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C. K. Sreeja, V. N. Meena Devi & M. K. Aneesh

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A novel neural network method using radial basis function for effective assessment of stiffness index on lumbar disc degenerative subjects

C. K. Sreeja[a], V. N. Meena Devi[a] and M. K. Aneesh[b]

[a]Department of Physics, Noorul Islam Center of Higher Education, Kumaracoil, Tamil Nadu, India; [b]Department of Radiology, Jubilee Mission Medical College & Research Institute, Thrissur, Kerala, India

ABSTRACT
Lumbar disc degenerative disc disease with back pain and its severity is a leading health issue in society and MRI is the best modality to detect the severity and degree of disc degeneration. The most critical component of degenerative disc disease deals with triggering rapid action for real-time-based system identification. The input is obtained from the non-invasive device called finger pulse plethysmography to assess the stiffness and its correlation with body composition in lumbar disc degeneration. The recent methodology contributions aim at predicting the stiffness which uses pulse wave velocity and reflection on signal features. As the signals are very sensitive to differences between high and low ranges, finger pulse plethysmography effectively detects irregularities at early stages. Based on the severity of degeneration, shown by the MRI report, subjects were grouped into the disc bulging group (DBG) and the nerve compression group (NCG). The supervised features help in training the signals to correct the limitations of prediction. Finally, the Radial Basis Function neural network approach helps in diminishing the local minimal values in the signal. It helps in the effective categorization of anomalous and ordinary stiffness index measurements for lumbar disc degeneration.

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KEYWORDS
Back pain; disc degeneration; stiffness index; finger pulse plethysmography; radial basis function neural network

1. Introduction

Osteoarthritis stiffness causes pain when the bones are rubbed against each other. Wearing down of the disc occurs on ageing which is a normal process. Most people have disc degeneration after the age of 40 but not with pain. Low back pain is a leading severe health problem, which finally results in hospitalization and increased risk of the financial burden for its treatment and management [1]. Lumbar disc degeneration (LDD), which includes disc herniation [2], spinal column stenosis, spondylosis and spondylolisthesis, is the major reasons for disability. The onset and progression of LDD is influenced by genetics, lack of physical exercise, changes in body composition, a high BMI, unbalanced food, body weight, stress, obesity and poor vascular supply and the like. Over the past few decades, obesity has become an independent predictor of back pain and its intensity, which is linked to degenerative discs in the lower back, sciatica and other lumbar disorders [3].

Many different elements impact blood vessel flexibility. The vascular inner annulus of the vertebral disc is supplied with glucose, oxygen and other nutrients through diffusion by blood vessels near the disc-bone junction of the vertebral body and in the outer annulus [4]. Obesity is one of the reasons why blood flow to the spine is reduced due to protein glycation or atherogenesis. As proteoglycan content in the nucleus pulposus diminishes and Type 1 collagen is gradually replaced by Type 2 collagen, the process of degeneration begins. The arrangement of elastic fibres in the annulus fibrosus is critical to its overall mechanical qualities. These smaller capillaries and arteriolar circulation depend on the tone and integrity of the aortic and larger arterial blood flow. The gradual loss of elasticity of the blood vessel leads to arterial stiffness and it will result in poor blood supply to peripheral vessels.

Age, obesity, excessive cholesterol, smoking, lipid concentrations and a sedentary lifestyle led to arterial stiffening. Diabetes and arteriosclerosis are also increased by unhealthy diets [5,6]. Signal waveform-based indexes can be used to track changes in the elastic properties of the arteries that cause arterial wall stiffening with age, to identify disease conditions, useful information on left ventricle activity, haemodynamic properties, drug effects in medical treatment and advice on the need for lifestyle modifications [7,8]. Among other potential factors, body composition dealing with health-related components of physical fitness [9] may be associated with arterial stiffness even in healthy people. One way to determine arterial stiffness is pulse wave analysis, plethysmography principles are the most

