COMPUTER AIDED TREATMENT OF PATIENTS
WITH INJURIES OF THE SPINAL CORD

by

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Abstract

The rehabilitation process of spinal cord injury patients is carried out by a multidisciplinary team. Such a step assures that all data needed for the treatment are available; however, it also creates the problem of the exchange of accurate and up-dated information to all members of the team. In order to solve this problem a study of the entire rehabilitation process has been made; that is the dynamics of the treatment itself have been modelled, and the information streams in relation to the organisation structure have been traced. In applying the model developed, a digital computing facility has to be introduced in the rehabilitation center. In order to be aware of the consequences of such an introduction a study of the information flows and of the organisation has to be executed, since it is important to know how strongly automation of the data processing could act on the functioning of the individual staff members. Finally, the consequences as far as they can be overlooked at this moment will be discussed. A first experiment with the introduction of a demonstration system in the clinical setting will be elucidated.

1. INTRODUCTION

The World Health Organisation defines rehabilitation as the multidisciplinary process to bring, and to keep, handicapped patients in a state of health in which they can function in the most optimal way in their social and physical environment. Hence, in dealing with spinal cord injury patients, the rehabilitation process is carried out by a multidisciplinary team consisting of members from the medical the occupational and physio-therapeutical, the social and psychological, and the technical disciplines. Such a set up assumes that all data needed for the treatment will become available to all team members, correctly and in time. It thus requires an accurate exchange of up-dated information to all team members. Because the multidisciplinary aspect in rehabilitation medicine is such a basic point. A detailed study was set up with the following goals in mind.

• To achieve a better understanding of the dynamics of the entire rehabilitation process.
• To study the possibilities of direct digital data processing of the treatment data.
• To propose, if worthwhile, a data acquisition system in order to automate the data processing within the rehabilitation center. This proposal should include the consequences in relation to the organization, the data transfer lines and the different tasks of the personnel.
At this stage the first two goals have been realised, the last one is under study and a great deal of the work has been done.

2. THE REHABILITATION PROCESS

The study of the rehabilitation process of spinal cord lesions was executed at the rehabilitation center "De Hoogstraat" at Leersum, The Netherlands. The study started in 1973 and can be divided into five main phases, which are listed as follows:

- Recording of the data concerning the treatment of the patient and his/her state of health.
- Description of the state of health of the patient, and data reduction
- Development of a prognosis model of the future state of health of the patient.
- Analysis of the rehabilitation process dynamics on the basis of the treatment (input) and the state of health (output).
- Prediction of an optimal treatment plan.

In the period of 1973-1975 58 patients were observed on a weekly basis; 74 treatment variables as well as 148 state of health variables were recorded. The average period of treatment of the patient was about 43 weeks. The data collection was carried out by the treatment team members. The data can be classified as input and output variables concerning the medical aspects (84 and 39 variables), the Activities of Daily Living (41 and 19), the psycho-social variables (6 and 7) and the support of assistive devices and home adaptations (3 and 19), respectively. The medical variables were related to aspects like urinary tract inflammation, pressure sore, and para-osteoarthritis; the ADL variables concerned activities like dressing, eating, personal hygiene and wheelchair riding; the psycho-social variables described the relation with the partner, the family and the team members, emotional stress, etc.; and finally the support variables represented the progress in the support of wheel chairs,

Figure 1: Block diagram of the rehabilitation process of a patient with a spinal cord lesion.
orthoses and home adaptations. The input variables were quantified on the basis of the duration of the treatment and the kind of treatment. To be able to compare the completely different output variables with each other, all variables were scored at a scale from 0 to 5 in the order of a decreasing restriction that a particular variable may have on the functioning of the patient, i.e. 0 is impossible, 1 is very restrictive, 2 is restrictive, 3 is lightly restrictive, 4 is may become restrictive and 5 is not restrictive at all.

The data reduction of the output variables was achieved by the following procedure. By using the knowledge and experiences of the clinical staff a number of variables could be skipped because they did not provide additional information. Furthermore a number of variables did not change at all, and so they did not give any dynamic information about the treatment process. From the 148 variables only 67 remained. As a next step a covariance analysis was carried out, resulting into 12 major independent variables, i.e. pressure sore, micturition, paraosteo-arthopathy, dysregulation, spasticity, communication and personal hygiene, wheel chair activities, ability to stand in an upright posture, period the patient is out of his bed, acceptation at home, mood, and the relation with the members of the treatment team. In this list of variables the support variables were left out, because they turned out to be just a result of the medical, the ADL and the psycho-social variables. The final result was checked by means of the Delphi ranking method. The variables were judged by 20 specialists on the basis of the following three aspects: Direct danger for life, clinical treatment, and post-clinical function. Although a reduction of the twelve variables just mentioned to only four, being the medical, ADL, psycho-social and support variables, was found to be too rough for practical use, Fig. 2 shows as an example what rehabilitation medicine actually means: Living with

![Figure 2: The four major variables as a function of the treatment period.](image)

your handicap (no increase or decrease in the medical state), learning to use what is left (a strong increase in ADL performance), becoming a psycho-socially stable person (only small variations in the psycho-social state), and receiving the necessary support in assistive devices etc (increase in the support variable). The figure also shows very clearly that the support variable may be considered to be a result of the progress of the other variables. Mostly a time at least
10 weeks is found, mainly due to the procedures necessary to obtain financial support.

