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The intelligent estimating of spinal column abnormalities by using artificial neural networks and characteristics vector extracted from image processing of reflective markers

Mohammad Yousefi* and Saeed Ilbeigi

Faculty of Physical Education, University of Birjand, Birjand, Iran.

Spinal column abnormities such as kyphosis and lordosis are the most common deformity that normally compare to the standard norms. To classify the subjects into the healthy and abnormal groups based on the angle values of the standard norms, the aim of this study was to use the artificial neural network method as a standard way for realizing the spinal column abnormalities. In this way, 40 male students (26 ± 2 years old, 72 ± 2.5 kg weight, and 169 ± 5.5 cm height) volunteered for this research. The lumbar lordosis and thoracic kyphosis angles were analyzed using an image processing of 13 reflective markers set on the spines process of the thoracic and lumbar spine. Therefore, after analyzing the position of these markers, a characteristic vector was extracted from the lateral side of every subject. The artificial neural network was trained by using the characteristic vector extracted from the labeled image of that person to diagnose abnormalities. The results indicate that the high efficiency of this method as the CCR (train) and CCR (test) was about 96 and 93%, respectively. These results show that the neural network can be considered as a standard way to diagnose the spinal abnormalities. Moreover, the most important benefit of this method is the estimation of spinal column abnormalities without considering intermediate quantities, and also the standard norms of these intermediate quantities can be considered as a non-invasive method.

Key words: Abnormality, spinal column, kyphosis, lordosis, neural network, classification.

INTRODUCTION

The spinal column is considered as a part of the body that due to its structural positioning and also connection of different muscles and ligaments has several functions. In this way, the several functions can be accounted for by the spinal column as follows: provide structural support and balance to maintain an upright posture, connection of the head to the rest of the body, and protection for the spinal cord. The spinal curvature can refer to the normal concave and convex curvature of the spine, and it is very important to keep balance, flexibility, and also absorption and distribution of the load applied to the spine. Although, the spinal column reduces the pressures on the vertebrates, however, because of bad habitual positioning, the spine usually gets abnormalities such as kyphosis and lordosis (Letafatkar et al., 2010).

To measure spinal abnormalities, firstly, the angles of lumbar and thoracic curves were calculated and then compared with the standard norm (Rajabi and Latifi, 2008). In this way (Rajabi and Samadi, 2008), both invasive and non-invasive methods can be considered for calculating spinal abnormalities. In this instance, the Cobb method is normally used to calculate the spinal angles in an invasive way, including the fluoroscopic,

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*Corresponding author. E-mail: yousefi_mohammad2008@yahoo.com.
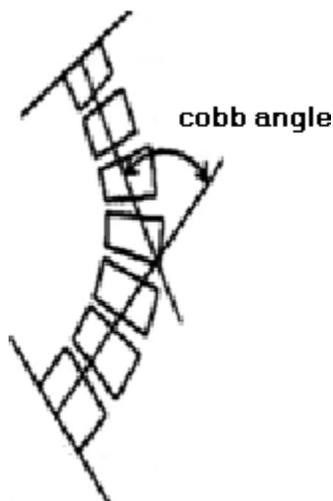
Figure 1. The Cobb angle.
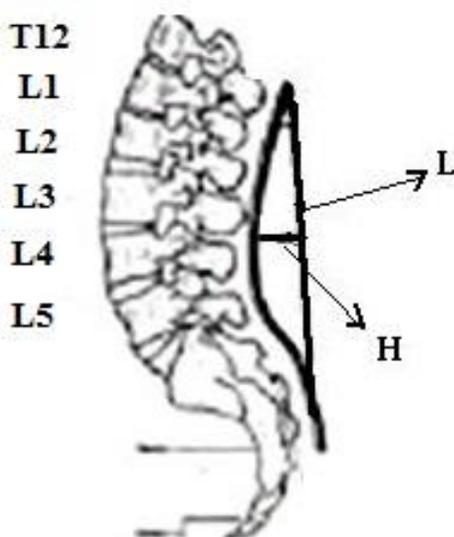
Figure 2. The flexible ruler method.

computerized tomography (CT) scans, and magnetic resonance imaging MRI. Therefore, the Cobb method is used for calculating of considered angles as follows: as depicted in Figure 1, firstly tangent lines are plotted at the beginning and end of the extracted arc. Then, from each tangent, a plumb line is drawn; the crossing of these tangents represents the Cobb angle that is equal to the angle of the arc (lundon et al., 1998; Vrtovec et al., 2009).