CONTACT V. N. Meena Devi meenadevivn.physics@outlook.com Department of Physics, Noorul Islam Center of Higher Education, Kumaracoil, India

widely used non-invasive methods. As an accepted metric of arterial stiffness, Boyle's law describes the relationship between volume and pressure. Subsequently, the goal of the present work was to measure the body composition analysis by bioelectric impedance analysis and measure arterial stiffness by finger pulse photoplethysmography and the correlation between body composition and arterial stiffness in lumbar disc degenerative subjects with low back pain. Finger pulse photo plethysmography's simple, non-invasive tool measures the opacity changes in disc degree. The neural network system on Radial Basis function helps in classifying the ordinary and anomalous stiffness measurement on disc degeneration.

2. Related works

Many techniques were introduced for lumbar disc degenerative diseases, including analysis of body composition and measures of the stiffness index. This section looks at a few of those techniques in depth. A wide collection of techniques and algorithms are used in the regulation of signals obtained for the degree of degeneration of the disc in both the normal and in sickness state. Otluoglu et al. [10] presented an impact of mechanical factors on disc degeneration disease as an indication for surgery. The Pfirrmann grading system assesses inter-vertebral disc degeneration. Spinopelvic characteristics appear to be the most pervasive factor in predicting the surgical needs of patients with degenerative disc degeneration. However, data on metrics to assess patient status are not available.

Murakami et al. [11] evaluated the arterial stiffness from accelerated photoplethysmography using the SB200 pulse-oximeter, giving a level between 1 and 6. The baPWV is used for determining arterial stiffness and then compared to ASI. The amplitude is calculated from each signal pulse using the Discrete Cosine Transform. The change is detected in the area during any complication of computing the amplitude [12]. Haraguchi et al determined the body composition indices and stiffness by brachial-ankle pulse wave velocity. The baPWV is used to determine body stiffness. The body mass index measures obesity [13].

The independent component analysis with the wavelet transform approach effectively extracts the information based on the morphological operation which is added to reduce the dimensionality functions. The support vector machine overcomes the poor performance which holds onto the class of sample data values [14,15]. Ravikanth [16] presented an MR characterization and analysis of lumbar disc degeneration and sequelae. The Pfirrmann disc classification method, Modic classification, Weishaupt Classification for Facet Degeneration and the spinal canal using the Borenstein criteria were evaluated. Physicians will find it useful for practical examination of lumbar spine degeneration and simple communication.

Many recent academics have tested the sample data to fetch automatic decision-making strategies using pulse wave methods. In this area and conditions, signal processing has become the most common cause of therapeutic models in recent decades [17]. Zekavat et al. [18] presented finger photoplethysmography with ASI with blood pressure. This method suggests that signals from finger photoplethysmography are self-determining which creates a causative risk factor for blood pressure but not the idea that is a good alternative for other risks. Huang et al. developed a Convolutional Neural Network for medical experts to analyze and to categorize diverse features from various databanks without deviation [19]. Lipid profile and several cardiovascular disease threats in patients experiencing treatment for lumbar disc degeneration with the emphasis level were set for all tests to $P \leq 0.05$ [20]. Contrast-Enhanced T1w FS sequences after the supervision of contrast medium. MR protocols allow a better diagnosis of degenerative disease [21] on lumbar spine by MRI with fat saturation and contrast medium. Recent studies were conducted in Refs. [22–25].

Many classification methods have been discussed in different research papers. In this research, the body composition analysis has been measured by bioelectric impedance analysis and measure stiffness by finger pulse photoplethysmography and correlation between body composition and arterial stiffness in lumbar disc degenerative subjects with low back pain. The feature extraction for classifying the various classes is done by Radial Basis Function. In this research paper, Section 2 describes the existing techniques and their limitations. The proposed model is discussed in Section 3. Section 4 covers the result and discussion, while section 5 provides conclusion.

