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ORIGINAL REPORT

ARTIFICIAL INTELLIGENCE TECHNIQUES: AN EFFICIENT NEW APPROACH TO CHALLENGE THE ASSESSMENT OF COMPLEX CLINICAL FIELDS SUCH AS AIRWAY CLEARANCE TECHNIQUES IN PATIENTS WITH CYSTIC FIBROSIS?

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Objective: **To construct an artificial intelligence application to assist untrained physiotherapists in determining the appropriate physiotherapy exercises to improve the quality of life of patients with cystic fibrosis.**
Subjects: **A total of 42 children (21 boys and 21 girls), age range 6–18 years, participated in a clinical survey between 2001 and 2005.**
Methods: **Data collected during the clinical survey were entered into a neural network in order to correlate the health state indicators of the patients and the type of physiotherapy exercise to be followed. Cross-validation of the network was carried out by comparing the health state indicators achieved after following a certain physiotherapy exercise and the health state indicators predicted by the network.**
Results: **The lifestyle and health state indicators of the survey participants improved. The network predicted the health state indicators of the participants with an accuracy of 93%. The results of the cross-validation test were within the error margins of the real-life indicators.**
Conclusion: **Using data on the clinical state of individuals with cystic fibrosis, it is possible to determine the most effective type of physiotherapy exercise for improving overall health state indicators.**

Key words: cystic fibrosis; physical therapy modalities; neural networks (computer); pattern recognition automated.

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INTRODUCTION

Cystic fibrosis: history and current situation

Cystic fibrosis (CF) is an autosomal genetic disease that mainly affects Caucasian people, as shown by Taussig (1), who also describe the side-effects of the disease: diarrhoea, sinus infections, malformed growth and, most problematic, difficulty in breathing caused by abnormal secretions in the lungs.

The life expectancy of people with CF varies from country to country, but is generally low and is influenced by the quality of medical treatment and by age at diagnosis. However, using a proper combination of drug therapy and physiotherapy, the symptoms of CF can be ameliorated, and the patient's quality of life and life expectancy may increase (2, 3).

Various physiotherapy techniques and their effect on the patient's state have been reported (4–10).

In Romania, there are 7 regional centres and a national centre for the treatment of CF, which was founded in 2006 at Timisoara, as described on the National Center for Cystic Fibrosis webpage (11). Following a diagnosis of CF, patients are examined at the local level (i.e. family physician, local specialist). Every 3 months, patients should also be examined at the regional centre, where they receive treatment recommendations (drugs and physiotherapy). Further examinations are performed once every 6–12 months at the national centre for CF.

The regional centres, although they provide good management of patients with CF, are not fully equipped (staff and equipment) to manage all CF-related problems. The only fully equipped centre is the national centre at Timisoara.

We do not intend to discuss drug therapy for CF in this article. Different physiotherapy techniques have different effects on patients with CF, depending on multiple factors: disease severity, availability of medication, quality of training, etc. A constant challenge is determining the most suitable physiotherapy exercise for a given patient based on the medical records available. This skill is acquired through years of practice and is not easy to gain. The importance of an appropriate physiotherapy recommendation for patients with CF becomes more obvious when one takes into account that a mistake can have severe (or even deadly) consequences.

Aims of the study

The aims of this study were to describe and construct a computer-aided tool that can predict the effects of a certain physiotherapy exercise, taking into account the various health state indicators of the patient. The tool is a neural network that was trained, based on real-life data, to estimate the health state of a patient after they have followed a certain physiotherapy exercise for an established period of time, knowing his or her initial health state. Whilst such a tool may not be necessary for an experienced physiotherapist, it is very useful during the instruction of untrained physiotherapists (beginners, nurses

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or students), in order to ensure that they follow and apply internationally accepted protocols (2, 4). The tool described here may also be used in the regional centres to compensate for the lack of qualified personnel.

