From: Proceedings of the Twelfth International FLAIRS Conference. Copyright © 1999, AAAI (www.aaai.org). All rights reserved.

This Is a Publication of
The American Association for Artificial Intelligence

This electronic document has been retrieved from the
American Association for Artificial Intelligence
445 Burgess Drive
Menlo Park, California 94025
(415) 328-3123
(415) 321-4457
info@aaai.org
http://www.aaai.org

*(For membership information,
consult our web page)*

The material herein is copyrighted material. It may not be
reproduced in any form by any electronic or
mechanical means (including photocopying, recording,
or information storage and retrieval) without permission
in writing from AAAI.

From: Proceedings of the Twelfth International FLAIRS Conference. Copyright © 1999, AAAI (www.aaai.org). All rights reserved.

This Is a Publication of
The American Association for Artificial Intelligence

This electronic document has been retrieved from the
American Association for Artificial Intelligence
445 Burgess Drive
Menlo Park, California 94025
(415) 328-3123
(415) 321-4457
info@aaai.org
http://www.aaai.org

*(For membership information,
consult our web page)*

The material herein is copyrighted material. It may not be
reproduced in any form by any electronic or
mechanical means (including photocopying, recording,
or information storage and retrieval) without permission
in writing from AAAI.

From: Proceedings of the Twelfth International FLAIRS Conference. Copyright © 1999, AAAI (www.aaai.org). All rights reserved.

This Is a Publication of
The American Association for Artificial Intelligence

This electronic document has been retrieved from the
American Association for Artificial Intelligence
445 Burgess Drive
Menlo Park, California 94025
(415) 328-3123
(415) 321-4457
info@aaai.org
http://www.aaai.org

*(For membership information,
consult our web page)*

The material herein is copyrighted material. It may not be
reproduced in any form by any electronic or
mechanical means (including photocopying, recording,
or information storage and retrieval) without permission
in writing from AAAI.

From: Proceedings of the Twelfth International FLAIRS Conference. Copyright © 1999, AAAI (www.aaai.org). All rights reserved.

This Is a Publication of
The American Association for Artificial Intelligence

This electronic document has been retrieved from the
American Association for Artificial Intelligence
445 Burgess Drive
Menlo Park, California 94025
(415) 328-3123
(415) 321-4457
info@aaai.org
http://www.aaai.org

*(For membership information,
consult our web page)*

The material herein is copyrighted material. It may not be
reproduced in any form by any electronic or
mechanical means (including photocopying, recording,
or information storage and retrieval) without permission
in writing from AAAI.

From: Proceedings of the Twelfth International FLAIRS Conference. Copyright © 1999, AAAI (www.aaai.org). All rights reserved.

Expert System for the handling of the attendance Mechanical Ventilation in recently born

Mauricio F. Deabate
Departamento de Computación
Universidad Nacional de Córdoba
- F.C.E.F. y N. –
Av. Velez Sarfield 1600 - C.U. -
5000 - Córdoba, Argentina -
deabate@arnet.com.ar

Luis Manzanares
Servicio de Terapia Intensiva
Hospital Maternidad Nacional
Universidad Nacional de Córdoba
Santa Rosa 1047
5000 - Córdoba, Argentina –
neomat@powernet.com.ar

Carlos A. Bartó
Departamento de Computación
Universidad Nacional de Córdoba
- F.C.E.F. y N. -
Av. Velez Sarfield 1600 - C.U. –
5000 - Córdoba, Argentina -
cbarto@gtwing.efn.uncor.edu

Abstract

The present work is an Expert System, called LETi, carried out in CLIPS. It was perfomed in a medical environment, the Neonetal Intensive Care Unit of the Maternity and Neonatal University Hospital. Althouth this unit specializes in different pulmonary pathologies which uses mechanical ventilation in thier rehabilitation therapy, this application centers on the most frequent problem, the Respiratory Distress Syndrome. The problem tackled here is the mechanical ventilation control by means of rule based sytems. This sytem will advise the professional assistant on what decision to make related to the veriables of the mechanical ventilation, based on the specific parameters being controlled on the infant.