3. Proposed methodology

The study was done with 197 subjects taken from Jubilee MRI scan, Jubilee Mission Medical college, Thrissur. Patients with lower back pain referred for MRI analysis were included as the disc bulging group and the nerve compression group as per the degree of damage shown from their MRI report within the age group of 30–70 years. Some participants reported a prior history of hypertension, diabetes mellitus, thyroid dysfunction, and cholesterol, and each participant's medications were also recorded. Exclusion criteria include any anomaly, myeloma, spinal surgery, spinal defects and accident and injury case. Inclusion criteria include ambulant patients. All participants gave their written informed consent. This study was granted by the institutional ethical committee. Figure 1 depicts the proposed method. The study has undergone various testing devices MRI of lumbosacral and the nucleus

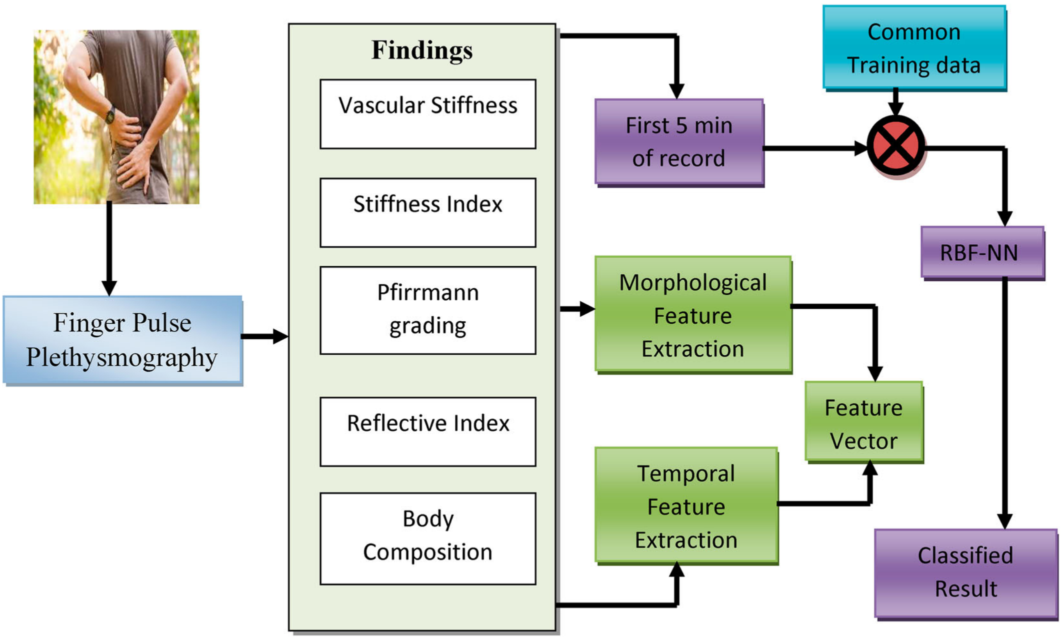

Figure 1. Proposed workflow.

and annulus of the intervertebral disc, with its signal intensity and height.

The degree to which the total body fat or the abdominal fat affects arterial stiffness in lumbar disc degenerative patients in the Indian population is still not known. So, this study was to assess the relationship between the measures of total body fat (WBF) and visceral (VF) with stiffness index and reflective index, measures of arterial stiffness calculated from DVP were recorded with a finger photoplethysmography in lumbar disc degenerative patients suffering low back pain. Measurement of the arterial stiffness is the indicator of the vascular endothelial condition. The endothelial damage may lead to poor blood supply and poor supply of nutrients to the surrounding tissues. So, the importance of measuring the arterial stiffness is the indicator in the patients suffering back pain with disc degeneration. Being vascular, the inter-vertebral disc depends on surrounding peripheral smaller capillaries. The arteriolar blood flow depends on the tone and integrity of the aortic and larger arterial blood flow. The gradual loss of elasticity of the blood vessel leads to arterial stiffness and it will result in the poor blood supply to peripheral vessels.

To record the pulse wave by PPG, a pulse transducer was placed around the index finger of the left hand. The density of blood in the fingertip was tested using the PPG. Meanwhile the ECG was also taken which is essential for the calculation of SI, RI and PWV. Five minutes are required for recording.

