Estimating *SAD* Low-Limits for the Adverse Metabolic Profile by Using Artificial Neural Networks

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Abstract **– Cardiovascular atherosclerotic diseases represent the significant cause of death worldwide during the past few decades. Obesity is recognized as an independent factor for the development of the cardiovascular diseases. There is a strong correlation between the central (abdominal) type of obesity and the cardiovascular and metabolic diseases. Among a variety of anthropometric measurements of the abdominal fat size, sagittal abdominal diameter (*SAD*) has been proposed as the valid measurement of the visceral fat mass and cardiometabolic risk level. This paper presents a solution based on artificial neural networks (ANN) for estimating *SAD* low-limits for the adverse metabolic profile. ANN inputs are: gender, age, body mass index, systolic and diastolic blood pressures, HDL-, LDL- and total cholesterol, triglycerides, glycemia, fibrinogen and uric acid. ANN output is *SAD*. ANN training and testing are done by dataset that includes 1341 persons.**

Keywords **– Artificial Neural Networks, Adverse Metabolic Profile, Obesity, Sagittal Abdominal Diameter.**

1. Introduction

It is well known that the risk of cardiovascular and metabolic abnormalities is determined by specific distribution of the adipose tissue. Abdominal (central) obesity is associated with dyslipidemia, impaired fasting glucose, insulin resistance and hypertension, which result in increased risk of cardio- and cerebrovascular diseases, and consequently premature death [1]. Adverse effects of the abdominal obesity have been supported by many studies of the metabolism and endocrine activity of adipocytes from different regions of the abdominal adipose tissue. Abdominal fat includes two morphologically and functionally different depots: subcutaneous (superficial) and deep, visceral (intraabdominal). The latter is located in the abdominal cavity and includes intraperitoneal (omental and mesenterial) adipose tissue, which makes 80% of the intraabdominal fat mass, and retroperitoneal adipose tissue, which makes 20% of the intraabdominal fat mass [2]. Visceral adipose tissue function plays a crucial role in the development of metabolic abnormalities and insulin resistance, mainly due to the direct access of intraperitoneal adipose tissue to the liver through the portal circulation [3, 4].

Body mass index (*BMI*) has been widely accepted as a simple and the most practical measure of fatness in clinical and epidemiological surveys, eventhough it does not distinguish fat from lean body mass. The values $BMI \geq 25\ kg/m^2$ correspond to the overweight, and values $BMI \geq 30\ kg/m^2$ correspond to obesity and indicate increased risk of obesity-related adverse health outcomes [5]. In Serbia 54.4% of adult suffers from excessive body mass, while 36.2% of the population is obese [6]. The highest prevalence of overweight and obesity is observed in the region of Vojvodina and is as high as 58.5% [7]. *BMI* does not provide sufficient information about fat mass. Therefore, body composition assessment is necessary for the diagnosis of obesity and prediction of its comorbidities.

Several anthropometric indicators of abdominal obesity have been developed to measure abdominal adipose tissue mass. Sagittal abdominal diameter (*SAD*), or abdominal height was first demonstrated in 1988 by Kvist et al. to be a good correlate of visceral adipose tissue volume, observed by CT [8]. In 1994, Sjöstrom et al. proposed the use of sagittal abdominal diameter in the assessment of visceral fat mass [9]. Soon after, Richelsen and Pedersen confirmed its value in assessing the abdominal fatness and prediction of the metabolic risk profile [10].

In this paper, the multilayer feed-forward ANN with back-propagation as the training algorithm has been applied to estimating low-limits of the sagittal abdominal diameter *SAD* for the adverse metabolic profile. Our idea is to train ANN to predict *SAD* based on gender (*GEN*), age (*AGE*), body mass index (*BMI*), systolic blood pressure (*SBP*), diastolic blood pressure (*DBP*), total cholesterol (*TCH*), HDL-cholesterol (*HDL*), LDL-cholesterol (*LDL*), triglycerides (*TG*), glycemia (*GLY*), fibrinogen (*FIBR*) and uric acid (*UAC*). We will test various

ANN architectures in MATLAB (Neural Network Toolbox) and select an optimal. The *SAD* low-limits for the adverse metabolic profile will be estimated by using optimal ANN architecture.

2. Measurements

The group inquired consisted of 1341 respondents (637 women and 704 men) aged 18 to 67 years, with *BMI* values between 16.60 and 63.00 kg/m^2. In the Table 1 are shown the minimal, average and maximal values.