Introduction

Approximately 10% of the newborn go to the Intesive Care Unit of this Hospital; thirty or fourty percent of these need Mechanical Ventilation (MV) due to the different illnesses they suffer from at this stage of their lives. Example of these are: Respiratory Distress Syndrome (RDS) in premature infants, persistence of the fetal pattern, pulmonary hypetension in term infants, lung malformations, congenital cardiopathologies, infectious ilnesses, etc.

In order to give correct respiratory assistance, adequate infrastructure, appropriate technology and human resources properly trained in such assitance are needed.

MV is necessary and vital in all these cases. However, like most therapeutic interventions, it implies certain risks in the short and long run.

During MV, the following risks may take place (Klaus1993, Sinclair 1991, Holtzman 1992, Schaffer 1991, Boyton 1995):

Copyright © 1999, American Association for Artificial Intelligence (www.aaai.org). All rights reserved.

1. Airblock Syndromes: pneumothorax, pneumopericardium, pneumoperitoneum, interstitial emphysema and pneumomediastinum.
2. Multiple or prolonged intubations can produce acquired subglottic stenosis with the consequent necessity for tracheotomy.
3. The prolonged administration of oxygen in premature Infants by means of the MV can cause retinopathy of premature in their different degrees of severity.
4. The development of bronchopulmonary dysplasia can lead patients to prolonged use of oxygen with the limitations that it brings about.
5. The intracranium hemorrhages and their consequences: hydrocephalus, leukomalacia lesions, psychomotor delays and alterations of superior functions.

These problems imperil the quality of life for the patients who receive this therapy and increse the cost of the health care system. This deepens the current lack of resources in the hospitals, a characteristic of the developing countries. Therefore, it is necessary to optimize the use of the MV in newborn with respiratory diseases.

It is known that the patients that need MV have altered lung functions such as compliance, resistance of the airways, their time constants, and their breathing work (Harris 1988, Dreizzen 1989, Carlo 1986). Recently, by means of monitors of lung functions, the degree of commitment produced by the illness in the patient's breathing system, and therefore, the moment in which these functions approach the normal parameters and the moment in which the patient does not require MV any longer, can be deduced (Lloyd 1994, McDonald 1992, Rosen 1989).

At the present, in Argentina, the physician determines when the patient no longer need a MV by analysing of clinical, radiological and laboratory parameters. However this method is so subjective that sometimes the patient is withdrawn from the MV before it is appropriate, and must be put back soon after, thus putting the patient’s life at

further risk. Other times, the patient's extubation is delayed unnecessarily, thus prolonging this high-risk therapy (Carlo 1986, Carlo 1988, Chatburn 1983).

The present work was undertaken with the objective of integrating the biggest quantity of information offered by the patient, in an Expert System, so that it can guide the physician to optimize the use of the MV.

Problem to solve

The problem is the control of the variables of the mechanical ventilation: positive inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), inspiratory time (IT), respiratory rate (RR), inspired oxygen concentration (Fi_{O2}); these variables should be considered in order to normalize the following parameters on the newborn: partial pressure of arterial oxygen (Pa_{O2}), Partial Pressure of arterial carbon dioxide (Pa_{CO2}), Oxygen Saturation ($Sat.O_2$), Compliance (C), Thorax X-ray Inspection (Rx), Thoraxic Excurtion (Tx), Tidal Volumen (T.V.), Time Constant (Time ct.). Once these parameters are normalized, the values of the variables should be taken from the mechanical ventilation to the lowest possible point maintaining the normality of the parameters of the infant (Milner 1985, Greenough 1987, Greenough 1991, Heicher 1981, Marini 1989).

Most of the patient's parameters can be normalized if the ventilator works properly, except for the Time ct. However, it should be kept in mind that the time constant is necessary for making decisions when handling the variables of the ventilator in order to normalize the other parameters.

