haemodialysis, neural network

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MODELLING OF HEMODIALYSIS: REGRESSION VERSUS NEURAL MODEL[1]

In the paper, evaluation of two approaches to modelling of hemodialysis is performed. Results obtained by regression are compared to those generated by neural models. Differences in the modelling quality are small. Both models shown the same qualitative dependencies between analyzed parameters.

1. INTRODUCTION

In literature one can find many examples of mathematical modelling of chemical compounds, which are accumulated in the body of patient with chronic kidney dysfunction, for example [1, 4]. Taking complicated dependencies between processes in human body into consideration, large number of parameters were introduced and complicated mathematical models were created. These models were difficult to use in clinical practice due to a large number of input data a difficult to obtain.

The universal and commonly recognized index of the efficiency of the dialysis is *Kt/V* ratio, where *K* is the total urea clearance[2] – sum of the clearance of the dialyser and patient's kidneys, *t* – session duration, and *V* – total urea which is assumed to be the whole body water volume. It can be observed, that the efficiency of the dialysis is proportional to the total clearance and session duration, and inversely proportional to the distribution volume of urea. Equilibriated blood concentration (after fixed time since end of dialysis) of urea C_{eq} can also be used to assess dialysis' efficiency. On this basis the efficiency of the dialysis Kt/V_{eq} can be evaluated.

The research in artificial neural network (ANN) modelling of hemodialysis [2, 9] was carried out. The ANN gave very promising results. ANN was highly precise in predicting the equilibrated C_{eq} and equilibrated Kt/V_{eq} coefficients. Errors were small and fall into acceptable limits of clinical norms. However, the well known statistical techniques of linear regression could compete with neural models, especially in the simplicity of creation.

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1 Partly supported by the Polish Scientific Committee (KBN); grant no. 4T11E02925
2 Clearance – coefficient describing a level of a certain substance (here urea) filtration (here by a kidney) from blood. It represents the volume of blood (in [ml]), that is cleared in 1 minute from the certain amount of a substance (in [mg]).

2. NEURAL MODELLING AND REGRESSION TECHNIQUE

According to the applied methodology of The Dialysis Center in the Regional Hospital in Lodz satisfactory information about the efficiency of the dialysis gives the blood concentration of urea 30 minutes after the end of the dialysis. The research was divided into four parts.

In the first phase, the problem of predicting the equilibrium blood concentration of urea C_{eq} by the use of all postdialysis data has been solved using both mentioned techniques.

In the second phase, the regression has been performed to predict the equilibrated Kt/V (Kt/V_{eq}) by the use of all postdialysis data. The value of Kt/V_{eq} is predicted for the moment 30 minutes after the end of hemodialysis. In both phases a number of models were created, and the best ones for the given conditions were chosen.

When dialysis is over, a rapid increase of blood urea concentration is observed as urea still continues to be transferred into the central circulation system from other bodily compartments. This rebound, relatively greater in short high-efficiency dialyses, is not allowed for by the single-pool urea kinetic modelling (denoted henceforth by the superscript 'sp') and this is the reason why Kt/V_{sp} usually overestimates dialysis adequacy.

The aim of the third phase was to create models that able to predict C_{post} and Kt/V_{sp} coefficients by the use of predialysis data. The attempt to predict the values of C_{eq} and Kt/V_{eq} coefficients was also made. Here, C_{post} stands for blood urea concentration after dialysis session.

The data related to 180 patients were collected. Many parameters were taken into consideration: C_{pre}, C_{int} - blood urea concentrations before and at mid-point (here after 90 minutes) of the dialysis session, respectively; pre- and postdialysis body weights; height of the patient; hematocrit *Htk*; dialyser urea clearance; time; blood flow rate; dialysate flow rate; age; dialyser characteristics; residual renal clearance. The sets of data were the neural network inputs or they were used to create regression models.

Here, multiple regression and correlation analysis were applied. To obtain the best sets of parameters the method of forward stepwise regression was used. The "*F* to return" statistic value of forward regression was given a default value of 1 and "*F* to remove" statistic value was given a default value of 0. Level of significance was set to 0,05. In the first and the second phase the number of cases was 74, and in the third phase – 180. The method of forward stepwise regression was used to determine the subset of the most indicative parameters from the whole set of input parameters.

The basic ANN architecture was multilayer perceptron with one hidden layer [10,11]. In the experiments few neural networks with different number of hidden neurons were tested, but finally it turned out that the very simple model using sigmoidal activation function of the form (1) is sufficient – Fig.1.

