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# Therapeutic process formalization in the treatment of respiratory failure in infants

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**Abstract**

The model described formalizes the therapeutic process developed in the Pediatric Intensive Care Unit (PICU) of Merate's Hospital as a support of medical decisions and as a continuous control of the adequacy of the ventilatory therapy. Causal and temporal structure of the keypoints of the treatment are represented by Petri Nets.

The model could be utilised in different pathologies and for different clinical approach giving a meaningful organizational impact.

## Introduction

The necessity of modeling the therapeutic procedure derives from the necessity to reduce both the empirism and the individualism in clinical decision making, providing a common methodological framework for the training of junior doctors and for the day-by-day clinical practice.

This paper reports the experience of Merate's Pediatric Intensive Care (PICU) in the modeling of the ventilatory support during the treatment of severe broncho-pneumonia in infants 3–12 months old. It formalizes the therapeutic process as a repetitive procedure, focusing on the causal and temporal structure of the key-points of the treatment.

The stimulus for this experience was given by the introduction of an Expert System in the PICU concerned the support of medical and nurse decisions upon the artificial ventilation. The task of the expert system was to evaluate respiratory parameters set up by the doctor on the mechanical ventilator in order to adjust these parameters to the actual clinical condition of the infant.

## Methodology

The methodology chosen for the modeling of clinical process was the Condition/Event (C/E) Petri nets notation, where events (the squares) may occur depending on a set of conditions (circles).

Petri nets allow to describe concurrent processes, not only sequential processes. In the case of therapeutic interventions, as in other complex processes, certain actions must be undertaken in parallel, and only when their results are available it is possible to move on to the next step.

Petri nets allow to describe systems at several levels of abstraction. The same language can be used for the more general description of a system as well as for low-level details of a computer application. Intensive care can be described in a top-down method, with a hierarchy of levels of abstraction. At each level only few key nodes are represented. Details of each node can be developed at lower levels.

With this rappresentation was possible to describe the actions at different levels: starting from a

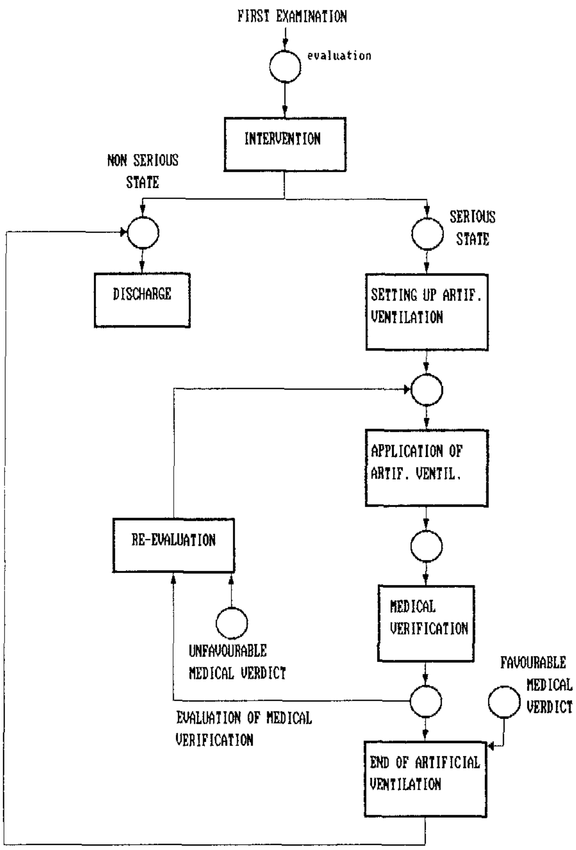



*Fig. 1.* General representation of highest level procedure for patient's treatment.