Artificial intelligence and medical artificial intelligence

At the confluence of information science, computer science and healthcare, medical informatics has been defined as a stand-alone discipline since 1977. Artificial intelligence is a branch of computer science that evolved from the desire to simulate the functions of a living brain. Among the tools of artificial intelligence, artificial neural networks (ANN) are used to solve difficult real-life problems, without necessarily creating a model. An ANN consists of individual processing units (called neurons) that store, process and transmit information. One of the most efficient ways of extracting statistical summaries from inferred data are ANNs, which are able to learn patterns and map input data to particular classes of results, as shown, for instance, by Slavici (12). According to Russell & Norvig (13), artificial intelligence has been used in medicine since 1984 and is primarily concerned with the construction of programmes for diagnosis and therapy recommendations.

MATERIAL AND METHODS

A standard surveillance period is defined as the period between two consecutive visits to the regional centre (3 months).

Data collection and usage

The clinical study was requested by the institutional review board of the National Cystic Fibrosis Center in Timisoara. All the participants in the study (or their tutors) understood and agreed that their data should be collected and used anonymously for medical and statistical purposes. These anonymously collected data were further used to construct the ANN.

Clinical study

Data collection involved 42 test subjects, with 20 (9 boys and 11 girls) subjects in the age range 6–12 years, and 22 (12 boys and 10 girls) in the age range 12–18 years. At the beginning of the study, the mean age was 12.4 years. The work was carried out in the Pediatric Clinic II and Cystic Fibrosis Center Timisoara. All of the subjects had various levels of CF and, based on this criterion, a particular exercise was assigned to each subject to practice on at least a weekly basis. This rehabilitation programme was carried out over a period of 4 years (2001–2005) and was designed in accordance with internationally accepted physiotherapy techniques (5, 14, 15). Its effectiveness was monitored periodically through:

- clinical evaluation, i.e. general clinical condition and nutritional status; cough and sputum character; presence of dyspnoea; presence of chronic obstructive lung disease signs; pulmonary physical signs (wheezing, rales, etc.);
- paraclinical evaluation, i.e. bacteriological examination of sputum or hypopharyngeal aspirate; pulmonary X-ray and computed tomography (CT); pulse oximetry; pulmonary function tests;
- evaluation of the effectiveness of the specific physiotherapy exercises and aerosol therapy.

Drug treatment was administered to the patients by specialized physicians and consisted of: mucolytics, bronchodilators, corticosteroids, pancreatic enzymes, vitamins, minerals, antioxidants and antibiotics if needed. All patients received the same type of medication and followed the treatment. Suggestions concerning the physiotherapy exercises to be used were made based on references such as Selvadurai et al. (16) and personal experience. Thus, appropriate physiotherapy exercises were recommended for every standard surveillance period. Since the airway clearance techniques should be performed on a regular basis, but their long-term benefit is rather moderate (this fact was underlined, for instance, by Flume et al. (17)), we used a combination of 3 major types of exercise: respiratory training (huffing games or TRAINAIR), physical exercises (mild- or medium-intensity exercises), and airway clearance techniques (oscillating positive expiratory pressure (PEP), autogenic drainage (AD) and active cycle of technical breathing (ACBT)). The specific combination of exercises was chosen according to various factors: severity of disease, complexity of exercise appropriate to the age of the patient, socio-economic status of the patient's family, etc.

Computer-aided approach

Based on the data collected during the clinical study, a neural network was trained to correlate the health state indicators at the beginning of a standard surveillance period, the type of physiotherapy exercise recommended during this period, and the health state indicators at the end of the surveillance period.