From Fig. 2 one learns that the discharge of the patient from the rehabilitation center is mainly determined by the moment the home adaptations and assistive devices are available, since in general most of the other variables have reached a steady state value at least 10 weeks earlier. It was therefore worthwhile to investigate whether it is possible to predict the medical, ADL, psycho-social and support variables over a 10 weeks period, so that possible supplies can be arranged in time. Two prediction methods have been studied, i.e. one based on a description of the output variables by a Semi-Markov Series, and one on the state variable description.

The dynamics of the Semi-Markov Series are given by: The probability that a variable makes a change from a certain value \( i \) directly to another value \( j \) at any time, and by the probability that the variable has a value \( i \) during \((n-1)\) weeks before a transition is made to the value \( j \) on week \( n \). In using this description it is assumed that the future changes of a variable describing the state of a patient depend only on the present state of health and on the amount of time the patient has been in it. By counting the transitions in the measured data, the probabilities can be easily found. Hence, given these probabilities based on a population of patients, and given the data point over a certain period of a particular patient, a prognosis can be made. Fig. 3 shows an example, where

![Figure 3: The prognosis over a 10 weeks period of medical, ADL, psycho-social and supply variables based on a 10 weeks record of a particular patient.](image)

A more sophisticated method to predict the future value of the variables is based on a state variable description. Since input and output variables have been measured the dynamics of the entire rehabilitation process can be determined. Hence with the model \( y(k+1)=A y(k) + B u(k) \), where \( y(k) \) is the state variable as well as the output
vector, \( u(k) \) is the input treatment vector, \( A \) is the system matrix and \( B \) is the input matrix, the state variable can be predicted given a certain treatment plan.

![Figure 4: Prognosis of an ADL variable over a 28 weeks period based on the data measured over the previous 10 or 20 weeks.](image)

The matrix \( A \) and \( B \) can directly be found from the input/output data measured. Fig. 5 gives an example of such a prediction. Of course, if the treatment plan is a standard one, this method can help in overseeing the consequences of a particular treatment for a given patient. However, often it is the treatment plan itself that should be defined. Thus, the problem should then be formulated as an optimization problem. Given the rehabilitation process dynamics, and

![Figure 5: Four predictions of state variables of a particular patient on the basis of the initial state at the second week of treatment and a given treatment plan.](image)

given the inherent limitations in treatment possibilities, one has to optimize a cost function concerning the benefits of the treatment on the one side and the cost of the treatment on the other. In this way one can conclude to an optimal
treatment plan; this final step is presently under study.

Although not all details of the study can be given here, a number of interesting conclusions has been reached.

- The introduction of a cybernetic modelling approach in the rehabilitation center yielded that the team members became to realize that a systematic recording by means of checklists at regular times increased their understanding of what the team was doing actually. Moreover it opened the possibility to evaluate the rehabilitation process. One also became aware of the efficiency of uniformly quantified information exchange in a multidisciplinary team.

- The 153 variables originally recorded in order to describe the patient's state of health could be reduced to only 65 variables without any loss of information; out of these measurements twelve state variables could be determined for a sufficient description of the patient's state of health.

- The medical, ADL, and psycho-social variables show that at least 10 weeks earlier a patient could be discharged from the rehabilitation center, if in time the supply of assistive devices was started. The prediction models were such promising that it was believed that on the basis of this model the treatment period could indeed be decreased by ten weeks, whereas the quality of care will remain the same.

- The description of the rehabilitation process dynamics was felt to be so attractive and accurate that a proposal of an optimal treatment can be a worthwhile contribution as an input to the treatment team, in this way aiding in making the final treatment plan decision.

- The goals of the treatment (Fig. 1) seem to be dependent on the results obtained, that means the goals during the entire rehabilitation process may change due to new circumstances. Besides that, patient and team members should have equal expectations about what may be reached. Therefore a goal check list has been developed which has to be filled out by patient and team separately, once every three months. In discussing the differences between the goals of the team members, including the patient, one harmonizes the joint goal of the treatment team. The results of the introduction of these check list were so successful that presently the method is fully accepted as a standard procedure.

3. THE DATA PROCESSING IN THE REHABILITATION CENTER: HUMAN FACTOR ASPECTS.

The overall impression of the approach followed raised high expectations, so the introduction of an on-line data processing system was considered. However, the introduction of such a system means much more than just a kind of automation of data handling. From the view point of man-machine communication it yields a number of different aspects, among which the most important ones are:

- With the introduction of a data processing system one starts to control the information flows along carefully planned pathways, probably different from the existing ones. This might lead to situations where people are not or badly informed, whereas others are informed in different ways.