So, eight parameters of the newborn are measured, four of which are measured on-line, by means of a Vital Sign Monitor (Sat.O2) and a Lung Function Monitor (C, T.V., Time ct.), and by means of clinical (Rx, Tx) and laboratory (Pa_{O2}, Pa_{CO2}) inspection. Also, the ventilator is controlled by means of 5 on-line variables (PIP, PEEP, IT, RR, Fi_{O2}) whose values are obtained from a serial RS232 interface. Therefore, the system has 13 inputs: the values of the parameters measured on the newborn plus the values of the variables of the Ventilator, and 5 outputs: the new values which the Ventilator variables take.

Consequently, the values taken by the variables of the Ventilator are also inputs to the System, since the values taken as output by the system will depend on their current value. Figure 1 shows an outline of the general operation of the system.

First, only one of the five possible pathologies from which a neonate may suffer during its first hours of life, and whose therapy is based, to a great extend, on the correct handling of a Ventilator was considered: RDS, which is the most frequent and the most severe from which to recover.

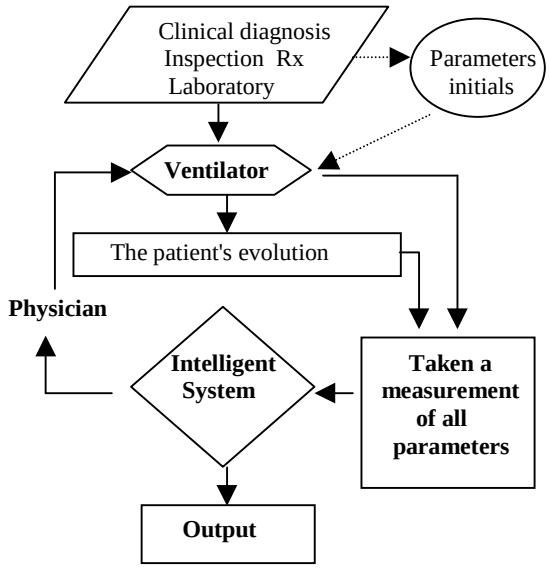

Figure 1. General representation of the System

Knowledge Acquisition

When meeting the expert, the first step was the acquisition of knowledge (Gonzalez 1993). Knowledge that is not formally represented by the expert is in principle, for him, the decision to make in each situation depended on the measure of each of the variables, and on the general analysis of the problem and he represented the solution by means of physical and physiologic knowledge.

It took approximately 2 months to outline the knowledge used in the solution of the problem. The acquisition and formalization of the knowledge were carried out by means of personal interviews and the presentation of the prototype at each step. It is worth mentioning that such a procedure was the best one in order to show the possible capacity of the system to the expert.

General strategy for the generation of rules

For this pathology (RDS) the following steps were carried out:

The neonate's parameters were divided into exact ranges of normality: high, normal and low. These ranges were crisply defined by the expert.The inexact linguistic terms that may have induced a possible fuzziness of these sets were not used. In daily practice, the actions depended on the state of these variables: if they were low (smaller than a certain threshold value), normal (within a certain range of values), or high (higher than a certain threshold value).

The exact definition of these limits for the states of the parameters of the neonate was needed for an objective, concrete answer when confronted with a critical

situation such as what these patients have to go through during their first hours of life.

The variables of the ventilator are increased or decreased in constant (small) steps, which do not depend on the evolution of the neonate's illness. The way in which the biological parameters vary, it is impossible to foresee their response to action taken on such to the ventilator's variables but it is not possible to foresee the patient's reaction to this action. So it is convenient to modify the variables in a constant and controlled fashion. The way to obtain this smoothness in the control is this constant and steady increase or decrease. This is the way in which the expert handles the ventilator's variables daily.

The problem was finally outlined in the following way:

I. Because there are 8 parameters of the neonate that are being measured and considering the 3 possible states (low, normal, high) of each of these parameters, there will be 6561 possible combinations of these parameters.

Considering that not all the possible combinations of these parameters are feasible, physiologically speaking, their number is significantly reduced.

Since the normalization of all these parameters is not possible at the same time, an order of priorities for the physiological normalization of the parameters of the infant was established. Table 1 illustrates this point.

