
Image 6	50º	63º	13°
Image 7	66º	63º	3°
Image 8	37º	35º	2°
Image 9	17º	9º	8°

limit, while the other four are slightly above, except image 6, which showed a significant variation between measurements.

The variation between measurements taken with the app and those of the specialist may have occurred due to variations in tilt during the positioning of the mobile device on the X-ray image or during the capture of the device's tilt, as the accelerometer data is constantly changing.

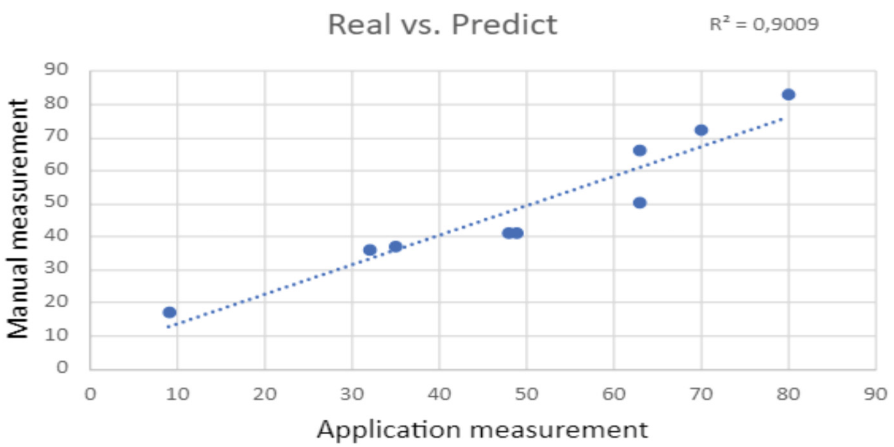


Fig. 7. Scatter plot of the results of the measurement functionality through the inclination of the cell phone about the X-ray image.

Table 2 contains the test results for the measurement by marking the vertebrae on the x-ray. The Application column shows the degree of Cobb's angle obtained by marking lines on the images supplied to the application. The manual column shows the results of the measurements made by the expert with a pen and goniometer to calculate the angle mentioned, and the Difference column shows the degree of difference between the measurements.

Table 2. Comparison between the app's measurement and the specialist is use of the markings of the vertebrae on the X-ray.

Images	Application	Manual	Difference
Image 1	48º	48º	0º
Image 2	28º	32º	4º
Image 3	60º	70º	10º
Image 4	60º	80º	20º
Image 5	36º	40º	4º
Image 6	15º	12º	3º
Image 7	10º	9º	1º
Image 8	80º	63º	17º
Image 9	18º	16º	2º
Image 10	48º	49º	1º
Image 11	63º	63º	0º

Figure 8 shows the scatter plot with the results of the predicted and actual angles. By analyzing the measurements, it was possible to obtain an R^2 of 0.86 and Pearson's coefficient of 0.92, indicating that the predicted angles correlate well with the angles calculated by the expert.

Among the 11 analyzed images, 8 had a variation of less than 5º, while images 1 and 11 showed no difference. However, images 3, 4, and 8 varied from 5° to 15° above the expected degree of difference between the measurements. This variation may be related to the positioning of the lines on the X-ray image during measurement, resulting in a less accurate calculation of the inclination. Therefore, it is possible to see that most of the images were measured correctly.

For the automatic calculation, the correlation between each actual and predicted angle was calculated for the PT (proximal thoracic), MT (main thoracic), and TL/L (thoracolumbar or lumbar) regions, resulting in a Pearson's coefficient of 0.83, 0.81, 0.59 for each region respectively, and an average correlation of 0.74. These results are shown in the scatter plots in Figs. 9, 10 and 11.

To measure the level of dispersion between the predicted and actual results, the standard deviation was calculated, resulting in 3.59 for PT (proximal thoracic), 9.38 for MT (main thoracic) and 11.76 for TL/L (thoracolumbar or lumbar) angles, indicating that there is still a considerable difference between some measurements, which can be seen in the number of measurements that were above and below the 5º of variation considered between measurements. Of the 128 images measured for PT, 40 were above the limit, and 88 were within the limit. For MT, 89 images were above, and 39 were within the limit. Finally, 105

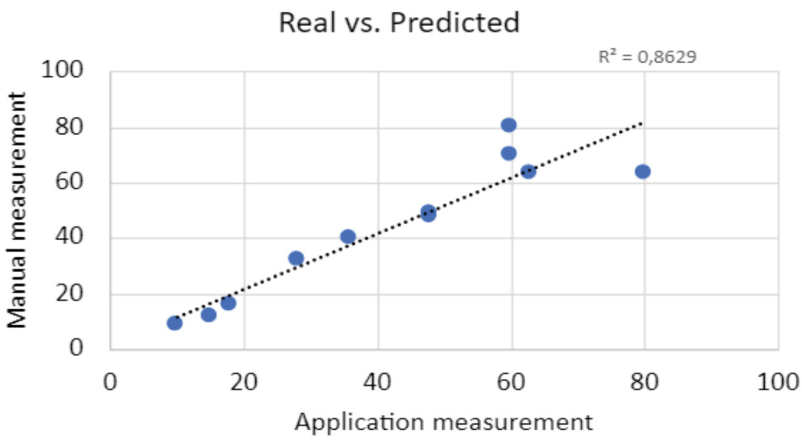


Fig. 8. Scatter plot with application and expert measurement results.

images were above and 23 within the limit for TL. Therefore, there was a smaller difference between the measurements taken for PT compared to MT and TL.