3.1. Feature extraction

The feature extracted helps to figure out the amplitude and interval values of signal segment in finger photoplethysmography. Based on the severity of degeneration, shown by MRI report, subjects were grouped

Algorithm to compute the duration of a signal state:

Step 1: Read the signal from finger photoplethysmography
Step 2: Identify the duration with the complex signal waveform
Step 3: Wavelet analysis is executed

$$F(e) = ff(e+1) - f(e);\ 1, 2 \ldots n-1 \quad (2)$$

where $f(e)$ is the peak time of the eth wave.
Step 4: The wavelet decomposition wavelet signals are analyzed based on the fitness function

$$r \cdot r = 1/n \sum (x - \text{out}) \quad (3)$$

n indicates the output ranges with the goal output states x. Both the negative and positive values correspond to the fitness functions.
Step 5: Identify the smallest values and the highest values corresponding to the peak location basics which depends on the chromosome reproduce given by Equation (4)

$$CR = f(xi) \Big/ \sum_{n=1}^{0} f(xn) \quad (4)$$

Step 6: The false positive range detection is given based on the ventricular premature complex values with the low amplitude ranges. This is also analyzed based on the low SNR values.
Step 7: The process is repeated until the entire signals are analyzed.

into the disc bulging group (DBG) and the nerve compression group (NCG). Vascular stiffness was measured by pulse wave velocity, SI and RI by the non-invasive device finger photoplethysmography and digital volume pulse (DVP) waveform. Body compositions such as visceral fat and whole-bodyfat were measured by body composition analyzer. This research work helps to extract the morphological highlights. The maximal and minimal pulse wave signals are captured. This is dependent on equation (1) as follows

$$F(e) = f(e) - \min(e)/\max(e) - \min(e) \quad (1)$$

The minimal and the maximum values are chosen, which are taken from the esteems, lie between 0 and 1.

3.2. Neural network – radial basis function

The structure of the RBF-NN is shown in Figure 2. RBF mostly acts as the approximation function for

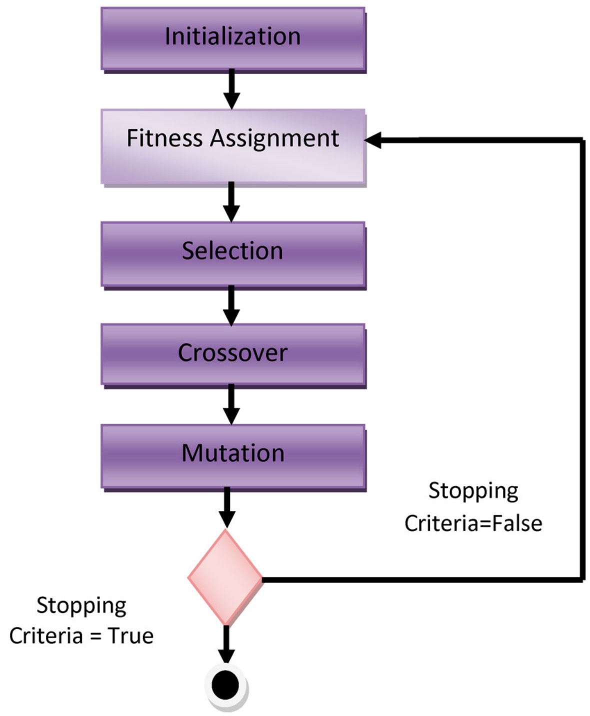

Figure 2. RNF-NN Algorithm – Structure.

classification of signals that are dependent on three layers such as output, hidden and input layers. The transformation from input to output is done effectively by the hidden layers. These layers activate the output layers.