The inevitable risk of invasive method such as bone cancer in men and breast cancer in women is predictable (Akbari et al., 2008). Therefore, in order to diagnose spinal abnormalities, researchers usually apply non-invasive methods. In this way, flexible ruler is considered as a most common non-invasive method for extracting

the spinal curve angles (Levine and Whittle, 1996). In this method as depicted in Figure 2, the ruler that has been formed from the spinal curve moves, and considered arc is drawn on the paper. The beginning and end points of this arc are connected to each other and the acquired amount is called L. In a further step, at the deepest point of the arc, a line is drawn parallel to a horizontal surface and it prolongs to meet with the L line, therefore this line is called H (Rajabi et al., 2008; Simpson, 1989). Then, according to Equation 1, with the H and L quantities, the considered angle can be calculated.

$$\theta = 4\arctan\left(\frac{2H}{L}\right)$$

(1)

As seen from the Equation 1, if the value of H is zero then the amount of θ which describes the curvature also will be zero, but if H equals to half of L, then the amount of θ will be 180º. On the other hand, the spinal column posture was measured by surface scanning of the skin in spinal mouse method. In this method, besides both lordosis and kyphosis, the angle of two adjacent vertebrate also can be measured. Moreover, there is an algorithm for each parameter such as, normal curvature of the lumbar, displacement of the vertebrates, pelvic tilt, hip displacement, spinal column deviation, and spinal column length, that all of them can be compared with a standard position. However, it should be noted that the standard position here is normalized only for the Austrian people (Carlucci et al., 2008).

To identify an abnormality in both invasive and also flexible ruler methods, only one angle was considered as a diagnosis criterion of abnormality. Additionally, after extraction of any angle, the subjects can be categorized as a healthy and unhealthy group based on the rate of this angle (Rajabi and Latifi, 2008). It also should be noted that only the extraction of angle cannot be considered as a suitable criterion to describe spinal curvature, but also, the calculation of standard norm values to analyze kyphosis and lordosis angles would be difficult for different age and sex. The spinal mouse device has been made for Austrian people, so, it is not suitable for people from other countries. Moreover, little studies have shown that the validity of spinal mouse method indicated some high correlation (Guermazi et al., 2006; Kellis et al., 2008) and some low ones (Ripani et al., 2008). Therefore, as mentioned above and also high cost of this device, there are a lot of problems to use a spinal mouse in research method study. The intelligent method was presented here, and is based on image processing of reflective markers of the set on spinous processes.

Therefore, the aim of this article was to diagnose spinal abnormalities using extraction of 11 angles (six and five angles for kyphosis and lordosis, respectively) from spinal curvatures of every person. This method also has

the ability to describe the spinal curvatures as general (kyphosis and lordosis) and special angles (angle between two adjacent vertebrate). Additionally, according to this method, a standard norm can be extracted from artificial neural networks. In this way, every spinal curvature patterns with their angle, and also the type of deformity can be recorded, and then a learning model with decision ability formed. Moreover, the learning model with every curvature pattern will be up-to-date and also make more precise decision. Therefore, the intelligent method that is presented here can categorize the people as quantitative (rate of angle) and qualitative ones (type of abnormality).

MATERIALS AND METHODS

This study was descriptive-comparative in nature. The statistical population of this research consists of all male students during the 2009 to 2010 educational year (n = 108). After using a normal test for all of the students by the use of the flexible ruler method, 40 students (20 normal and 20 abnormal subjects) was selected as sample population (using the simple random sampling method and based on Kakron sample size formula). The angles of thoracic kyphosis and lumbar lordosis for each individual were calculated using both methods (the proposed method and flexible ruler method). Both proposed method and flexible ruler was used for thoracic kyphosis and lumbar lordosis angles measurement. Angle measurement in both methods is discussed in details below.