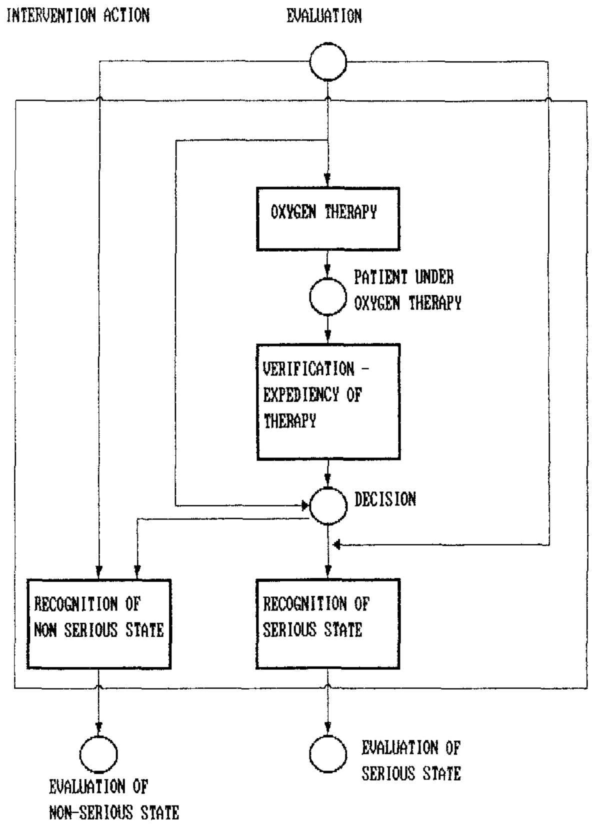



*Fig. 2.* Intervention-action during first observation of the patient.

general net, it was obtained a specific and particular detail.
Petri nets was definited during different stages:
(1) consultation of specialized literature;
(2) realization of a primitive informal procedure made by the director of the PICU;
(3) doctor's and nurse's discussion of this primitive procedure and consequent modification;
(4) validation of the final procedure in 50 sick infants.

## Description of the model

### *General representation*

The net of highest level is described in the Fig. 1. It presents the general structure and includes the whole therapeutic procedure for the patient (from first meeting with the doctor up to discharge from the department or the hospital). From this general structure, it is possible to obtain consequent differentiated nets.

### *Infant first examination and assessment (Fig. 2)*

Through the first examination, a tentative diagnosis of the respiratory failure is made and, in case of emergency, a symptomatic therapy is administered (eg. oxygen therapy).

This first step is greatly influenced by the experience of the operator and his collaborators. The immediate availability of adequate technical equipment would facilitate the task of the operators.

At this first stage, infants may be subdivided into two broad categories:
(i) Infants who are in a 'non acute' respiratory

failure (non serious state) requiring no therapy or, in case it should result necessary, who may continue following the therapy at home or in a general ward. In this case the procedure would then end with the discharge after examination and assessment.

(ii) Patients in 'acute' respiratory failure (serious state) who need immediated therapeutic intervention. It will be possible to assess the severity of illness and the kind of respiratory support to be followed through the response of the patient to the first intervention. Therapy administration would require admission to the PICU and utilisation of specific equipment as mechanical ventilators.

In case of a particularly ill infant, symptomatic therapy (heart massage, ventilation support, etc.) is administered without waiting for a precise diagnosis. Its effectiveness will be assessed in order to decide, on the basis of the patient's critical condition, any further necessary intervention.

*Setting artificial ventilation (Fig. 3)*

Such procedure will be carried out following different protocols in relation to the severity of illness and clinical condition of the infant.

It provides for the specific equipment needed for the ventilation and for the preparation of the patient.

Preparation of ventilator and patient may be implemented following two different methods in relation to the severity of illness. Once the patient and the specific equipment for his treatment have been prepared, the ventilatory therapy is administered following a pre-established protocol which covers the specific scientific knowledge and the results of the treatment experienced on infants having same characteristics in same conditions.

In case the preparation of a patient has taken place in emergency, it will be completed when possible.