	Minimum	Average	Maximum
AGE	18	43.50	67
BMI	16.60	30.64	63
SBP	100	134.05	200
DBP	60	86.52	130
TCH	3	5.99	12.60
LDL	2.20	3.79	9.65
HDL	0.46	1.13	2.02
TG	0.38	2.14	26
GLY	3	5.19	13.10
FIBR	1.25	3.46	8.50
UAC	107	310.12	715

Table 1. Characteristics of dataset.

All respondents were from the north part of Serbia. The study was conducted in accordance with the Declaration of Helsinki. The respondents volunteered in the study. All the inquires were taken during the morning hours (after the fasted overnight) at the Department of Endocrinology, Diabetes and Metabolic Disorders of the Clinical Centre of Vojvodina in Novi Sad (Serbia).

Body height (*BH*) was measured using Harpenden anthropometer with the precision of 0.1 cm and body mass (*BM*) was measured using balanced beam scale with the precision of 0.1 *kg*. *BMI* is calculated as the ration of body mass (*BM*) and the square of body height (*BH*):

$$BMI\left[kg/m^2\right]=\frac{BM\left[kg\right]}{\left(BH\left[m\right]\right)^2}\ .$$

Waist circumference (*WC*) was measured using flexible tape with precision 0.1 *cm*, at the level of middle distance between the lowest point on the costal arch and the highest point on the iliac crest. *WHtR* is calculated as the ration of waist circumference (*WC*) and body height (*BH*):

$$WHtR=\frac{WC\left[m\right]}{BH\left[m\right]}\ .$$

Systolic blood pressure (*SBP*) and diastolic blood pressure (*DBP*) were measured in the morning hours, after 10–15 minutes of rest, by the standard procedure and using sphygmomanometer after Riva-Rocci. According to recommendations of European Society of Hypertension and American Heart Association, the values $SBP \geq 140$ *mmHg* and $DBP \geq 90$ *mmHg* are regarded as high [11, 12, 13].

Levels of cholesterol and triglycerides were determined by the standard enzyme procedure. The values of HDL-cholesterol were determined by precipitation procedure with sodium-phospho-wolframate, and the values of LDL-cholesterol were calculated using Friedewald's formula [14]. For the estimation of lipid and lipoprotein levels the following reference values were used: $TCH \geq 4.50$ *mmol/l*, $TG \geq 1.71$ *mmol/l*, $LDL \geq 2.50$ *mmol/l*, $HDL < 1.29$ *mmol/l* for women and $HDL < 1.03$ *mmol/l* for men [13, 15, 16].

Concentration of the fibrinogen in plasma in our patients was determined by the turbidimetric method, and the value in plasma $FIBR \geq 3.50$ *g/l* was taken as predictive with respect to development of cardiovascular diseases [17].

The level of uric acid in the blood was determined using modified PAP method, and the following reference values were used: $UAC \geq 420$ *μmol/l* in women and $UAC \geq 360$ *μmol/l* in men [18].

Fasting glucose levels were determined by Dialab glucose GOD-PAP method, with a limit of $GLY \geq 7$ *mmol/l* [13, 15, 16].

3. ANN system, results and discussion

Cardiometabolic risk encompasses a number of factors that precipitate the development of cardiovascular diseases [19]. Apart from the traditional signs of metabolic syndrome (insulin resistance, abdominal obesity, hypertension and dyslipidemia), it incorporates other factors such as pro-inflammatory and prothrombotic state, smoker status, physical inactivity, improper diet, psychosocial characteristics of a person, age, gender, race and genetic predisposition [19, 20].

Previous results showed significantly higher values of SAD in obese women who displayed lipid and lipoprotein disturbances and hyperinsulinemia, comparing to healthy normal-weight women [21, 22]. In the large longitudinal study, Iribarren et al. confirmed utility of SAD in prediction of cardiovascular risk, independently of body mass index [23]. Reed et al. found association between SAD and carotid artery intima-media thickness [24]. Empana et al. established that age-adjusted risk of sudden death increases linearly with SAD increasement in both, normal-weight and overweight

men [25]. SAD has been shown to be an independent risk factor for death and morbidity in patients in the intensive care unit [26].

Artificial neural network (ANN) is a well-known method of artificial intelligence that has been used to simulate the human brain's own problem-solving process. ANN has proven to be a better predictive tool than classical statistical methods in numerous clinical fields (eg. prediction of the heart attack, easy and low-cost identification of metabolic syndrome, primary estimation of the cardiometabolic risk, determination of WHtR limit for predicting hyperglycemia [20, 27, 28]).