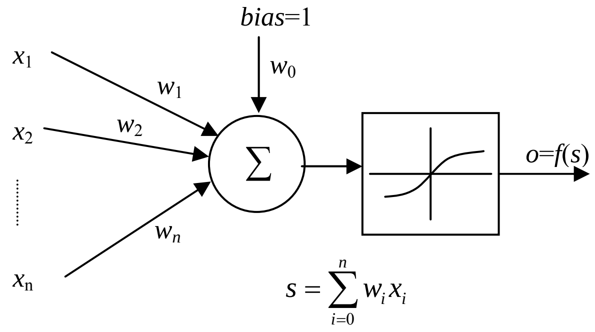

Fig. 1. Nonlinear perceptron

$$f(s) = \frac{1}{1+e^{-s}} \quad (1)$$

Because of the small amount of learning data, the well-known cross-validation learning method was applied. A resemblance to multiple regressions was observed.

3. COMPARISON OF MODELS

The last phase was to compare neural network model to regression models. Criterion was the mean-relative-error (MRE).

The regression model predicting C_{eq} is based on postdialysis data and the best set of parameters results in error of 3,5%. The corresponding neural network model leads to error 4,3%. With number of blood tests lowered to 1, both models show slightly worse results – errors 4,1% and 5,1%, respectively. However, all the results fall into clinical norm limits. Errors are shown in Fig. 2; they are compared to the Smye formula [4].

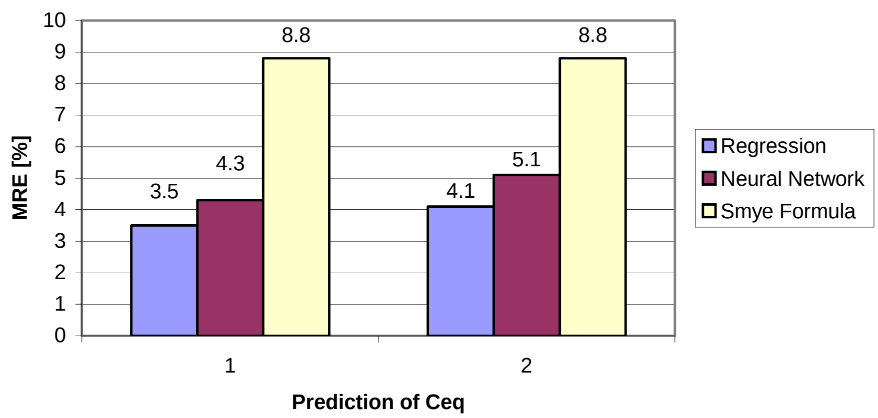

Fig. 2. Mean-relative-errors for models predicted C_{eq} by the use of postdialysis data;
1 – for the best set of parameters; 2 – for one blood test.

It can be observed that regression models are slightly better than neural networks.

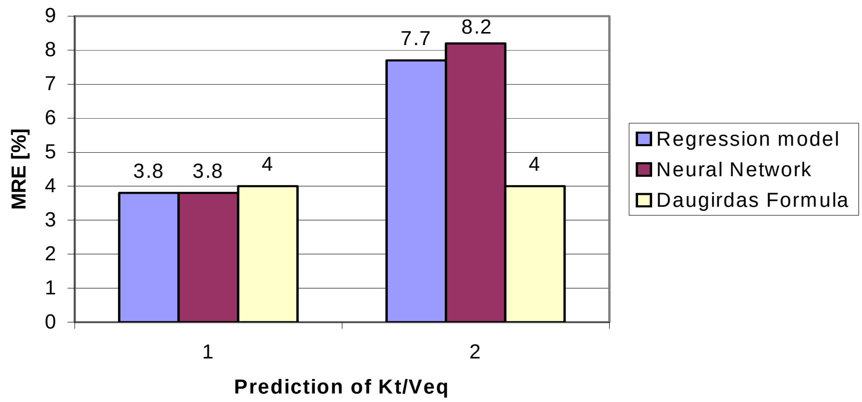

Fig. 3. Mean-relative-errors for models predicted Kt/V_{eq} by using postdialysis data; 1 – for the best set of parameters; 2 – for one blood test.

The error in prediction of Kt/V_{eq} based on postdialysis data and the best set of parameters, result in error of 3,8% for both methods. However, using just one blood test, the errors become significantly higher, although in clinical norm limits. They were 8,2% for neural network and 7,7% for regression, and the error of Daugirdas formula [1] is 4%; cf. Fig. 3.

With pre- and postdialysis blood tests, both errors (i.e. for neural network and regression model) are similar and comparable to Daugirdas formula error. Using one blood test, the errors of neural network and regression models are twice higher.