The difference in the number of correct measurements compared to the angle calculated by the specialist for PT, MT, and TL may have occurred due to the choice of vertebrae by the method to perform the Cobb angle calculation, given that the vertebrae used are not fixed and are selected based on their inclination and position.

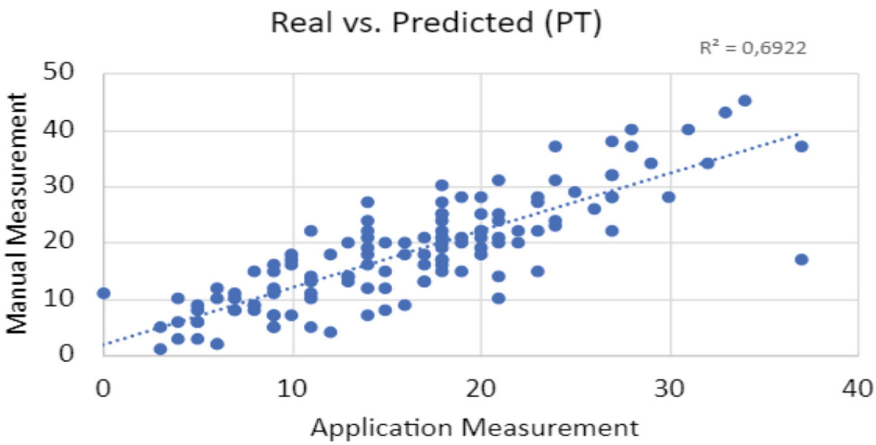


Fig. 9. Test results of the automatic Cobb angle calculation feature for PT (proximal thoracic).

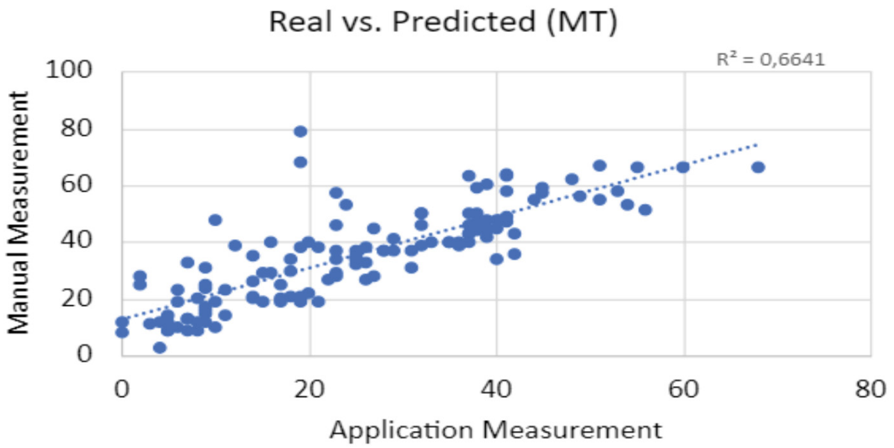


Fig. 10. Test results of the automatic Cobb angle calculation feature for MT (main thoracic).

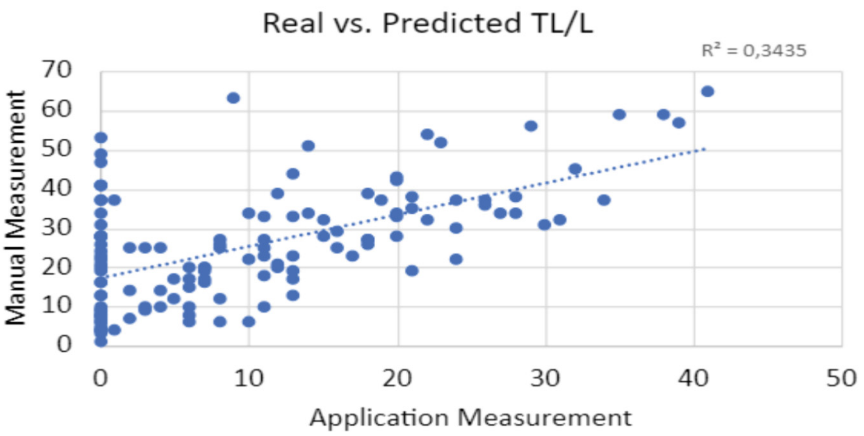


Fig. 11. Test results of the automatic Cobb angle calculation feature for TL/L (thoracolumbar or lumbar).

As shown, good results were obtained, even though there were some significant differences between the measurements. It is therefore possible to use the application in everyday clinical practice.

5 Conclusion

Three functionalities have been developed to calculate the Cobb angle: two manual ones, which require the intervention of an expert, and an automatic one that allows the calculation of three angles using image processing and deep learning techniques. The application stands out from other applications because it combines the two manual functionalities offered separately and provides an automatic method for conducting measurements, enabling an objective assessment by the specialist. In addition, by storing the exams, the professional will be able to monitor the progress of each patient's treatment. The limited number of X-ray images with the calculated Cobb angle restricted the ability to perform more tests; nonetheless, the tests demonstrated that the application can be used in clinical practice.

Furthermore, in future work, we intend to develop a method to calculate the Cobb angle automatically, also based on segmenting the spine in X-ray images as an initial step and then using a regression network to measure the Cobb angle, using approaches such as that presented in [9], whose method obtained good results.

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