The architecture of the network consisted of one input layer with 12 elements, 1 hidden layer with 13 neurons and an output layer with 11 elements. Corresponding to the input layer, 12 data of two types were fed into the network:

- *a priori* data, i.e. the health state indicators of the patient at the beginning of the standard surveillance period. These data are either qualitative (i.e. general clinical state, nutritional status, cough characteristics, physical respiratory marks, radiological signs, CT scan, respiratory infection case) or quantitative/percentages (i.e. forced expiratory flow (FEF), forced expiratory volume in 1 s (FEV_1), ratio of forced expiratory volume in 1 s and forced vital capacity (FEF/FEV_1), forced vital capacity (FVC)). The overall clinical state has 3 levels: good, average and compromised. The features of the nutritional status are: good, growth failure, moderate growth failure, severe growth failure and weight gain. The cough characteristics are a combination of 3 characteristics: frequent, rare or absent; productive, unproductive or abundant; green, greenish-yellow, yellowish, or yellow. The physical respiratory marks have 3 values: rare broncho-alveolar rales, disseminated broncho-alveolar rales, and hyperinflation. The radiological and CT signs refer to: emphysema (generalized or bullous), micro-nodular opacities, bronchiectasis of different levels and located on different lobes. The respiratory infection case refers, according to Sordelli et al. (18), to the presence of either non-pathogenic flora or *Pseudomonas aeruginosa* and/or *Staphylococcus aureus*.
- *a posteriori* data, i.e. the type of exercise that should be followed by the patient to achieve the corresponding health indicators at the end of the standard surveillance period. More precisely, it refers to 1 of the 12 possible combinations of the following types of exercises: huffing games or TRAINAIR; mild- or medium-intensity physical exercises; oscillating PEP, AD or ACBT.

The output contains 11 elements describing the health state indicators at the end of the standard surveillance period corresponding to the *a priori* initial data.

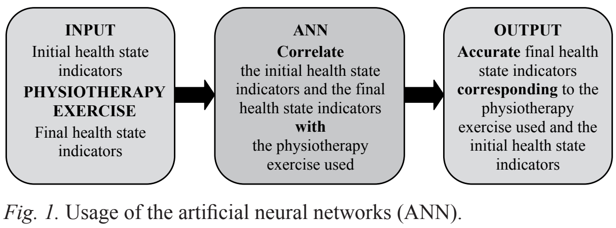

Fig. 1. Usage of the artificial neural networks (ANN).

Original qualitative data		Non-pathogenic flora		*Pseudomonas aeruginosa*		*Pseudomonas aeruginosa* and *Staphylococcus aureus*		*Staphylococcus aureus*	
Coding intervals	**0**		**0.25**		**0.50**		**0.75**		**1**
Coded input		**0.125**		**0.375**		**0.625**		**0.875**	

Fig. 2. Coding and decoding of qualitative data (example).

The functioning of the ANN is presented schematically in Fig. 1.

To obtain better convergence, all the data were re-coded into discrete values between 0 and 1. For a given qualitative data, with *n* levels, the interval [0; 1] was divided into *n* subintervals. As input data, the mean value in an interval was chosen to represent one specific feature. As output data, any value in the interval corresponding to a certain term was assigned to that term. The quantitative data were coded by division by 100.

All the qualitative data were coded/decoded in the same manner as in the case of the respiratory infections presented below (Fig. 2). The order of the qualitative terms has no special meaning, but is still important to be set. The mean of the second subinterval, 0.375, represents the input coded data corresponding to an infection with *Pseudomonas aeruginosa* and is fed into the ANN. Any value between 0.25 and 0.50 returned by the ANN is decoded as an infection with *Pseudomonas aeruginosa*.

Currently, there is no automatic choice of the exercise that should be followed in order to achieve the best results or the selection of the different exercises that should be followed during more than one standard surveillance period. However, the outputs corresponding to the *a priori* inputs could be fed again into the network, and thus the estimated results of different types of exercises could be obtained for the next standard surveillance period.