*Infant preparation*

It is strictly related to the severity of illness and to the urgency to ventilate the infant. It consists of various actions (venous catheterization, electrodes

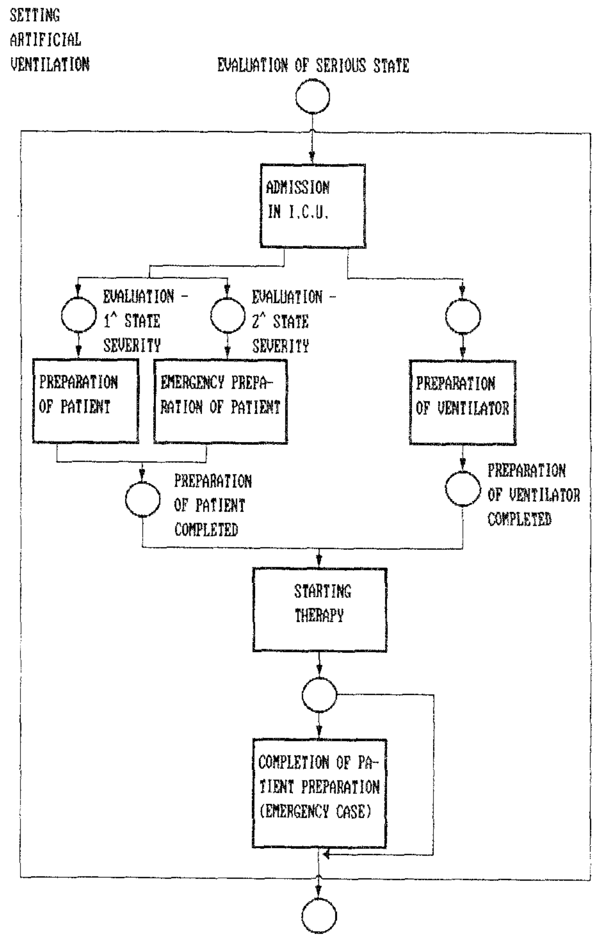



*Fig. 3.* Setting and starting artificial ventilation. Evaluation of serious state and admission in I.C.U.

application for ECG, laboratory tests, etc.) which allow a continuous monitoring of the patient as well as of the therapy. The accuracy of the preliminary interventions will help in obtaining better results from the therapy (Fig. 4).

In case of conscious or non-conscious infant, it could be necessary to provide sedation and/or curarization before to performe the tracheal intubation.

The urgent preparation (2nd state of severity, Fig. 5) of the infant is related to the severity of the respiratory failure and will follow a sequence differing from the previous diagram (Fig. 4).

Preliminary intervention will be minimized to step immediately to the tracheal intubation without sedation or curare administration, application of electrodes for ECG, etc.. Final preparation will