The input layer is given depending on the normalization and de-normalization functional states. The input layer is denoted as x_i which is dependent mainly on the R^n denoted as the real vector values. The resultant network value is given by equation.

$$\partial(x) = \sum_{L=1}^{M} a_L x(||x - c_L||) \tag{5}$$

Here, the hidden layer with the neurons is given with the representation N, c_L gives the central vector value and a_L gives the neural weight values. These parameters effectively optimize the fitness values between the resultant network signal and the input signal values. The scalar input value with the RBF component is given by the first layer values as in Equation (6)

$$f(\mathrm{x}) = \exp(-(x - c_L)^2/r^3) \tag{6}$$

The possible values for the normalized and the denormalized input forms are given by Equation (7). This equation delivers the stage that it effectively belongs to the denormalized state values.

$$\partial(x) = \sum_{L=1}^{N} a_L \rho(||x - c_L||) \Big/ \sum_{L=1}^{N} \rho(||x - c_L||) \tag{7}$$

The expression at the input layer is given by Equation (8) as follows

$$\partial(x) = \sum_{K=1}^{2N} \sum_{L=1}^{N} e_{KL} \delta_{KL}(||x - c_L||) \tag{8}$$

where $e_{KL} = \begin{cases} a_L, \text{if } L \in [1, N] \\ b_{KL, \, if} \ L \in [N+1, 2N] \end{cases}$.

In the normalized vector form the value corresponding to the unit vector is δ_{KL} given by the Equation (9) as follows

$$e_{KL} = \begin{cases} 1, \text{if } K = L \\ 0, \text{if } K \neq L \end{cases} \tag{9}$$

The probability density function, corresponding to the signal at the input and the output state, is given by Equation (10)

$$O(x) = \int O(x \wedge y) dy = \frac{1}{N} \sum_{L=1}^{N} \delta_{KL}(||x - c_L||) \tag{10}$$

The output vector corresponding to the input signal; the term is given by Equation (11)

$$\partial(x) = E(y/x) = \int yO(y/x) dy \tag{11}$$

This resembles the conditional term of y with respect to the specified values of x that are represented by the values as $O(y/x)$. The classification of the signal corresponding o the stiffness, reflective indices, grading values and body composition index is determined for performing an effective classification for the trained and the test-based input signal values.

4. Result and discussion

For statistical analysis, SPSS software version 19 was employed. Comparison of body composition with PWV, stiffness index and reflection index of the disc bulging group and the nerve compression group were analyzed by independent two sample t-test and correlations between body composition and arterial stiffness were analyzed with Pearson correlation coefficient.

Table 1 has been described as per the sex and age, out of 197, 116 females (58.9%) were experienced disc degeneration than 81 males (41.1%) and age groups 30–40 (31%) and 51–60 (31.5%) came under disc degeneration. The table depicts lower back pain increases when people reached near 50–60s and people with aged group 30–40 also showed disc degeneration.

Table 2 describes that subjects with disc degeneration were divided into three groups based on fat mass, as normal (1%), 116 overfat (58.9%) and 79 obese (40.1%) subjects had increased whole body fat had disc degeneration and out of 197, 25 overfat (13.2%) and 26 obese (12.7%) belonged to the visceral fat group also had shown disc degeneration. Table 3

Table 1. Disc degenerative subjects' gender and age distribution.

Variables		Frequency	%
Sex	Male	81	41.1
	Female	116	58.9
Age	30–40	61	31.0
	41–50	48	24.4
	51–60	62	31.5
	61–70	26	13.2

Table 2. WBF and VF distribution of disc degenerative subjects.

Variables		Frequency	%
WBF	Normal	2	1.0
	Over-fat	116	58.9
	Obese	79	40.1
Visceral fat	Normal	146	74.1
	Over-fat	26	13.2
	Obese	25	12.7
	Total	197	100.0

Table 3. Distribution of disc degenerative subjects based on the degree of degeneration.

Variables		Frequency	%
MRI	Disc bulging group	123	62.4
	Nerve compression group	74	37.6
	Total	197	100

shows MRI based on the disc bulging group, the nerve compression group gives the degree of degeneration and the frequency.

SI = Stiffness index, RI = Reflection index, PWV = pulse wave velocity, Significant $p < 0.01$ level. Table 4 – Disc degeneration may be influenced by subcutaneous fat; however, arterial stiffness is unrelated. In patients with degenerative conditions, the pulse wave velocity

Table 6. Comparison between the disc bulging group and the nerve compression group.