Cross-validation

A real-life test was designed to cross-validate the results of the ANN. At the beginning of a standard surveillance period, the *a priori* clinical results for a patient, together with various types of physical exercises, were fed into the network. The network's prediction was noted in all cases. The specialist recommended a certain physical exercise during the standard surveillance period. At the end of the standard surveillance period, the clinical results of the patient were compared with the results predicted by the network. The validity of the ANN result is given by the number of matches (or correlation between predicted values of indicators and real values of indicators) reported to the number of indicators considered. The quantitative data are considered to match if the predicted value of the indicator is inside the confidence interval of the real value of the indicators. This correlation was computed at the end of the surveillance period.

RESULTS AND DISCUSSION

The clinical study

Based on the clinical and paraclinical evaluations at the beginning of the study, the patients received appropriate medication and physiotherapy recommendations. Their physical state was evaluated at the end of each standard surveillance period, and the medication and physiotherapy recommendations were modified accordingly. It has been claimed (19, 20), that an improvement of 10–15% of the FEF per year is enough to state that the physiotherapy is efficient.

The monitored health state indicators and their evolution are presented below.

While, at the beginning of the study, 17 patients had a good clinical state, 8 a mean clinical state, and 17 a compromised clinical state, at the end of the study the clinical states of all patients improved or, at worst, remained constant (Fig. 3). At the beginning of the study 17 patients had good nutritional status, 11 presented signs of growth failure, 11 presented signs of moderate growth failure, and 3 presented signs of severe growth failure. All the patients with good nutritional status maintained it during the surveillance period, and all the patients with moderate growth failure presented a weight gain.

Initially all the patients presented a certain level of cough, but at the end of the study the cough was absent for 6 patients (initially presenting rare cough signs). All the patients initially diagnosed with hyperinflation maintained their diagnosis, 8 patients initially diagnosed with disseminated broncho-alveolar rales were diagnosed with rare broncho-alveolar rales, and 3 patients initially diagnosed with broncho-alveolar rales were diagnosed with hyperinflation. Forty-one patients maintained the same level of radiological and CT signs during the study, and one patient presented at the end of the study signs of micronodular

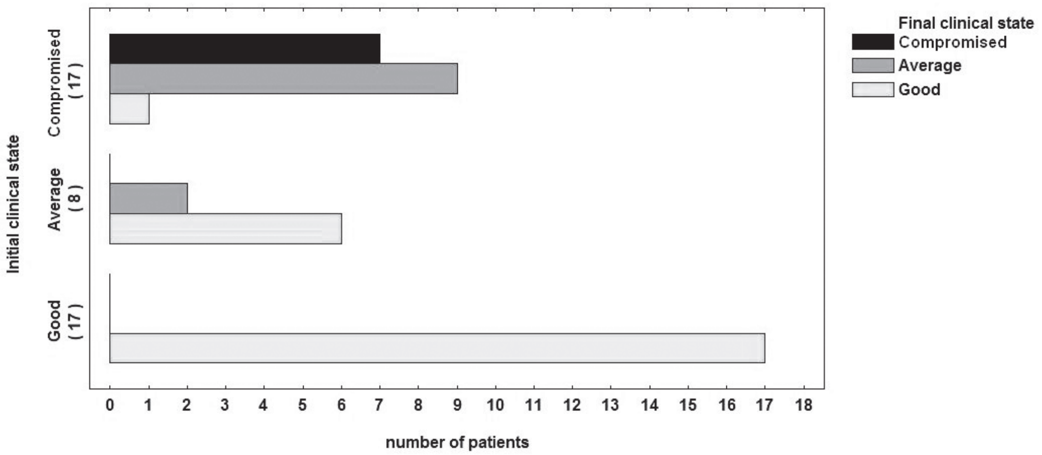

Fig. 3. Initial vs final clinical state of the patients.

