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MULTIPLE SONOGRAPHIC FEATURES BASED IUGR DIAGNOSIS USING ARTIFICIAL NEURAL NETWORKS

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Foetal growth disorder is an important cause of perinatal morbidity and mortality. Any such disorder will have long term health implications for the survivor of Intra Uterine Growth Restriction (IUGR)[1]. Even though the accurate assessment of foetal growth during pregnancy is difficult, recent methods have improved this important aspect of obstetric care with positive implications for antenatal mothers and their babies. In this paper, a novel method using multiple features extracted from sonography of the foetus is proposed for developing a Computer Aided Diagnosis (CAD) system for identifying foetal abnormality. An artificial neural network classifier system is developed from a database of 100 cases containing 56 normal and 44 abnormal foetuses. The ANN then distinguishes abnormal foetus from the normal one based on five features such as Gestational Age (GA), BiParieatal Diameter (BPD), Abdominal Circumference (AC), Head Circumference (HC), and Femur Length (FL). The architecture of the ANN is based on statistical parameters such as Root Mean Square Error (RMSE) and degree of agreement (d). Performance of the developed ANN system is re-examined with new sonographic data in a generalized patient population of fifty cases (28 normal and 22 abnormal).

***Keywords**:* IUGR, ANN, RMSE, Foetal,

1. INTRODUCTION

Foetal Intra Uterine Growth Restriction (IUGR), formerly known as intrauterine growth retardation, is a confusing medical problem during pregnancy and is difficult to diagnose. One of the reasons for this confusion is the fact that the diagnosis is based on non-consistent definitions [2]. IUGR, therefore, remains a challenging problem for both the obstetrician and the paediatrician. IUGR, if left undetected, may result in stillbirth, may have detrimental effects on neuro-developmental progress in childhood, and may cause higher risks of degenerative diseases in adulthood [11][12]. The aim of detecting IUGR is to reduce perinatal morbidity and mortality, primarily by optimizing the timing of the delivery of the affected foetus [1][13].

1.1 Clinical Background

It is important to distinguish between IUGR foetuses (Fig. 1) and low weight foetuses. IUGR, used synonymously with Small for Gestational Age (SGA), implies a pathological condition. Often the term SGA is applied to a neonate and IUGR is applied to the foetus. The most widely accepted definition of IUGR is foetal weight below the 10th percentile for gestational age [1]. Unfortunately, this definition includes both constitutionally small and pathologically small foetuses.

There are two types of IUGR foetuses, symmetrically impaired and asymmetrically impaired. Symmetrically growth restricted foetuses tend to have impaired head growth during earlier stages of pregnancy and are often encountered in foetuses with infection or genetic and anatomic defects. Their mortality risk and intrapartum foetal distress risk are higher, in the range of 40-50% [1][14]. Asymmetric IUGR foetuses tend to have head growth that increases appropriately during earlier stages of pregnancy but lag behind during the later stages of pregnancy. This is expected in most cases of primary or secondary placental insufficiency, and accounts for two thirds of IUGR cases.

Figure 1: IUGR Foetus

1.2 Incidence

The incidence varies depending upon the population. About one third of all infants weighing less than 2500 grams at birth have IUGR and approximately 4-8% of all infants born in developed countries and 6-30% in developing countries are classified as growth restricted [1][15].

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1.3 Prevalence

The overall prevalence of IUGR is 10% because IUGR is defined to include all foetuses whose weight falls below the 10th percentile for gestational age[1]. The prevalence is not uniform across all populations, however, some groups have rates below 10% and others above 10%. In a population, where mothers are generally healthy and well nourished, IUGR occurs in approximately 3 to 5% of the cases. In women with hypertension or with previous history of growth restricted foetus, in contrast, the prevalence rises to 25% or more.

1.4 Diagnosis

One of the major requirements for accurate diagnosis of IUGR is the accurate calculation of gestational age. Assuming that dates can be determined from last menstrual period (LMP) or early first trimester ultrasound, the following are the ways to diagnose IUGR.