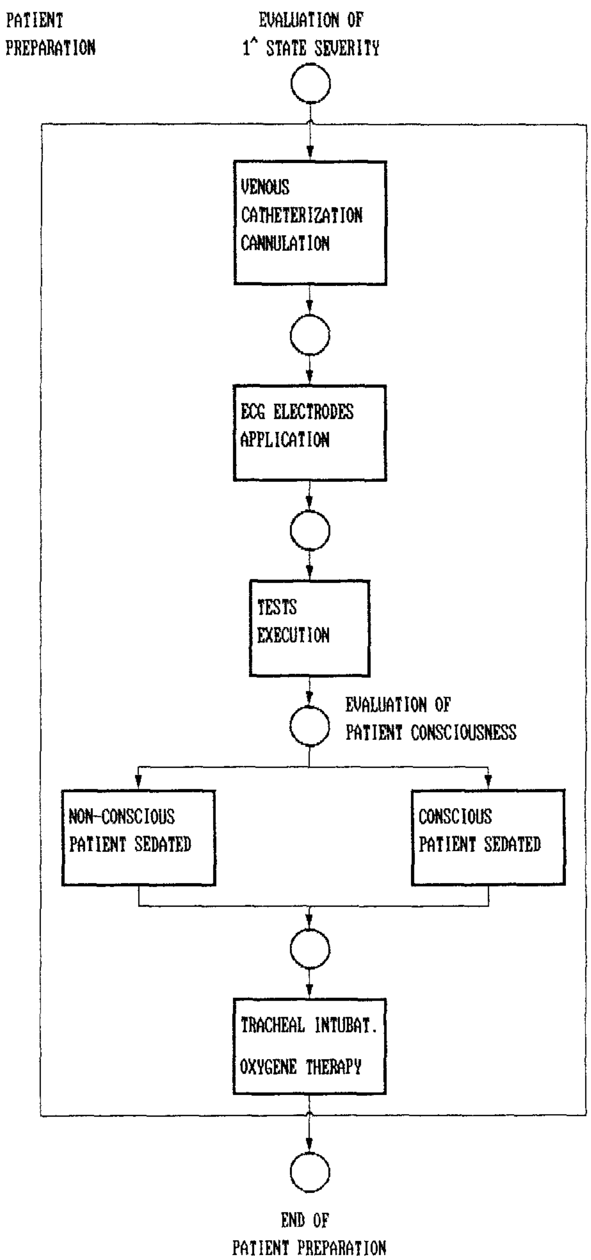



*Fig. 4.* Preparation of patient on I state of severity.