The procedure of angle measurement in flexible ruler method

Flexible ruler was used to measure the spinal curvatures (lordosis and kyphosis). Firstly, the subject stood barefooted on a piece of cardboard at a natural and comfortable position, and the location of feet was marked. Then, feet were spread out at the size of shoulder width and the subject asked to stare forward at a horizontal angle. At this stage, the rater stands behind the subject in order to find the reference points. These reference points include posterior superior iliac spine, whose localization was made by thumb fingers in line with two hallow positioned at the lower back area. After marking these points with a marker and connecting them with a straight line, the spinus process of the second sacral vertebra (S2) was selected as the midpoint of this line. In order to determine the spinus process of the fourth vertebra, at first, the soft tissue should be moved aside by pressing the fingers on the two sides of the subject's body (above the iliac crest), and then by moving the two thumbs horizontally, the spinus process of the fourth vertebra is determined at the meeting point of two thumbs. At this moment by counting the spinus process in upward direction, the first spinus process of the vertebrae (L1) can be determined and marked by a marker. After obtaining L1 and S2 positions, the examiner can simply set the flexible ruler on these points, and by applying pressure along the ruler, the ruler completely takes the form of spinal curve.

In this stage, ruler takes off from the subject's lumbar slowly and carefully and the curve that formed in the ruler drawn on a paper. Then, for next measurements, all marks that remained from previous trial on subject's skin were erased and after 1 min of rest, all previous steps were repeated (Raei and Chavoshi, 2003). To eliminate the effect of examiner's expectations, examiner was not informed of measured angles in the previous trials. The lordosis angle was extracted and recorded in each of the five angles, using number one equation. An average of the five trials is a relatively accurate value of lordosis angle. In order to measure the kyphosis

angle with the flexible ruler, C7 spinus process was first determined by palpation method and then marked. Then, the subject bends his head downward and the first bump in the lower part of the neck is found. The spinus process of C7 vertebra is usually the largest spinus process at the lower of neck. Due to C6 and C7 spinus process resemblance, C7 spinus process is not easily found. In order to facilitate this procedure, we asked the subject to reposition his head slowly; during this movement, the C6 spinus process disappears sooner than C7. In this procedure, we determine and mark the C7 spinus process. After C7 spinus process marking, T12 spinus process also should be determined and marked.

To determine T12 spinus process, we asked the subject to set his hands on the edge of table, in leaning forward position, in order to measure the weight transferring to hand. Spinus process of T12 vertebra is at the same level as the lower edge of the 12th ribs on both sides. Therefore, the edges of these ribs are simultaneously touched with the tip of thumbs and their traces were followed in upward and inward directions until they disappear in soft tissue. At this point, the location of T12 spinus process was estimated by drawing a straight line from the tip of one thumb to another. After the finding of this process, it was also marked and the flexible ruler is placed on two processes (C7 and T12), and after the ruler takes the form of curve, it was transferred to paper and the resultant curve was drawn, then the kyphosis angle calculated using Equation 1 (Rajabi et al., 2008).

Image processing and constructing feature vector

"Image processing and constructing feature vector" method consists of 10 stages:

The first stage (markers attachment by palpation)

First, the locus of lumbar spinous processes (five lumbar vertebrae and sacral vertebra) and spinal spinous process (1, 3, 4, 7, 9 and 11th spinal vertebrae and spinous process of 7th cervical vertebra) are located by palpation, and then the reflective markers are attached at their locations. C7 and T12 processes are located by the procedure mentioned in flexible ruler method. Having located spinous process of T12 vertebra, spinous processes are counted in an upward direction to locate spinous processes of T1, T3, T5, T7, T9 and T11 vertebrae. Flexible ruler method was again used to locate spinous processes of spinal vertebrae and sacral vertebra. Then, the subject is positioned 2 m away from the camera, and five images are taken from side view. This stage is the most important stage of measurement, and care should be taken so that the subject remains at a completely natural position when the shots are taken. Also, to avoid complication of image processing algorithms in the next stages of measurement, it is necessary to take the image under controlled conditions in terms of lighting and background's color. Figure 3 depicts an example of such image taken against a dark background.