	Disc Bulging group Mean ± *SD*	Nerve Compression Group Mean ± *SD*	*P*-value
WBF	32.8092 ± 6.14108	37.7703 ± 7.43490	$P < 0.000$
VF	8.646 ± 2.9998	11.149 ± 3.4904	$P < 0.000$
PWV	5.58810 ± 1.416862	6.09892 ± 1.863384	
SI	9.45744 ± 2.563260	10.26847 ± 1.793016	$P < 0.01$
RI	35.47819 ± 14.089201	35.81322 ± 15.877876	

exhibits a statistically significant ($p < 0.01$) positive connection with stiffness index and reflection index.

Table 5(a) gives statistical research indicated that visceral fat reduces as whole-body fat rises, and the link was statistically significant ($p < 0.01$). There is also a link between visceral fat and the reflection index in disc bulging that is statistically significant ($p < 0.01$). The conclusion from the table is that visceral fat has no additional function in disc bulging.

Table 5(b): The results showed that PWV had a significant connection with the reflection index of the disc bulging groups ($p < 0.01$). As a result, the WBF and PWV had a separate impact on disc degeneration Figure 3.

Table 6 explains that subcutaneous fat had a strong link with disc degeneration in the bulging and the nerve compression group ($P < 0.000$), while the VF of disc bulging had no significant correlation in the analysis.

Table 7 statistical analysis noted that there was no significant correlation in each division of visceral fat with disc bulging. The classification of visceral fat and stiffness index was seen only in the nerve compression group, according to Table 8 is given by Radial Basis Function.

Table 4. Correlation between WBF and VF with pulse wave velocity, stiffness index and reflection index.

	No. of subjects	PWV (Correlation)	*P* value	SI (correlation)	*P*-value	RI (Correlation)	*P*-value
WBF	197	−0.086		0.050		−0.035	
		0.229		0.490		0.625	
VF	197	0.132		.204**	$P < 0.01$	−0.095	
		0.064		0.004		0.185	
PWV	197	1.000		195**		.400	$P < 0.01$
				0.006		0.000	

Table 5. (a) Correlation between WBF and VF with arterial stiffness in the disc bulging group.

WBF	No. of subjects	WBF (correlation)	VF (Correlation)	PWV (Correlation)	SI (Correlation)	RI (Correlation)
	123	1.000	−254	−0.121	0.088	0.021
			0.005	0.181	0.331	0.818
VF	123	−254	1.000	0.149	0.111	−210
		0.005		0.099	0.221	0.020

Table 5. (b) Correlation between PWV with Stiffness index and reflection index in the disc bulging group.

WBF	No. of subjects	WBF (correlation)	VF (Correlation)	PWV (Correlation)	SI (Correlation)	RI (Correlation)	
PWV	123	1.000		0.060		.263	$P < 0.01$
				0.508		0.003	
SI	123	0.060		1.000		−0.069	
		0.508				0.448	
RI	123	.263**	$P < 0.01$	−0.069		1.000	
		0.003		0.448			

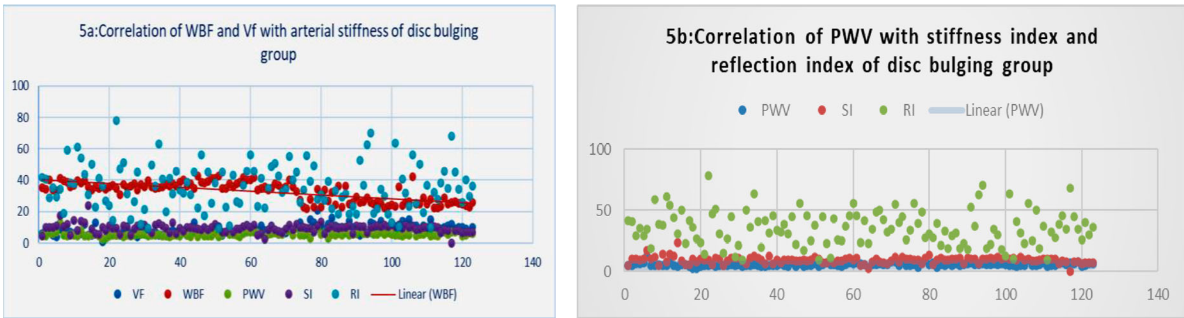

Figure 3. Correlation of body composition and arterial stiffness in disc bulging patients.