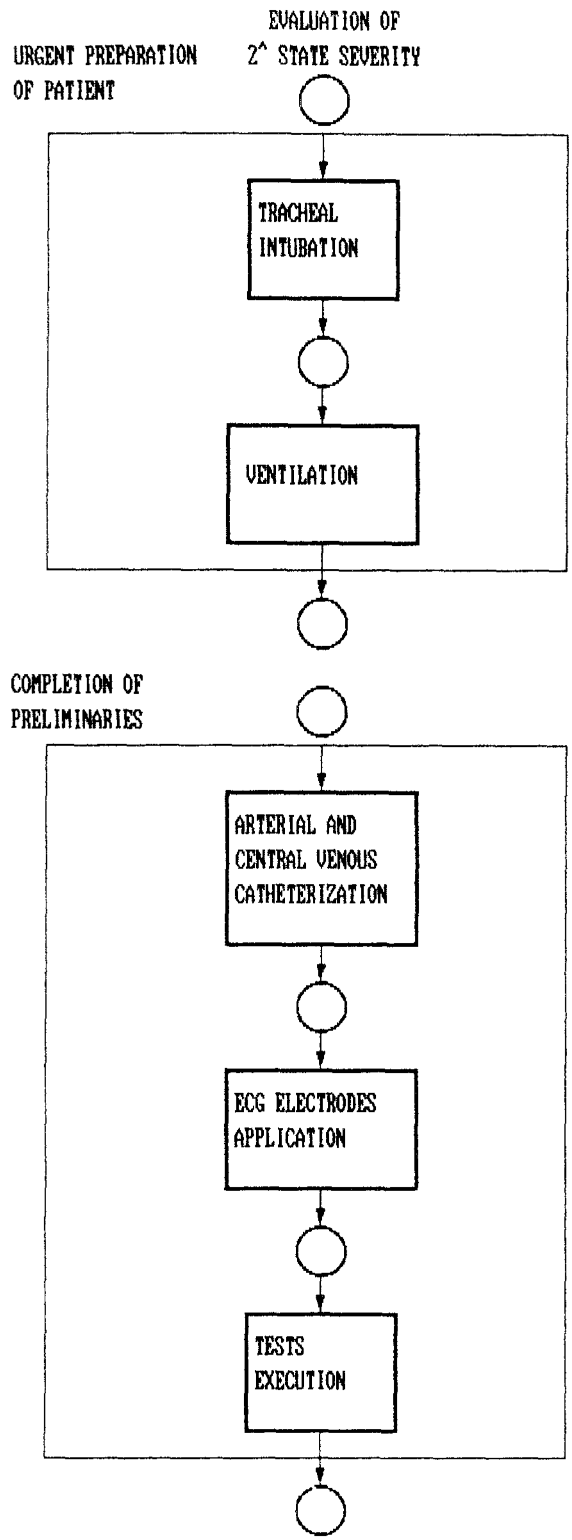
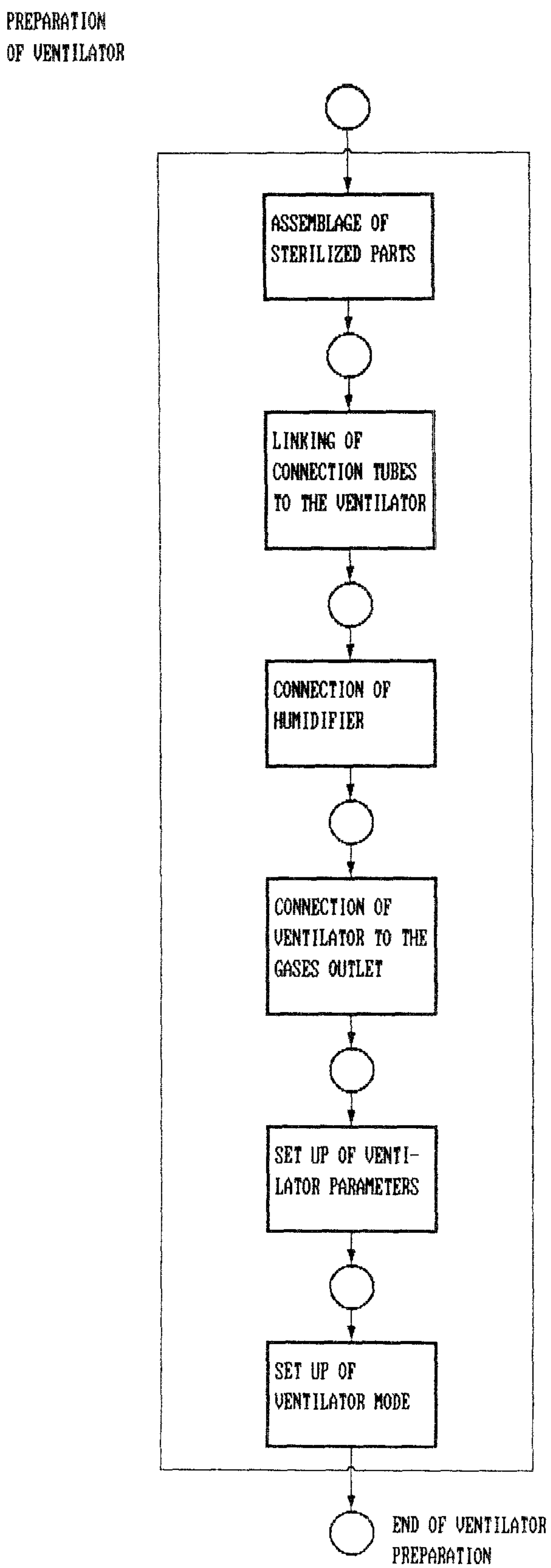