Clinical: Maternal weight gain and fundal height may be used but are not very sensitive with a low positive predictive value [1]. Clinical estimates of foetal weight are notoriously inaccurate especially in the lower foetal weight ranges.

Ultrasound: The most common determination of foetal growth restriction is based on the estimated foetal weight (EFW), determined from a combination of BPD and AC [1]. Foetal measurements using formulae incorporating more than one body part, such as BPD, HC, AC and FL, have the highest accuracy for in utero weight estimation. Other ultrasound parameters of use in the diagnosis of IUGR is the ratio HC/AC that normally exceeds 1.0 before 32 weeks, is approximately 1.0 at 32-34 weeks and falls below 1.0 after 34 weeks. In asymmetric IUGR, the HC remains larger compared to the AC because of the brain sparing growth phenomenon. In symmetric IUGR, the HC and AC are both reduced and therefore, the HC/AC ratio is not helpful. One more ratio that may be useful is the FL/AC ratio. In asymmetric IUGR, the FL is spared in comparison to the AC measurements from 21 weeks on and therefore, a ratio greater than 23.5 suggests the presence of IUGR [1].

Fluid measurements: Decreased amniotic fluid volume has been associated with asymmetrical IUGR. A vertical pocket of amniotic fluid less than 2 cms suggests the presence of IUGR. The four quadrant technique consists of measuring the vertical diameter of the largest pocket of the fluid found in each of the four quadrants of the uterus. The sum of the results is the amniotic fluid index (AFI). An AFI between 5 and 25 cm is normal and less than 5 indicates oligohydramnios [8].

Doppler: Doppler studies of the foetal, placental and uterine vasculature were developed in the 1980's and have since become an integral part of protocols used to assess IUGR Elevated uterine artery systolic/diastolic ratio greater than 2.6 and or the presence of diastolic notch are associated with IUGR and intrauterine foetal death [8]. Decreasing diastolic flow, absence of diastolic flow and reversed diastolic flow during a cardiac cycle are signs of worsening IUGR.

Clinical methods such as identifying risk factors and palpation detect only 49% of IUGR neonates; the false-positive rate can be as high as 71%. The sensitivity of serial measurements of Symphysis-Fundus Height (SFH), however, is higher than that of clinical methods and varies from 60 to 85%. A single ultrasound measurement of abdominal circumference around 34 weeks gestation has been shown to detect 85% of growth-retarded foetuses and its sensitivity is found to be better than SFH measurement. [3]. Therefore, ultrasonography is considered to be the most convenient and safe tool for classifying the IUGR foetuses.

The purpose of this study is to develop a diagnosis tool using artificial neural network model to identify IUGR foetuses. The rationale of this approach for achieving the goal is based on two factors. First, sonographic features are extracted automatically from an image by digital image processing techniques, thereby, inter-and intraobserver variability problems are solved. Then, by providing multiple sonographic feature values such as GA, BPD, AC, HC, FL to the ANN, the performance of the decision algorithm can be improved.

2. FEATURE EXTRACTION

To determine whether a foetus is normal or abnormal, five features such as gestational age, biparietal diameter, abdominal circumference, head circumference and femur length are extracted from ultrasonography [4].

Gestational age (GA): One of the major requirements for an accurate diagnosis of IUGR is an accurate calculation of gestational age. It is assumed that the required date can be determined from LMP or early first trimester ultrasound scanning.

Biparietal diameter (BPD): This parameter is used in the second trimester. It measures the diameter between the 2 sides of the head (Fig. 2). Studies report that the growth of the BPD in the mid trimester is linear and rapid and biological variation at each week of gestation is small. In 95% of the cases, the measurement of BPD between 14th and 26th weeks predicts the correct duration of gestation to an accuracy of +9 days. At times, when the foetal head may be short and wide (brachycephaly) or long and flattened (dolicephaly), the assessment of age from BPD will be either under estimated or over estimated.