Table I. *Quantitative health state indicators*

Indicator	Min–Max	Mean (SD)
FEF, %		
Initial values	28–68	48.52 (11.425)
Final values	38–78	57.07 (10.32)
Individual evolution	0–20	8.55 (4.76)
FEV_1, %		
Initial values	34–97	60.55 (17.28)
Final values	42–99	68.86 (16.06)
Individual evolution	0–20	8.31 (4.88)
FEF/FEV_1, *n*		
Initial values	48–90	70.33 (11.24)
Final values	60–95	76.38 (8.84)
Individual evolution	–9–22	6.05 (6.90)
FVC, *n*		
Initial values	56–110	82.40 (17.71)
Final values	61–116	89.12 (16.59)
Individual evolution	0–20	6.71 (5.69)

FEF: forced expiratory flow; FEV: forced expiratory volume in 1 second; FVC: forced vital capacity; SD: standard deviation.

opacities in addition to the initial generalized emphysema. From the total number of participants, 38 maintained the respiratory infection state, and 4 eliminated the initial respiratory infection.

The evolution of the quantitative indicators (FEF, FEV_1, FEF/FEV_1, FVC) are summarized in Table I. The individual evolution represents the evolution of a certain indicator for a certain patient.

It can be observed that, after carrying out the appropriate physiotherapy exercises, all the patients improved or, at worst, maintained their health status indicators.

Table II describes the overall evolution of the patients during the clinical survey. For each indicator, the number of patients who maintained the initial level of a certain indicator, the number for whom the initial level of a certain indicator improved, and the number for whom the initial level of a certain indicator worsened are listed.

The neural network

We have shown that appropriate physiotherapy exercises (recommended by experienced physiotherapists), together with appropriate medication (recommended by experienced physicians), could ameliorate the health status indicators for the patients with CF. However, what if the physiotherapist does not have the experience, or the CF centre does not have a staff physiotherapist? The neural network we created will help to address these inconveniences.

In creating an appropriate model to fit the patients' data, two aspects should be taken into account:

- the available patients' recordings do not cover all the possible combinations of data; and
- there are both qualitative and quantitative data to take into account.

These issues are solved by using artificial intelligence, more specifically, a classification neural network. An ANN could be trained to predict the health status indicators of a patient (both qualitative and quantitative) depending on the physiotherapy exercise followed during a standard evaluation period. The construction of the neural network was described previously in the Methodology section.

The trained ANN showed a correlation of 93% between the outputs (i.e. the values actually returned by the ANN) and the targets (i.e. the values expected to be returned by the ANN). This suggests that there exists a correlated data model, and this model can be learned by appropriate means and further used.

Cross-validation

The health state indicators of a newly diagnosed patient were recorded following the same procedures used during the initial study. The recordings were subsequently processed independently by the physiotherapist involved in the clinical survey and by the computer scientist who created the ANN. At the end of a standard surveillance period, the concrete results obtained for the patient were compared with the results predicted by the ANN. All differences observed between the predicted and actual values of the parameters were within the error margins.

This procedure was repeated over the period of a year, and each time, the computer scientist correctly predicted the evolution of the health state indicators for the given physiotherapy exercise followed by the patient. Even if the ANN correctly predicted the evolution of the patient's health state, the values of these indicators did not change dramatically after the first surveillance period. Table III presents the real values of the health indicators and the predicted values of the same indicators for two different combinations of physiotherapy exercises.

Actual limitations and further developments

Construction of the ANN was accomplished by taking into account the medical records of 42 patients, age range 6–18 years. The limitations of our tool and the further improvements that can be made derive from this fact (i.e. the input data considered). Further improvements are related to an increase in the medical recordings entered into the ANN (e.g. increasing the number of medical records, extending the age groups of patients), which will determine an increase in the accuracy of prediction of the ANN.