Table 7. Classification using Radial Basis Function Neural Network.

	No. of Subjects	VF	*n*	Mean ± *SD*
PWV	123	Normal	98	5.58 ± 1.40
		Overfat	19	5.95 ± 1.87
		Obese	6	5.46 ± 1.38
SI	123	Normal	98	9.36 ± 2.73
		Overfat	19	10.36 ± 0.62
		Obese	6	9.66 ± 1.91
RI	123	Normal	98	35.64 ± 13.80
		Overfat	19	27.71 ± 8.44
		Obese	6	37.06 ± 16.59

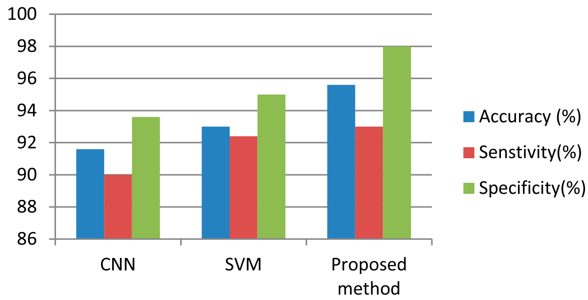

Figure 4. Classification performance.

Table 8. Based on the distribution of VF, correlation of VF with arterial stiffness in nerve compression patients – RBF-NN classifier.

	VF	*N*	Mean ± *SD*	*P*-value
PWV	Normal	48	6.29 ± 2.01	
	Overfat	7	5.06 ± 1.84	
	Obese	19	5.98 ± 1.36	
		74	6.09 ± 1.86	
SI	Normal	48	10.08 ± 1.82	$P < 0.05$
	Overfat	7	9.19 ± 1.94	
	Obese	19	11.12 ± 1.34	
		74	10.26 ± 1.79	
RI	Normal	48	36.36 ± 16.83	
	Overfat	7	29.98±15.06	
	Obese	19	36.56 ± 13.84	
		74	35.8 ± 15.87	

Finger photoplethysmography is used to measure central and peripheral arterial stiffness. This technique is less expensive and easy to handle. The stiffness index shows a positive correlation with pulse wave velocity. In addition, the feature extraction with neural network indices is also applied on the input signals obtained from the detection instrument. The performance of the methodology is compared with the traditional methods such as CNN and SVM, where the proposed method achieves an accuracy of 95.6%, a specificity of 98% and a sensitivity of 93%, whereas the accuracy of the system performance outperforms other novel approaches, as depicted in Figure 4.

In our study, there is no correlation between pulse wave velocity, stiffness index or reflection index with subcutaneous fat (WBF). This could describe that abdominal or visceral fat has some correlation with the stiffness index and reflection index. The results clearly demonstrated the comparison of the disc bulging and nerve compression group that disc bulging subjects had a significant link with the stiffness index, but the nerve compression group had shown a positive correlation with the stiffness index.

5. Conclusion

In Indian population, global obesity and related variation the distribution of body fat can promote arterial stiffness. The novelty of this research study describing the manufacturing of the new device finger photo pulse plethysmography is a noninvasive method for measuring the stiffness index and reflection index to give an idea about determining the structure and function of vascular tone on lumbar disc degeneration in individuals suffering back pain. The proposed research work increases the accuracy of the diagnosis of disc degeneration, eliminating the serious artifacts. The specified algorithm gives high value of accuracy of sensitivity and accuracy when compared to other state-of-the-art methods. These proposed algorithms are computationally facile which aid in easier processing of values. The proposed method gives better acknowledged performance than other frame works.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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