Order	Normalization of parameters
1-	To normalize pO2
2-	To normalize pCO2
3-	To normalize V.T.
4-	To normalize Rx
5-	To normalize Tx
6-	To normalize Cte of Time

Table 1. Order of priorities for the physiologic normalization of the neonate's parameters.

First, the normalization of the most important parameters, Pa_{O2} and the Pa_{CO2}, was undertaken considering that the other parameters and variables adopted normal values for these cases. Therefore the normalization of other parameters in these cases was not considered.

II. The group of possible combinations was divided into MV cases (actions on the ventilator for certain states of the inputs variables), most of which contained more than one combination of neonate's parameters for one prescription of the actions to take on the ventilator. That is to say, each parameter of the case can be in more than one state (for e.g. C = normal | high), to trigger the case. This explains why each case is made up of more than one possible combination of the parameters.

In the first instance, for the normalization of Pa_{O2} and Pa_{CO2}, 11 cases of possible MV were represented: 1) low Pa_{O2} and low Pa_{CO2}, 2) high Pa_{O2} and high Pa_{CO2}, 3) low Pa_{O2} and high Pa_{CO2} , 4) low Pa_{O2} and normal Pa_{CO2}, 5) normal Pa_{O2} and high Pa_{CO2}, 6) high Pa_{O2} and normal Pa_{CO2}, 7) normal Pa_{O2} and normal Pa_{CO2} with low Time ct., 8) normal Pa_{O2} and low Pa_{CO2}, 9) high Pa_{O2} and low Pa_{CO2}, 10) normal or low Pa_{O2} and low Pa_{CO2}, 11) normal Pa_{O2} and normal Pa_{CO2} with high Time ct..

For example, for the case of high Pa_{O2} and high Pa_{CO2}:

Pa_{O2}	> 85 cm H_2O (high)
Pa_{CO2}	> 50 cm H_2O (high)
Sat. O_2	> 95% (high)
C	> 0.5 ml/cm H_2O (high)
T.V.	< 7 ml/Kg (normal or lower)
Rx	< 9 espaces (normal or low)
Tx	normal or low
Time ct.	not considered.
PIP	> 15mmHg
PEEP	> 3 mmHg
RR	< 70 resp/min
Fi_{O2}	> 21%
IT	> 0.25 seg.

Which imply the following sequence of actions on the Ventilator:

1º To increase RR up to 70 resp/min and to diminish PIP up to 25 cmH_2O.

2º To diminish Fi_{O2} up to 40% and to diminish the IT up to 0.25 sec.

3º To diminish PIP up to 20 cmH_2O and to diminish PEEP up to 3 cmH_2O.

4º To diminish Fi_{O2} up to 21%.

As can be seen, this case contains more than one possible combination of patterns (the patient's parameters and variables of the Ventilator) which, in common, will have the action to take on the 5 variables of the Ventilator (PIP, PEEP, IT, Fi_{O2}, RR).

III. These first 12 cases of MV, represent, approximately some 100 combinations within the possible physiological combinations. The solution of these cases generated a Knowledge Base of 595 rules.

IV. Each case results in a series of actions, executed sequentially, which are applied on the variables of the ventilator, depending on the state of the sick infant's parameters and of the current state of the variables of the ventilator.

For example, table 2 shows the steps to follow, as was already indicated in ittem II, for the case of high Pa_{O2} and high Pa_{CO2}.

As it is observed, the actions to follow are divided into one orderly sequence of actions (plan) in order to reach a good oxygenation (to normalize Pa_{O2}) and into another, in order to obtain a good ventilation (to normalize the Pa_{CO2}).

Order	**high Pa_{O2}**	**high Pa_{CO2}**
1	To diminish PIP until 25cmH_2O	To increase RR up to 70
2	To diminish Fi_{O2} up to 40%	To diminish the IT up to 0.25 sec.
3	To diminish PIP until 20cmH_2O	To diminish PEEP until 3cmH_2O
4	To diminish the Fi_{O2} until 21%	

Table 2 - Sequence of steps to follow in this case.