Head Circumference (HC): This parameter, along with FL is used in the third trimester fig 2). It is measured at the same level at which the BPD is taken. It measures the outer

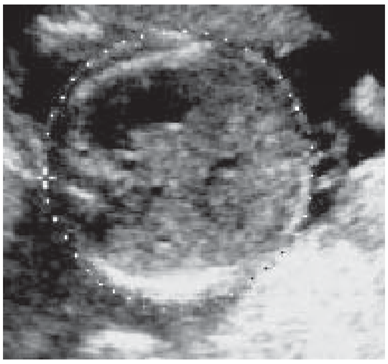

Figure 2: BPD & HC

margin of the skull. The accuracy of this parameter is ±2-3 weeks with 95% confidence interval.

Abdominal Circumference (AC): This parameter is less used for the assessment of gestational age (Fig 3). It is however, more used for monitoring foetal growth, especially in the third trimester and for the estimation of foetal weight. The abdominal circumference is shown by the white dots surrounding the structure in the middle of the image. The stomach is the black area located top left of the circle.

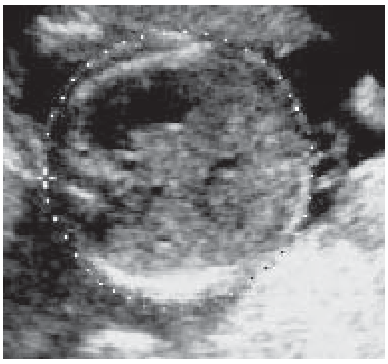

Figure 3: Abdominal Circumference (AC)

Femur Length (FL): The Femur length is a very useful biometric parameter used in the second and third trimesters of pregnancy (Fig 4). The femur, or thigh bone, is the white structure located near the top of the image. Its length is measured from one end to the other [white +], and reflects the longitudinal growth of the foetus. It grows linearly throughout the pregnancy and is best measured after 14 weeks of gestation. The accuracy of gestational age calculation by FL is within 6-7 days of menstrual age at 95% confidence level.

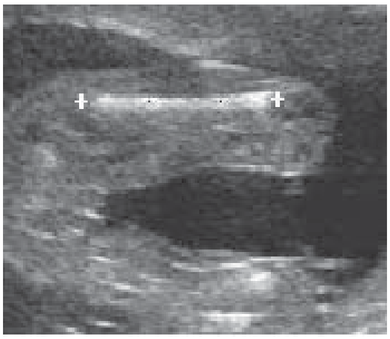

Figure: 4 Femur Length (FL)

3. NEURAL NETWORK CLASSIFICATION

To identify whether a foetus is normal or abnormal, an ANN classification system is proposed. This system is a general multilayer perceptron (MLP) neural network using the back propagation learning rule (refer Table 1).

3.1 ANN based IUGR Detection Modeling

The ANN based IUGR detection model consists of following steps

(1) Selection of optimal ANN based IUGR detection model architecture.
(2) Selection of the best activation function
(3) Selection of the optimum learning parameter ‘α’
(4) Initialization of network weights and bias
(5) Training and generalization of the model
(6) Evaluation of the model.

3.2 Statistical Parameters for Testing ANN based IUGR Detection Model

The statistical indicators used for testing and evaluating the IUGR detection model are Root mean square error (RMSE) and degree of agreement (d). The RMSE explains the actual size of the error produced by the model, defined as

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (P_i - O_i)^2 \right]^{1/2}$$

where, N = Total number of patterns
P = Predicted data
O = observed data

The ‘*d*’ is descriptive statistics. It reflects the degree to which the observed variate is accurately estimated by the simulated variate, and varies between 0 and 1. A computed value of 1 indicates perfect agreement between the observed and predicted observations, while 0 indicates the complete disagreement. The value of ‘*d*’ is expressed as [7]:

$$d = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} \left[\left| P_i - \overline{O} \right| + \left| O_i - \overline{O} \right| \right]^2}$$

where, $\overline{O}$ = average of the observed data.