*Fig. 5.* Urgent preparation of patient to treat on artificial ventilation.

be completed no soon the urgency is over and consists of the same actions (venous catheterization, electrodes application for ECG, etc.) described for the infant of the 1st state of severity.

*Preparation of the ventilator*

It includes any and all the actions which influence



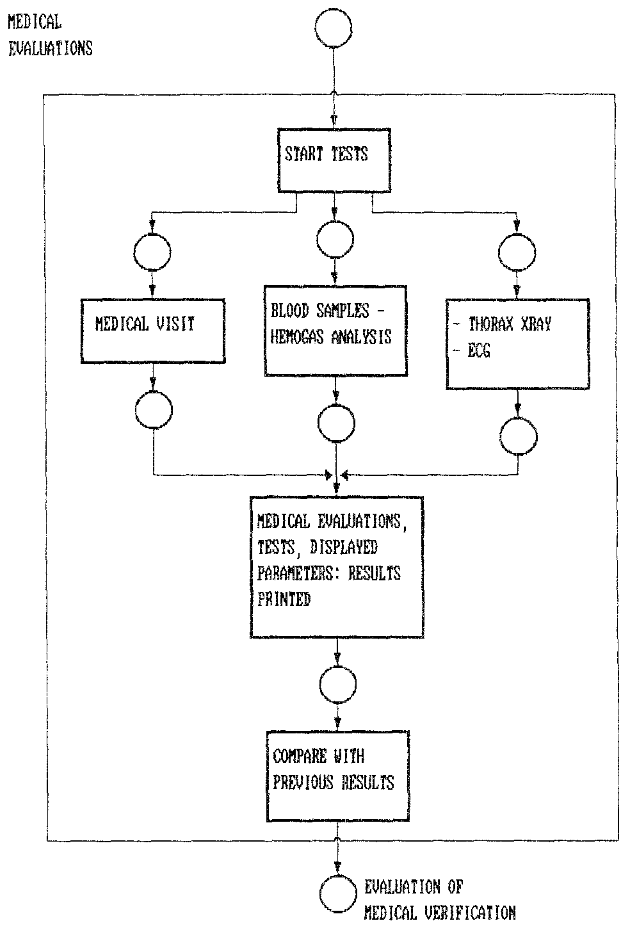




*Fig. 7.* Medical evaluations during artificial ventilation.

the setting up of ventilator, connection tubes and humidifier. Once the ventilator, connection tubes and humidifier are prepared, their functionality is tested. The parameters and the ventilatory mode for the specific infant are established (Fig. 6).

*Medical evaluations*

They represent the fundamental moment in the checking of the therapy effectiveness (Fig. 7). At the end of this process, a judgment is expressed and compared to the previous condition of the infant. This verdict may be:

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*Fig. 6.* Preparation and test of mechanical ventilator.

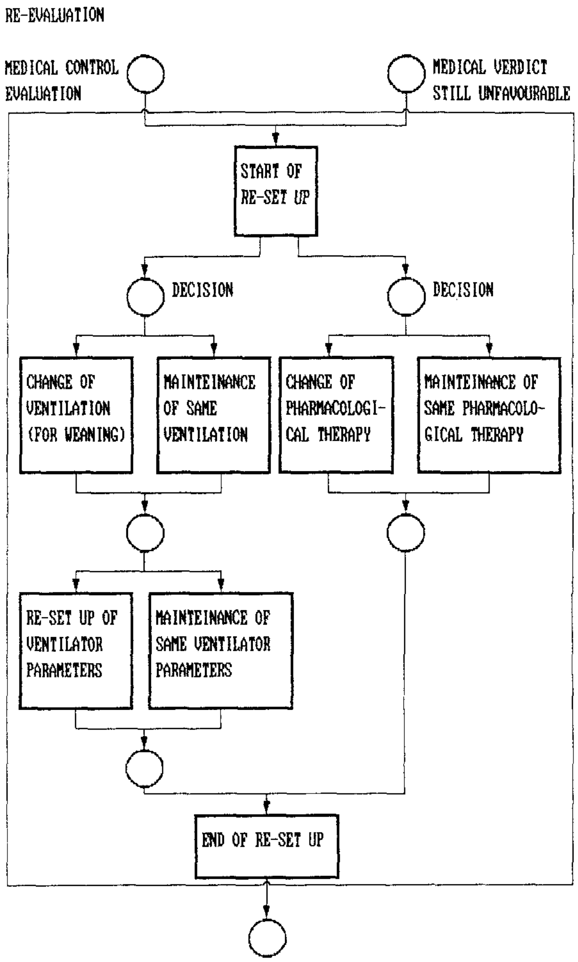


*Fig. 8.* Evaluation of treatment in order to start the weaning or to re-assess the respiratory support.

- POSITIVE, in this case the infant will follow the therapeutic procedure up to his discharge;
- NEGATIVE, the validity of the first diagnostic hypothesis and/or of the therapeutic intervention should be re-discussed.

*Re-evaluation*

Owing to the discrepancy between the first hypothesis and the data obtained from subsequent checkings, a different diagnosis and therapy should be decided upon.

All therapeutic protection utilised should be reconsidered in order to suggest a different ventilatory and/or pharmacological therapy (Fig. 8).