Since these decisions are completely independent of each other, it is necessary to consider all the possible combinations of all actions, in order to get a good oxygenation and a good ventilation, since they will act jointly. This particular case generated 46 rules. There were also cases of MV with low Pa_{O2} and low Pa_{CO2} and with low Pa_{O2} and normal Pa_{CO2} which generated 86 rules each case, and of low Pa_{O2} and high Pa_{CO2} which generated 97 rules.

V. After generating the rules in order to normalize Pa_{O2} and Pa_{CO2}, work was continued on the rules that act on the other parameters of the neonate (C, Rx, Tx, T.V., Time ct, Sat. O2 is normalized together with Pa_{O2}) following the order of priorities established by the expert (see Table 1), also considering the state of Pa_{O2} and of Pa_{CO2}.

In this moment, the most of least habitual cases of MV were studied.

In order to generate the rules that this heuristic involves, it was necessary to return to the knowledge acquisition stage being this time the strategy of acquisition, the generation of all the combinations of possible patterns, keeping in mind the physiologic impossibilities to eliminate many of them. Having all these combinations logically described, the expert solved and classified each combination in terms of frequency of occurrence; this implied working on aproximately 120 combinations.

Once all these combinations were worked out, they were grouped considering the actions that they had in common and, therefore, the rules that they had in common. Thus, in this way the cases of MV that contain each one of these combinations were generated in this way.

For the generation of these rules, the same strategy was continued. For example, Table 3 shows, the number of possible combinations that were made.

As can be observed, the sequential actions that should be followed for the normalization of the other parameter in question (in example C) were added to the rules that had been generated for the cases of MV of normalization of Pa_{O2} and Pa_{CO2}. See Table 3.

Order	**normal Pa_{O2}**	**high Pa_{CO2}**	**Another parameter to normalize, C in this case**
1	To diminish Fi_{O2}	To increase RR	To diminish PIP and PEEP
2	To diminish PIP	To diminish IT	To increase IT
3	To diminish PEEP	To diminish PEEP	To increase RR
4	To diminish IT		

Table 3 - Sequence of actions to normalize Pa_{O2}, Pa_{CO2} and another parameter, in this case C.

In some cases the MV actions to be continued were contradictory, for example:

If (Pa_{O2} = normal) = > decrease PEEP

If (Pa_{CO2} = low) = > increase PEEP

Then, the order of priorities already mentioned (See Table 1) for the plan of normalization of the neonate's parameters was considered. This order was already usually considered by the expert when confronted with contradicting situations. This way this conflict was eliminated.

Verification and Validation

These two processes were never completely separate. As has been explained, the knowledge is formally represented in MV cases; each of which was put together in a separate way and subjected to a superficial verification and to an exhaustive validation. Then, an exhaustive verification and a new validation were performed. These two processes were always executed together because it was necessary to prove each case on supposedly real situations, which always led to some observation made by the expert and, therefore to some modifications or improvements. Finally each case of MV underwent an exhaustive verification. This approach was taken because the expert was able to formalize his knowledge and, at the same time, acquire training for the representation of the problem in the form of rules.

The test cases for each MV case were first formed following the same logic as was used when the rules were generated, thus triggering the biggest number of possible rules (superficial verification). Then, tests cases were presented wich represented a patient's real situations. Answers were obtained which were not always the expected ones (first exhaustive validation). Afterwards, each MV case was subjected to tests cases

which triggered all the rules of the case and their answers were matched against the expected ones. Last, a definitive validation was performed. This way, a high error percentage, around 50%, was obtained at the end of the first validation. This was mainly due to the to the incorrect formulation of the MV case, and, less frequently, to the deficient knowledge contributed by the expert. It is remarkable to mention how this error percentage diminished after the second verification, achieving finally, after the last validation, 100% agreement with the expert. Over the course of time, the intervals needed to reach a total agreement with the expert became shorter, so the first validation became more and more accurate and, in some MV cases, the second validation became even unnecessary. Once the MV cases were put together, and the final system was completed, LETi underwent an exhaustive verification by means of real tests cases (successfully treated patients' clinical histories). A great similarity to the decisions taken by the Physician (though not exactly the same ones) was reached. The small differences did not entail any danger to the infant. On the contrary, the system was more conservative in certain situations. Later, the system was subjected to another validation by other experts. To this purpose, record sheets were given out to the most important ICU's in Córdoba city (Argentina). These sheets had to be filled out with information about each case of RDS and which briefly explain the steps that were to be followed to reach the patient's rehabilitation. So far, we have received many answers; However, the answers received are of great importance, since they allow us to match this system against experts that are totally outside of this project.

