

Knowledge based weaning

Knowledge-Based Systems for Automatic Ventilatory Management



Introduction

Despite their enormous potential to facilitate bedside management, the practical role of computers in critical care environments is generally restricted to the storage and the retrieval of data coming from electronic medical devices and hospital information networks.

Benefits of the use of computers in health care may be extended by the design of computerised medical assistants that can efficiently discharge the clinical staff of repetitive tasks (which, in practice, often are not performed) and, importantly, help practitioners to make efficient decisions in time. In intensive care and anesthesia, the demand for computerised medical assistants is potentially considerable, in order to filter and synthesize the growing mass of clinical parameters and information available. The progressive introduction of computerised protocols has been proposed to standardise the bedside decision making process for mechanical ventilation and to reduce unnecessary variation among practitioners³², reinforcing the potential impact of computerised medical assistants.

Ventilation Management today

Modern methods of mechanical ventilation partially assist the patient's ventilation by adding a variable amount of mechanical support to his/her spontaneous activity. In this context, since the needs of the patient are evolutive, it is essential to continuously control the ventilatory support, in order to avoid excessive work of breathing and effort, discomfort and dyspnea on the one hand, or excessive support, hyperinflation and dyssynchrony on the other hand.

In parallel to this ideal automatic adaptation, it may be necessary to plan the long term adaptation of the therapy according to specific medical goals. For instance, it may be indicated to gradually decrease the level of assistance in order to facilitate the weaning from the ventilator or to take into account large variations of physiological needs during the patient wake-up from anesthesia or drug intoxication.

Planning and control are two different tasks that have a common goal: choosing actions over time to influence a process, based on some model of that process⁹. Control is a local task to determine what to do the next instant.

Automated Ventilation Management

A Practical and Successful Experience Using the NéoGanesh System – Hôpital Henri Mondor, Créteil France.

The initial objective of the design of the knowledge-based system called NéoGanesh, was to build a closed-loop system 1) efficient for the automatic control of mechanical support, 2) which could be extended to gradually improve its reasoning and planning capabilities and 3) which could be tested at the patient's bedside to measure its performance at each step.

A Knowledge-Based System Working in Closed-Loop

Instead of computerising a specific recipe for ventilation management^{37, 47}, the design of NéoGanesh tried to respect the golden rules of knowledge engineering: make an explicit model of medical tasks and reasoning involved, and distinguish between the conceptual model (knowledge level, see for instance Figure 3) and the representation paradigms (symbolic level) used to implement it¹³. NéoGanesh is based on current Artificial Intelligence techniques: a knowledge representation that mixes objects, rules



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and temporal abstractions¹⁶ in a distributed architecture¹⁴.

It combines a “tactical” component and a “strategic” component. The “strategic” component relies on the model and representation of the intensivist’s decision-making process. The “tactical” component uses three physiological parameters to modify the level of assistance during pressure support mode ventilation, and to maintain the patient within a zone of acceptable ventilation defined as Zone of Respiratory Comfort: $12 < RR < 28$ cycles/min, $V_t > 300$ ml or 250 if weight < 55 Kg, $PetCO_2 < 55$ mmHg or 65 mmHg if COPD).

The system is based on the modeling of the medical expertise required to mechanically ventilate patients with the pressure support ventilation mode. It does not include mathematical equations of a physiological model. There are three reasons for that: i) in pathological situations, physiological models are uncertain and can require data that are not available in realtime, or data whose the estimation is difficult or imprecise.

Data validation is still an open problem; ii) physiological models do not always represent useful information to the clinician in decision making. For instance, to follow up the recovery of patient after anaesthesia, pharmacological equations are imprecise and not used in practice; iii) the decision making process of clinicians may be less variable than the complex physiology of patients.

This is reinforced by the introduction of protocols or guidelines for mechanical ventilation based on objective measurements like respiratory frequency or the rapid shallow breathing index.

In conclusion, it seems simpler to model decision-making based on objective measurements, rather than based on physiology and multiple assumptions of the patient’s behavior.

Therefore the NéoGanesh system is more a “decision-driven” system than a “patient-driven” system, although it indeed uses data coming from the patient.

The introduction of a new mode of ventilation such as PAV⁵⁰, ALV²⁸ or ARIS⁵ is a long and difficult process. Therefore, the choice is to i) to ventilate patients with a standard ventilation mode, pressure support ventilation, largely used for weaning, and ii) to add heuristic knowledge to improve its use and to facilitate the weaning process.

Some Clinical Results

NéoGanesh has been used in closed-loop and tested in more than sixty ventilated patients at Henri Mondor hospital (Créteil, France). Two types of evaluation were performed i) one set of tests to assess the capacity of the system to control the level of assistance in accordance to the patient’s needs (evaluation of the tactical level) and ii) a second set of tests to assess the decision of extubation provided by the system (evaluation of the strategic level).