Another limitation is the supposition that the patients comply with the recommendations of the physiotherapist and continue

Table II. *Overall clinical evolution of the 42 patients*

Indicator	Maintained *n*	Improved *n*	Worsened *n*
Overall clinical state	26	16	0
Nutritional status	24	18	0
Cough characteristics	22	20	0
Physical respiratory marks	31	8	3
Radiological signs	40	2	0
CT signs	42	0	0
Respiratory infection case	38	4	6
FEF	2	40	0
FEV_1	1	41	0
FEF/FEV_1	7	31	4
FVC	7	35	0

CT: computerized tomography; FEF: forced expiratory flow; FEV: forced expiratory volume in 1 s; FVC: forced vital capacity.

Table III. *Real evolution of health indicators vs 2 predicted values of indicators*

	Real values of the indicators		Predicted values of the indicators	
Indicator	Initial state	Final state	Final state	Final state
Physiotherapy exercises followed	[Not the case]	Huffing games Mild exercises AD	Huffing games Mild exercises AD	Huffing games Medium exercises ACBT
Overall clinical state	Good	Good	Good	Average
Nutritional status	Good	Good	Good	Good
Cough characteristics	Rare, unproductive	Rare, unproductive	Rare, unproductive	Rare, productive
Physical respiratory marks	Hyperinflation	Hyperinflation	Hyperinflation	Hyperinflation
Radiological and CT signs	Generalized emphysema no bronchiectasis	Generalized emphysema no bronchiectasis	Generalized emphysema no bronchiectasis	Generalized emphysema bronchiectasis
Respiratory infection case	Non-pathogenic flora	Non-pathogenic flora	Non-pathogenic flora	Non-pathogenic flora
FEF	68	78	76	70
FEV_1	85	89	86	86
FEF/FEV_1	83	82	82	83
FVC	102	108	105	104
Correlation	[Not the case]	[Not the case]	11/11=100%	[Not the case]

CT: computerized tomography; FEF: forced expiratory flow; FEV: forced expiratory volume in 1 s; FVC: forced vital capacity; AD: autogenic drainage; ACBT: active cycle of technical breathing.

to follow the drug therapy, which is not always the case, given their age and the specific problems of teenagers (e.g. recklessness, stubbornness, rebellion). As these latter limitations could not be included in the ANN without adding more input data (e.g. a psychological evaluation of the patient), the response of the ANN is limited to a phrase of the form: "If a patient with the medical recordings A follows the recommended physiotherapy technique B and the recommended drug therapy, his or her final health state indicators would be C with a probability of 93%". In addition, a possible aggravation of the initial health state of a patient due to late detection of the disease was not taken into account.

Further developments should include listing all possible health state developments due to all physiotherapy exercises considered in a single output (i.e. eliminate the physiotherapy technique from the inputs of the ANN and modify the output so that it contains all the physiotherapy techniques and their corresponding health state indicators as predicted by the network), and estimating the health status of a patient after more than one standard surveillance period.

Currently, the neural network we have constructed is used for training and demonstration purposes at the National Cystic Fibrosis Center in Timisoara. It has proved very useful, especially as the network can accurately indicate the efficiency of a certain combination of physiotherapy techniques, without the risk of subjecting a real patient to unsuitable therapies. In future, a user-friendly interface will be constructed and the neural network will be distributed to the regional cystic fibrosis centres.

CONCLUSION

This clinical survey showed that appropriate physiotherapy exercises, recommended and surveyed by a qualified physiotherapist, can significantly improve the health status of a patient with CF and, eventually, his or her lifestyle.

The ANN we created could estimate (predict) the effects of various physiotherapy exercises on the health status of a patient, depending on his or her known health state, with an accuracy of 93%. At this stage, the tool could be useful in training physiotherapists and as a cross-validation method for experienced specialists. In addition, it could be used at regional and local CF centres to compensate for the lack of qualified staff. The final result is an improvement in the medical services offered to patients with CF.

Artificial intelligence provides powerful interdisciplinary instruments that contribute essentially to improvement in the quality of medical services. These instruments could be applied, not only to lung diseases, but also to the enhancement of quality of life for patients with potentially lethal diseases, such as CF.

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