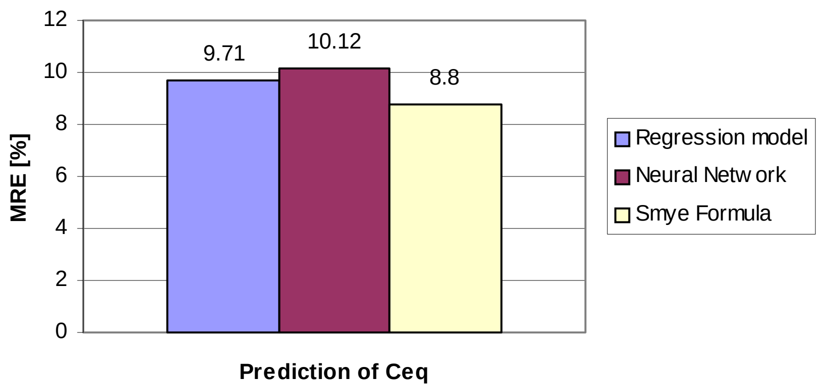

Fig. 4. Mean-relative-errors for model prediced C_{eq} by using predialysis data

Models using predialysis data can predict equilibrated parameters because they represent the actual state of patient after dialysis. The prediction error of urea concentration C_{eq} is as follows: 10,12% for neural network, 9,71% for regression model and 8,8% for Smye formula – Fig. 4.

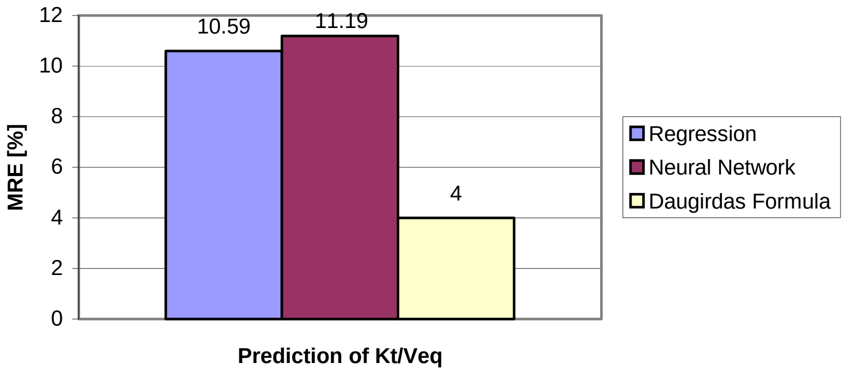

Fig. 5. Mean-relative-errors for model predicted Kt/V_{eq} by using of predialysis data

The models for prediction of equilibrated Kt/V_{eq} were not good enough. For both neural network and regression models, the errors were slightly higher than limits for clinical norms. Neural network model error is 11,19% while regression model error is 10,59%.

In general, regression models are slightly better than corresponding neural models.

4. SIGNIFICANCE ANALYSIS

Further analysis of input parameters has been performed using parameters indicated as the most relevant.

Usually, significance analysis indicated the same input parameters as being relevant. The differences appeared in model predicting C_{eq} by using postdialysis data without limited blood tests. For neural networks, significance analysis indicated C_{pre}, C_{post} and Kt/V_{sp} as relevant input parameters, while the stepwise regression method discovered only C_{pre} and C_{post}. However, the regression model without Kt/V_{sp} was better than the neural network. Also the Kt/V_{eq} predicting models based on postdialysis data without limited blood tests gave different sets of relevant input parameters. Neural network chosen C_{post} and Kt/V_{sp} parameters and regression method indicated Kt/V_{sp} only.

Also in [9] has been reported that the value of *Kt/Vsp* is a function of C_{pre} and C_{post}. This dependency can cause a difference between neural network and regression models.

Apart from the selection of the optimal set of input parameters, the existence of correlation of the results with medical knowledge is an important statement. The dependencies between input and output parameters discovered by all models were evaluated. Regression and neural network models indicate existence of the same dependencies between parameters.

5. CONCLUSIONS

It can be observed, that both regression and neural network methods are suited for prediction of hemodialysis process. They discovered similar sets of relevant input parameters and their errors were very similar.

However, correctness of statistical models can be established by the hypothesis verification theory. It helps to assess the model. Neural network error is the main indicator of network's quality. Both methods require good knowledge of the modelled processes. In case of lack of the knowledge, it can be easier to create a neural network then a statistical model.

Creation of neural network can be performed in a few steps. First, the problem has to be represented in the form related to the type of ANN. Secondly, network topology, number of layers, number of hidden neurons and activation function must be chosen. Then, the learning phase is completed. Finally, tests on some data should be performed to attain the required quality of the network.

Regression models allow defining the meaning of dependencies discovered. Coefficients of the regression function inform how the change of the value of a single parameter influences the change of the output. Neural networks do not allow precise interpretation of their weights.

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