The second stage (morphological operations with different structures)

By using a dilate morphological operation in the rectangle structure of 100 and 15 pixels for the height and width, respectively, the spinal column were aligned by using white points which remained on the markers, and finally the position of the spinal column were identified. Based on the fact that all vertebrae may not be connected together due to high curvature of the spinal column, therefore, the uniform surface are not created, after applying the morphological operation, a second close operation with disk structure to eliminate this likely defect also were applied

Figure 3. An example of images used for locating the relative place of markers.

Figure 4. An example of images to which rectangle operation is applied.

Figure 5. An example of images to which disk operation is applied.
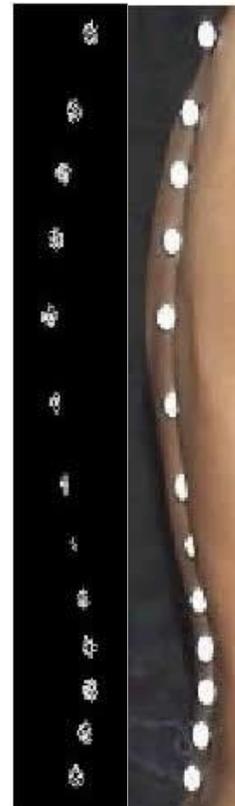
Figure 6. An example of images in which the place of spinal column is cropped.

(Figures 4 and 5).

The third stage (imcrop)

The portions with the largest area were selected from the juxtaposed areas, and then this portion was cropped out of the image as the portion containing spinal column (Figure 6).

The fourth stage (application of sequential operations to the cropped image)

Having applied sequential morphological operations (disk close, line erode, line dilate and finally disk dilate operations), the remaining points of the image indicate the location of markers quite clearly. By calculating metric factor (metric that shows roundness of the white zones), and locating the centre of each zone, the real landmark points can be found (Figures 7 and 8).

The fifth stage (extraction of feature vector)

In this stage, feature vector consisting of 11 components, each of which indicated the angle of each vertebra (markers), was obtained (Figure 9). In this stage, beside of angle of each vertebra, the angles of arcs also can be obtained by summing up of the each point.
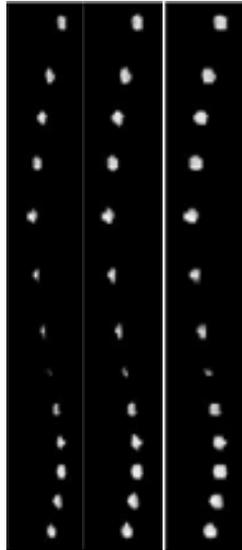
Figure 7. Application of erode, dilate and disk operations, respectively from right to left .

Diagnosis of abnormality using neural networks

As mentioned earlier, diagnosis of abnormality using neural network has 10 essential stages. In the first stage, markers are installed on spines processes and side view image is taken of spinal column. Then, a feature vector, the components of which are angles formed between these markers, is extracted. Finally, the neural network specifies the group of abnormality to which the resultant feature vector belongs. Block diagram of abnormality diagnosis algorithm is shown in Figure 10.

RESULTS

Table 1 shows the testable specifications of research's participators. Neural network used in the present research is as follows: abnormality diagnosis neural network consists of three layers; the first layer relates to images of input markers, from which a total of 11 angles, equivalent of 11 neurons, were extracted, and used as the input of the network. The second layer consists of seven neurons. The end layer or the output of the network in question includes two neuron called abnormal and normal (Figure 11). The best result of categorization by multilayer neural network with seven neurons in the median layer is shown in Table 2. As indicated, neural network has succeeded to distinguish between different types of abnormalities, for both training and test data (93 and 96%, respectively).