Table 1
Summarizes the Criteria used in Developing the ANN based IUGR Detection Model

Sl. No	*Item*	*Criterion used in present study*	*Remarks*
1	Criteria for selection of neural network architecture	input neurons → number of input variables output neurons → number of output variables hidden neurons → smallest number of neurons that yields a minimum prediction error on the test data set	5 Input neurons (for GA, BPD, HC, AC, FL) 1 Output neuron (to determine normal/abnormal foetus) Chosen based on 'RMSE' and 'd', Refer table 3.
2	Criteria for selection of neuron activation function	Input neurons → identity function Output neurons → sigmoid function Hidden neurons → sigmoid function	$f(x) = x$ $f(x) = 1/(1+e^{-x})$
3	Criteria for selection of learning parameters	The learning parameters converge to the network configuration and give best performance on the test data with least number of epochs/iterations	Learning rate (á) is assumed to be 0.005
4	Criteria for initialization of network weights	Weights are randomly chosen	Refer table 5(a)-5(d) for final weights.
5	Training algorithm	Back propagation	It is a gradient descent method which minimizes the total squared error computed by the net.
6	Stopping criteria for neural Network training	After each training iterations/epochs the network is tested for its performance on test data set. The training process is stopped when the performance reach the maximum on test data set	Refer table 4
7	Statistics for model testing	Root mean square error (RMSE) and degree of agreement (d).	Refer table 3 and 4
8	ANN modeling data set	Training data set: for training neural network	100 cases (56 normal and 44 abnormal fetuses)
		Test data set : for testing neural network during training	50 cases (28 normal and 22 abnormal fetuses).

3.2.1 Data Normalization

Data are normalized so that they fall within a small specified range (refer Table 2). This is carried out using the **Min-Max Normalization.** Suppose that $\min_A$ and $\max_A$ are the minimum and maximum values of an attribute '*A*', Min – Max normalization maps a value *v* of A to *v*' in the range (new_min_A, new_max_A) by computing

$$v' = \frac{v - \min_A}{\max_A - \min_A}\,(new\_max_A - new\_min_A) + new\_min_A$$

Table 2
Shows the Original and Normalized Range for Selected Features

Sl No	Feature	Original Range	Normalized range
1	GA	[12,41]	[0,1]
2	BPD	[5,100]	[0,1]
3	HC	[60,350]	[0,1]
4	AC	[35,370]	[0,1]
5	FL	[5,80]	[0,1]

For example, if GA = 20, then normalized value = (20–12)/(41–12)*(1–0) + 0 = 0.275

3.2.2 Network Topology Determination

Network topology is systematically determined in terms of 'RMSE' and'*d*' [7]. The data consisting of approximately same number of normal and abnormal features are randomly chosen for training the network. Once trained, the network is tested with the test data set. ANNs having 15 different topologies were tested and results of six typical network topologies are summarized in Table 3. Finally, an ANN with topology having five input nodes to receive the extracted features, eight neurons in the first hidden layer, eight neurons in the second hidden layer, and one output node to indicate whether the foetus is normal or abnormal was selected since it showed the maximum value of '*d*' and minimum RMSE, ensuring maximum reproducibility. The estimates of the statistical parameters during the generalization of the IUGR detection model are summarized in Table 3. With $\alpha = 0.005$, the best model prediction on test data set is achieved at 11000 epoch (refer Table 4). The final synaptic weights of the model are shown in Table 5(a) to Table 5(d).