Conclusions

From the point of view of the development of the software, the Problem-solving has been largely covered. It still needs to be extended to other important, albeit less frequent than RDS, illnesses, such as: Pulmonary Hypertension, Respiratory System malformations, Diaphragm Hernia and Cystic Adenomatosis, infectious processes as Congenital Pneumonia.

A knowledge base could be developed to replace the monitoring of lung functions, thus saving important economic resources.

A user's graphic interface is planned to be developed by means of wxClips.

With regard to the hardware, on-line data is still pending because of the type of instrumentation available at the moment. This will be carried out as a last step.

From the medical point of view, the expectations for its application in past cases have been covered. These expectations with regards to the setting in operation of the integrated System.

References

Gonzalez, A., and Dankel, D. eds. 1993. *The Engineering of Knowledge-based System.* Reading Mass.: Prentice-Hall, Inc.

Parsaye, K., and Chignell, M. eds. 1988. *Expert System for Expert.* Reading, Mass.: John-Wesley and san.

Brownstone, L., Farrell, R., Kant, E., and Martin N. eds Gonzalez A. 1998. Advanced Intelligent Systems. Ph. D. diss., Dept. of Computer, National University of Córdoba.

Klaus and Fanaroff, 4ta edition 1993, *Care of the High Risk Neonate.*

Sinclair J. And Bracken M., Oxford University Press 1991, *Effective Care of the Newborn.*

Holtzman, R.and Frank, L., eds. September 1992. *Clinics in Perinatology. Bronchopulmonary Dysplacia.*

Carlo W. and Chatburn R., 2da edition 1988, *Neonatal Respiratory Care.*

Schaffer and Avery, 6ta edition 1991, *Diseases of the Newborn.*

Harris, T. eds.2nd. 1988. *Phisiological Principles. In: Glodsmith, MD, Karotkin, MD. Eds. Assisted ventilation of he neonate.*

Reading, Mass.: Saunders.

Boyton B., Carlo W. and Jobe A. Cambridge. 1995. *New terapies for neonatal Respiratory Failure.*

Milner, A.1985a. Inspiratory time and tidal volume during internittent positive pressure vemtilation. *Arch. Dis. Children* 12: 422-427.

Carlo, W. 1986. Efficacy of computer-assisted management of respiratory failure in neonates. *Pediatrics* 139-143.

Lloyd, J. May/June1994. Continuous in-line respiratory monitoring in the critically ill preterm infant. *Neonatal Intensive Care.*

McDonald, K. Nov/Dec. 1992. Continuous neonatal pulmonary mechanics with the BICORE CP 100 monitor. *Neonatal Intensive Care.*

Rosen, W. 1989. Bedside pulmonary function testing reduces pneumothoraces during infant ventilation. *Pediatric Research* 4: 324 A.

Dreizzen, E. 1989. Passive total respiratory system compliance and gas exchange in newborn with Hyaline Membrane Disease. *Pediatric Pulmonology* 6: 2-7.

Carlo, W. eds. 1986. Principles of Neonatal assisted ventilation. *Pediatr. Clin. North Am.* 33: 221-37.

Greenough, A. 1991. Comparation of different rates of artificial ventilation for preterm infants ventilated beyond the first week of life. *Early Human Develation* 26:177-83.

Chatburn A. 1983. Clinical Algorithm for pressure-limited ventilation of neonates with respiratory distress syndrome. *Respiratory Care* 28: 1579-86.

Greennough, A. 1987. Synchronous respiration: Which ventilator rate is best?. *Acta Pediat. Scan.* 76: 713-18.

Marini, J. 1989. Determinants and limits of pressure present ventilation: a mathematical model of pressure control. *J. Appl. Physiol.* 67: 1081-92.