DISCUSSION

The present study is intended to provide a new intelligent
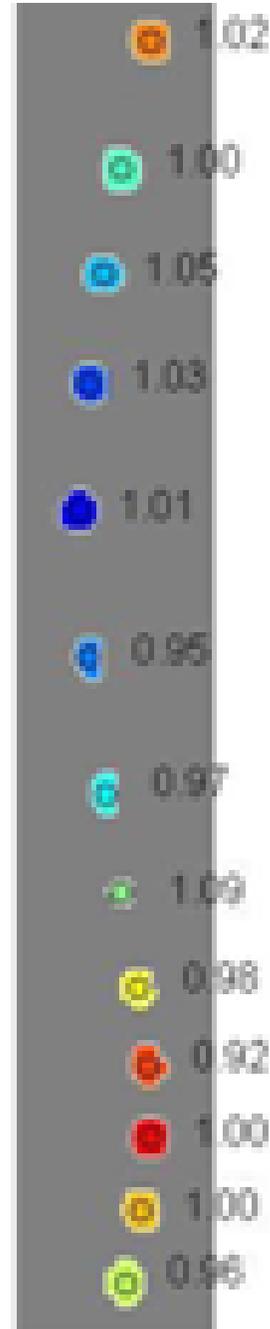
Figure 8. Calculation of metric factor for locating center of each marker.

method to diagnose abnormalities of spinal column. Considering the results of this research, the proposed intelligent network has succeeded to make a high distinction between different types of abnormalities of spinal column, whether in training stage or in test stage (93 and 96%). Today, to diagnose abnormalities of spinal column, first, the intended arc must be extracted, and based on the angle obtained by the arc, abnormalities of

1. $T_1 = 177.7681$

2. $T_3 = 176.5079$

3. $T_5 = 178.397$

4. $T_7 = 171.1701$

5. $T_9 = 177.4561$

6. $T_{12} = 177.5283$

7. $L_1 = 179.344$

8. $L_2 = 177.8901$

9. $L_3 = 173.5777$

10. $L_4 = 172.4260$

11. $L_5 = 174.1070$

Figure 9. An example of feature vector related to intended image.

Installing markers on spinus processes

Taking side view image of spinal column

Extraction of feature

Determining initial weights, training rate and the number of neurons in hidden layers

Training the neural network

Calculation of mean square error

Are conditions of stop met?

No

Yes

The end
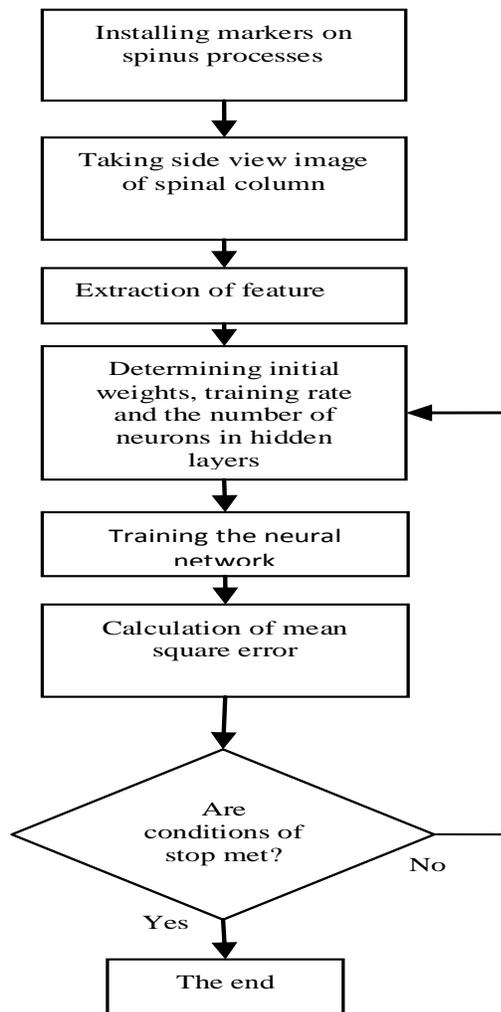
Figure 10. Block diagram of abnormality diagnosis algorithm.

spinal column are diagnosed. In invasive methods, first, on the basis of medical imaging (MRI, X-Ray and CT-Scan), the intended arc is extracted, and then, using Cobb method, angle of the intended arc is obtained. In the end, medical specialists categorize the subject in normal or abnormal category, based on the angle and norm (Rajabi and Latifi, 2008).