Table 3
Cross Validation Results of ANN for Different Network Topologies

Number of neurons in		*Statistical parameters*	
1st Hidden layer	*2nd Hidden layer*	*d*	*RMSE*
5	3	0.354839	0.935150
5	8	0.2	0.923711
5	10	0.2	0.923711
8	5	0.310345	0.911668
8	8	0.605634	0.857272
14	14	0.582090	0.918983

Table 4
Estimates of the Statistics during Generalization of the ANN Model

Epoch	*d*	*RMSE*
500	0.034483	0.986624
1000	0.034483	0.975332
2000	0.393939	0.943067
4000	0.446154	0.893499
5000	0.529412	0.887446
7000	0.529412	0.879551
8000	0.529412	0.877772
9000	0.529412	0.884717
10000	0.529412	0.876377
11000	0.605634	0.866523
12000	0.605634	0.861742
25000	0.605634	0.857272
28000	0.446154	0.892499
30000	0.034483	0.997496

Table 5
(a) Synaptic Weights in the ANN Model between Input Layer and Hidden Layer 1

	Hidden layer 1								
I	*unit*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
N	1	-0.1	1.2187	-0.3079	0.3171	0.2129	0.0055	-0.6167	0.1026
P	2	-0.1	1.6065	-0.5228	0.2295	0.4180	-0.3876	0.7564	0.2058
U	3	-0.1	-0.2885	-0.2259	-0.2574	-0.1966	-0.0693	-0.2592	0.3076
T	4	-0.1	-0.4984	0.2825	0.3883	0.2654	0.4760	0.0902	-0.0686
	5	-0.1	1.1176	-0.4373	0.4164	0.2107	-0.6206	-0.4279	-0.1964

Table 5
(b) Synaptic Weights in the ANN Model between Hidden Layer1 and Hidden Layer2

H *I*	*HIDDEN LAYER 2*								
D *D*	*unit*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
E	1	0.1000	-0.1000	0.1000	0.1000	0.1000	0.1000	-0.1000	0.1000
N	2	0.3108	-1.0497	-1.9166	-3.0035	1.0454	1.2837	-2.1986	0.1600
L	3	0.4106	-0.2219	0.4536	-0.0187	0.3323	0.4385	0.0004	0.3871
A	4	-0.1466	0.4928	0.4040	1.0414	-0.5414	-0.4895	0.8832	0.0142
Y	5	-0.2461	0.5417	0.4596	0.9493	-0.6420	-0.5921	0.9369	0.0638
E	6	0.5490	-0.6798	-0.6373	-1.9362	0.9337	1.4721	-1.2866	0.6467
R	7	-0.3119	0.5499	0.3359	0.0845	- 0.7052	-1.0364	1.0363	-0.4355
2	8	-0.2247	-0.0873	-0.0422	0.4324	0.00456	-0.4298	0.1456	-0.1844

Table 5
(c) Synaptic Weights in the ANN Model between Hidden Layer2 and Output Layer

	Hidden layer 2							
unit	1	2	3	4	5	6	7	8
Output layer	0.6715	-1.5778	-2.3282	-4.1582	1.7837	2.4367	-3.2894	0.7329

Table 5
(d) Biases in the ANN Model on Hidden Layer1 and Hidden Layer2 and Output Layer

	1	2	3	4	5	6	7	8
Hidden layer1	0.2000	-0.0388	0.1999	-0.0988	0.2009	-0.1112	0.1668	0.1001
Hidden layer2	0.0534	0.1393	0.4652	0.6583	-0.2441	-0.5966	0.7404	-0.0382
Output layer	0.5106							

4. CONCLUSIONS

The developed CAD program based on multiple sonographic features for IUGR detection using ANN is comparable to the clinical study in the similar patient population. Typical accuracy of classification on ultrasonography for IUGR is around 91 to 94%. There is no general rule in selecting ANN topology that would bring the best performance. In this paper cross validation is used to determine ANN topology. The ANN topology that showed the best accuracy and reproducibility is selected based the accurate values of RMSE, d. The results indicate that the selected features are adequate for the detection of IUGR.

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