This section presents our solution – ANN system for determining *SAD* low-limits for predicting adverse metabolic profile. The ANN input values are vectors:

$$\overline{X}(i)=\begin{pmatrix} AGE(i) \\ BMI(i) \\ SBP(i) \\ DBP(i) \\ TCH(i) \\ LDL(i) \\ HDL(i) \\ TG(i) \\ GLY(i) \\ FIBR(i) \\ UAC(i) \end{pmatrix},$$

while the output values are:

$$Y(i)=SAD(i),$$

where $i=1,2,...,1341$.

The optimal number of hidden neurons can be determined using various approaches, but we have used repeated random subsampling validation. The dataset is randomly divided into two parts with the proportion 90:10. The ANN training set is the first part (1207 persons) and the ANN testing set is the second part (134 persons). In the test phase, ANN estimates *SAD* based on given *GEN*, *AGE*, *BMI*, *SBP*, *DBP*, *TCH*, *HDL*, *LDL*, *TG*, *GLY*, *FIBR* and *UAC* and the estimation accuracy is:

$$AC[\%]=100\%\left(1-\frac{\left|SAD^{*}-SAD\right|}{SAD}\right),$$

where *SAD* is the exact value and SAD^{*} is the value estimated by ANN. Various architectures with one hidden layer and 1-15 hidden neurons were trained and tested 100 times. The average accuracy *AC* and standard deviation *SD* were calculated. The trained ANN was tested first on the known data (training set) and the obtained results are given in Table 2.

N_h	AC_{TR}	SD_{TR}
1	88.9135	0.0294
2	88.8916	0.1438
3	89.5994	0.0068
4	89.5946	0.0407
5	89.8698	0.0072
6	90.2554	0.0026
7	90.2669	0.0028
8	90.2634	0.0050
9	90.4363	0.0085
10	90.5152	0.0030
11	90.5457	0.0066
12	90.7006	0.0055
13	90.6066	0.0070
14	90.7260	0.0045
15	90.8749	0.0041

Table 2. The average accuracy AC_{TR} and standard deviation SD_{TR} on the training set.

After that, trained ANN was tested on the unknown data (testing set) and the obtained results are given in Table 3.

N_h	AC_{TS}	SD_{TS}
1	88.6541	0.1659
2	88.8055	0.2884
3	89.4039	0.0617
4	89.4760	0.0759
5	89.1513	0.0318
6	89.0225	0.0445
7	88.9284	0.0625
8	89.4008	0.0487
9	88.6030	0.0370
10	88.9596	0.0332
11	88.6450	0.0523
12	88.9875	0.0378
13	89.1885	0.0392
14	88.8073	0.0377
15	88.8522	0.0264

Table 3. The average accuracy AC_{TS} and standard deviation SD_{TS} on the testing set.

After every testing, given ANN architecture was asked to estimate *SAD* value for the inputs:

- *AGE* = 40,
- *BMI* = 30 kg/m^2,
- *SBP* = 140 *mmHg*,

- *DBP* = 90 *mmHg*,
- *TCH* = 4.50 *mmol/l*,
- *LDL* = 2.50 *mmol/l*,
- *HDL* = 1.29 *mmol/l* for women and *HDL* = 1.03 *mmol/l* for men,
- *TG* = 1.71 *mmol/l*,
- *GLY* = 7 *mmol/l*,
- *FIBR* = 3.50 *g/l*,
- *UAC* = 420 *μmol/l* in women and *UAC* = 360 *μmol/l* in men,

The average estimated *SAD* values are given in the Table 4.

N_h	Women	Men
1	23.0227	24.3730
2	23.3362	24.8505
3	23.2764	25.1590
4	23.4255	25.4680
5	23.2698	25.5885
6	23.2915	25.7968
7	23.3922	25.5725
8	23.4315	25.9148
9	23.9311	25.7852
10	23.2331	25.7575
11	23.2027	25.8702
12	23.0447	25.7870
13	22.9033	25.7799
14	22.7848	26.1893
15	23.1706	25.5934

Table 4. The average estimated SAD values for women and men.

Comparing results from Table 3, we conclude that the single-layered ANN architecture with 4 hidden neurons provides the best results (maximal average accuracy with standard deviation as small as possible), so it is accepted as the optimum. From Table 4, the values 23.4255 *cm* and 25.4680 *cm* are SAD limits respectively for women and men. This result is in accordance with [29].

4. Conclusion

In this paper, we have presented an ANN solution for estimating *SAD* low-limits for the adverse metabolic profile. Based on our results, if an woman has $SAD \geq 23.4255$ *cm* and if an man has $SAD \geq 25.4680$ *cm* then they will be classified as adverse metabolic profiles. This approach could be a useful tool in both, individual and public health prevention since it can select persons with increased cardiometabolic risk in an easy, non-invasive and cheap way.

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