In diagnosis of abnormalities of spinal column, non-invasive methods are also used due to harmful nature of invasive methods. Most commonly used tool to extract arcs of spinal column is a flexible ruler. In this method, first, using the flexible ruler, the intended arc is extracted, and after drawing the arc on the paper, we can use mathematical formulae to obtain the angle of this arc. Having obtained the angle, researchers use the intended norm to categorize subjects into normal and abnormal categories (Rajabi and Latifi, 2008; Seidi et al., 2009). Flexible ruler method has been frequently used in various researches and its validity has been demonstrated by many researchers (Hart and Rose, 1982; 1986; Abdolvahabi et al., 2012; Nourbakhsh et al., 2001; Yousefi et al., 2011; Bennett et al., 1989; Link et al., 1990). As already mentioned, except for the flexible ruler, the spinal mouse also can be used to extract spinal angles and abnormalities. However, there are some limitation to frequent use, such as contradictory validity, inconsistency norm with Iranian population, and high cost of spinal mouse. The presented method in this article can be considered as a non-invasive method. Although, the basis of the current method can be considered according to the image processing method, however, there are significant differences between these two kinds of methods, such as: the processing technique and also suing of plural point algorithm for the current method are among significant differences.

There are several studies about the image processing methods for example, Vilner (1984) indicated a significant correlation between radiographic measures and surface measures from usual images of spinal column (0.97 and 0.80 for the kyphosis and lordosis, respectively). In Vilner method, the images of spinal column were used to extract the angles of spine (Equation 1) (Willner, 1981). Moreover, Lorex et al. (2000, 2002) also used the Willner method to calculate the Kyphosis and lordosis angles, with which they obtained the validity of 0.89 and 0.84 for kyphosis and lordosis, respectively, as compared to the X-ray. The Willner method only could calculate the amount of curvature, but had any ability to make decision to identify the subjects as a normal and abnormal person; whereas, the intelligent method that are presented in this article have both abilities including quantities and also qualities analysis to calculate the amount of angle and also type of abnormality, respectively.

Among other capabilities of this method is the feature vector which is obtained by this method. This feature vector consists of 11 angles, which are sensitive to minor changes in spinal column. Therefore, this feature vector

Table 1. Specifications and variables of research.

Group	Variable					
	Number (person)	Height (cm)	Weight (kg)	Age (years)	Kyphosis angle (degree)	Lordosis angle (degree)
Normal group	20	167/2±2/13	70±2/17	25±2/15	21/72±1/4	23/42±2/03
Abnormal group	20	171/14±1/2	74±3/23	27±1/5	45/83±2/18	35/19±3/72
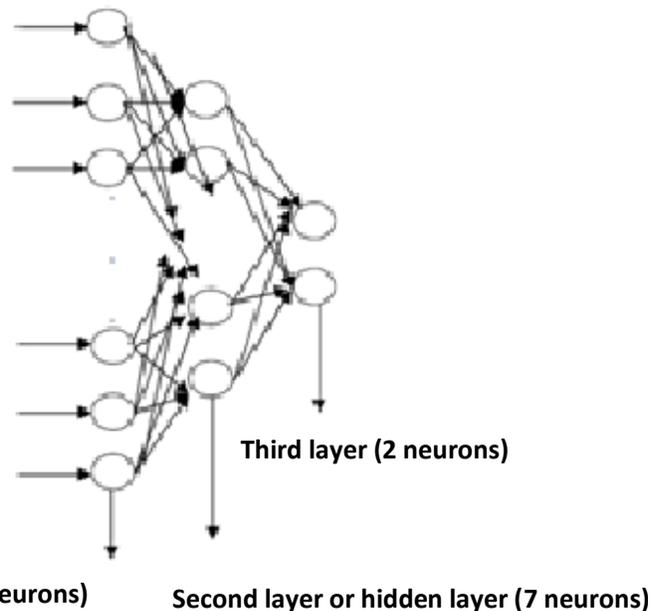
Figure 11. Architecture of neural network.

Table 2. Results from prediction of abnormalities using multilayer perceptron neural network.

Hidden layers' neuron	Repetition	Error	CCR (test)%	CCR (train)%
7	500	0.001	93	96

can be a better describer, compared with other non-invasive systems which describe the changes of spinal column with only one angle.

Conclusion

According to the mentioned abilities of this method, this method alongside other non-invasive methods can be used to diagnose abnormality of spinal column.

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