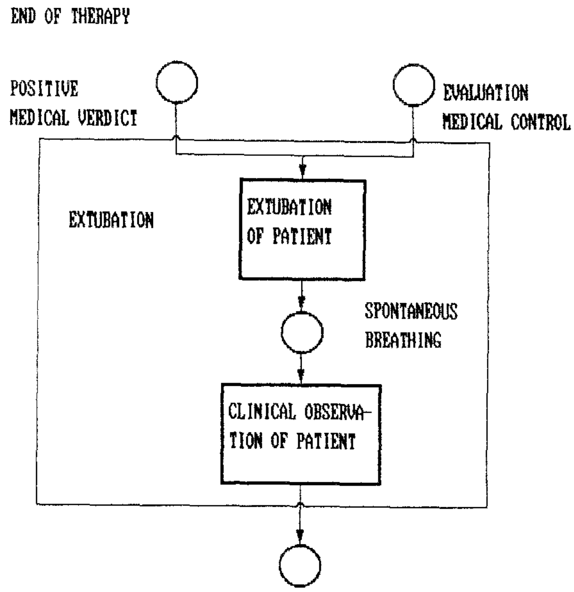


*Fig. 9.* End of ventilatory support.

In certain cases, it may be sufficient to change just an element of the therapy administered to obtain the improvement desired.

Once established, the new therapy should be continuously verified so as to ascertain its effectiveness. Through the comparison of the data obtained earlier and the evaluation of the clinical progress of the infant, it would be possible to express a judgement ever more exact on the clinical course of his pathology.

This process will be the more lengthy and complex, the more unforseeable the response of the infant to the therapy and the larger the gap in respect to the initial diagnosis.

Length of therapy is never pre-established. An assessment of the infant's condition is carried out during treatment and it may prove to be favourable or unfavourable. In the first instance, therapeutic support would be gradually reduced up to discharge. In the second instance, need may arise for a more thourough examination, a re-consideration of the therapy and possibly of the initial diagnosis, since both proved to be insufficient to solve the pathologic condition of the patient. Such assessment/re-consideration process should continue till the patient's conditions justify his extubation and after a sufficient period of observation, the discharge (Fig. 9).

## Discussion

The model was followed by a consequent computer application giving a meaningful organizational impact to the clinical staff. The changes introduced by this model did not concern only its domain of application but also involved the PICU environment. Changes concerned also the methodological approach to clinical practice.

The benefits deriving from such approach may be as follows:

- a valid support to major medical decisions concerning a given patient;
- a continuous control of the adequacy of therapy to the actual condition of the patient;
- an operational procedure that may be implemented in any kind of pathology;
- a common frame of reference within the clinical staff;
- an effective didactic tool to be used in the training of junior doctors.

In order to meet these objectives, the model should have the following characteristics:

- simplicity;
- repeatibility for any category of patients;
- adaptability to any working reality (different wards);
- possibility of modifying details without changing the structure.

Petri nets can provide a common language both to clinical staff and computer experts.

The model described above was developed in the environment of a specific ICU but it may be utilised in any kind of clinical practice for severely ill patients. In fact, replacing in all the diagrams the words 'artificial ventilation' with 'intensive therapy' or 'endocavital cardiac stimulator' or 'emodialysis treatment' and so on, the model is perfectly adjustable to any new clinical conditionand operative situation.

Moreover, the development of the model at lower levels of abstraction implied the generation of clinical protocols. The domain of these protocols are the pathologies treated in the ICU. They define the sets of conditions and events that may occur at three levels:

- therapeutic intervention;
- equipment preparation;
- drugs administration.

In Merate's PICU, the model of the ventilatory treatment and the protocol system have represented very useful tools in improving the average performance of the clinical staff and of the unit management.

The use of the model in the training of junior doctors proved very effective. In fact, the possibility of referring to a well defined protocol, that could continuously be developed through new experiences, allowed junior doctors to acquire an accurate methodology of approach to a clinical problem which otherwise would have resulted extremely empirical and dependent from the availability of those physicians who take care of junior's training.

The standardization necessary to implement the model also improved the day-by-day clinical practice and streamed the procedures for normal therapy.

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