Evaluation of the Management of Mechanical Ventilation

In a preliminary study, two different groups of patients were ventilated, both with NéoGanesh.

The two groups represented two different steps in the course of mechanical ventilation. The first group (n=9) was composed of patients considered as candidates for weaning, and the second one (n=10) of severe patients needing to be maintained under mechanical ventilation.

The mean time spent within the Zone of Respiratory Comfort expressed as the percentage of the total ventilation duration was 99% for the first group and 90% for the second group.

In a more recent study, 10 patients 24 ± 4 hours were randomly ventilated on Pressure Support Ventilation (PSV) with NéoGanesh and 23 ± 3 hours without standard pressure support ventilation



(PSV) without NéoGanesh. In standard PSV, the clinician in charge could modify the pressure support level at his/her discretion. The mean pressure support level was similar with the two modes (17 ± 4 cmH₂O and 19 ± 6 cmH₂O without and with NéoGanesh, respectively). The mean time spent into the Zone of Respiratory Comfort was $66 \pm 24\%$ and $93 \pm 8\%$ without and with NéoGanesh, respectively.

The number of changes in PSV setting was considerably higher with NéoGanesh (56 ± 40) than with standard PSV (1 ± 2). The mean time spent in a condition of critical ventilation (RR > 35 cycles/min, Vt < 300 ml or PetCO₂ \Uparrow 55 mmHg) was 3% with NéoGanesh compared to 23% with standard standard PSV.

Lastly, the time spent with a high level of occlusion pressure (P0.1), suggesting a high work of breathing, was significantly reduced with the knowledge-based system. NéoGanesh tries to automatically decrease the level of pressure support.

For some patients weaning can be a long and difficult process. Continuous adjustment of mechanical assistance as performed by NéoGanesh may positively influence the weaning outcome. The level of pressure support may be a useful

guide for determining the optimal time for performing tracheal extubation.

This strategy was implemented in NéoGanesh: when the patient is ventilated with a low level of assistance (9 cmH₂O for patients with an endotracheal tube or 5 cmH₂O for patients with a tracheotomy cannula), an observation period is triggered (1 or 2 hours depending whether the level of pressure support after one hour of ventilation is $15 <$ or \Uparrow 15 cmH₂O respectively) and a decision about extubation is displayed on the computer screen.

For 38 patients, the decisions between what was given by NéoGanesh to the standard set of weaning tests (pre-weaning tests +2 hours on T-piece +48 hours of follow-up) were compared. The negative predictive value was equal in the two cases. However, the positive predictive value was of 89% for NéoGanesh and 77% for standard PSV, and 81% for the rapid shallow breathing index alone¹¹. NéoGanesh predicted failure of weaning for 5 patients who tolerated the 2-hour T-piece trial but eventually failed weaning.

Towards Smart Ventilators

It has been proposed to integrate medical knowledge into closed-loop controllers. Clinical results indicate the potential interests of such an approach: adaptation

of assistance to the needs of the patient, reduced need for monitoring and better weaning outcomes. Further studies should now be launched to demonstrate that this new technology improves patient care or that it maintains patient care while decreasing cost. Up to now, none of the sophisticated closed-loop controllers proposed in the literature have had a major impact on clinical care. One reason suggested¹⁸ is that these systems are pure engineer-oriented products not related to common clinical practice. Clearly, in designing knowledge-based closed-loop controllers, we changed this view in adopting a clinician-oriented approach. Based on objective criteria, weaning protocols have been proposed by medical experts^{2, 19}. Results from a prospective multicentre randomised clinical trial indicate that a computerised system for directing ventilator therapy can significantly improve morbidity¹⁷.

It is considered that, for ventilation management, medical knowledge is mature enough to be incorporated into smart ventilators that can really assist clinicians in bedside care. The work with the NéoGanesh system constitutes a first step towards the construction of such machines. Specific lung function testing manoeuvres could be automatically performed by the smart ventilator in order to refine the evaluation of the patient's



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state, and then the therapy. This information could be used to manage several ventilatory modes. Improvement of planning capacities, via the automatic recognition of high level clinical scenarios as they are developing, is a prerequisite to improve the predictions and the dynamic adaptation of the strategy.

Interaction with the clinician could contribute to a dynamic adaptation of the strategy depending on information that cannot be directly accessible for the machine. Ventilatory care should be adapted to the patient's needs. Information provided directly by the patient about the quality of the assistance received could be incorporated into our future smart ventilators.

This article expresses exclusively the author's opinion.

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