- The information pathways are directly related to the organization structure of a clinical center. Automation thus may have its influence on the existing organization structure, that is the formal as well as the informal structure.

- If the information flows are changing, and as a result hereof the organization has to be adapted, tasks of different staff members may be influenced. Hence, the consequences of such an introduction on the personnel's tasks and
functioning should be carefully taken under consideration.

- The introduction of computer systems in a non-computer minded environment may lead to a number of interesting problems. Firstly, there is the problem of making the staff familiar with the new possibilities of the system, so that not old methods are used with new equipment, but that methods and equipment are used in an optimal way. Then, secondly, one has to train the fully naive staff in the use and operation of the system.

- Protection of privacy is a very important item in data processing in health care. Often it is wrongly believed that privacy protection will degrade when computers are used.

The five above mentioned items have been studied extensively during the last few years, although the entire project certainly will request another couple of years. To start with, a detailed study of the information structure as well as the organization structure at the rehabilitation center has been carried out, in this covering the first three items. Parallel hereto a demonstration of the possibilities of an information processing system has been worked out in order to get some feeling about the last two items. In discussing the information and organization structure the emphasis of this paragraph will be on the methodology of the study, because the results are so closely related to the particular setting at the rehabilitation center that in understanding the results a detailed description of the rehabilitation center is required.

Considering only the processing of the treatment data of the spinal cord lesion patients it is necessary to oversee the influence of modern information systems on the information exchange and the organization. This has been achieved by applying the ISAC method developed by the Department of Information Processing and Computer Science of the Royal Institute of Technology and the University of Stockholm, Sweden. The ISAC method stands for the Information System Work and Analysis of Changes. Due to the, in general, high complexity of the problems studied, the method distinguishes five interactive phases. Each phase, individually, leads to a set of documentation, i.e. graphs and descriptions. Starting with a global review graph of the entire system one zooms in to a set of graphs of the different subsystems. The five interactive phases are: (1) Change Analysis; (2) Activity Studies; (3) Information Analysis; (4) Data System Design; and (5) Equipment Adaptation.

The Change Analysis deals with the study of possible changes (improvements) in the activities of the organization. These possible changes are based on the insight gained about the organization, the observed problems and the problems to be expected in future.

The major purpose of the Activity Studies is the definition of the information subsystems, that is the system of information processing and not the actual treatment process. The results consist of a graph as well as a list of information subsystems, a cost-benefit analysis, the required financial means, a time schedule and a definition of the interaction between the subsystems. This phase will result in a final decision to continue or to stop the project.

The Information Analysis phase deals with a detailed description of all information subsystems. Three succeeding analyses have to be executed. During the Precedence Analysis one tries, starting from the output information sets, to find which preceding information sets are the roots of the outputs. This process is continued until the input information sets of the subsystem have been reached. The next step is the Component Analysis, during which an exact description of the information sets is obtained. Finally, a Process Analysis is executed, that is a description is given in which ways and under which restrictions the information sets are transformed into other information sets.
The last two phases, Data System Design and Equipment Adaptation refer to the realization of the information processing system. The DSD deals with the design of the system, that is the design of the structure of the system, the design of the required components and the data processing method - automatic or manual or a combination; batch or on-line or in-line etc -. During this phase the component and process descriptions are translated into data structures and procedures. The final step of the ISAC method is the adaptation of the data system design to the computer configuration chosen.

Figure 6: The activity graph and information graph of the treatment process of spinal cord injuries.
In the manner as described before the entire information and organization structure of the rehabilitation center can be depicted by graphs. As an example the activity graph and the information precedence graph for the treatment process of patients with a spinal cord lesion will be discussed now.

The activity graph: Before one is able to start the treatment of a patient an examination has been executed, moreover data from the hospital have been collected, hence at the beginning of the treatment a certain amount of data is available. With this information, the patient and the necessary means, one can start the treatment. During this process additional data will be collected on the basis of which the treatment can be evaluated, so that a decision can be made whether the patient will be discharged or whether the treatment has to be continued.

The information precedence graph: In order to be able to execute the rehabilitation process a perfect information exchange between the members of the treatment team is necessary. The information precedence graph illustrates how an information set is reconstructed from preceding sets. For instance, in order to supply a particular assistive device one needs a prognosis as well as data about the treatment process itself. The treatment data is constructed from the rehabilitation records, treatment instructions, and collected treatment data. A summary in which also the prognosis is included will result in the updated rehabilitation records set. The instructions for the different disciplines can be derived after the treatment goals as well as the treatment plan are known. Combined with the information gathered during the first examination as well as the rehabilitation data recorded one obtains updated rehabilitation record. Finally the set discharge information is obtained by a further evaluation of the treatment data.

Although the method discussed is a time consuming procedure, because the treatment of the bodily handicapped patient is such a complex and multidisciplinary process, the method certainly leads to a very clear insight in the structure of information and organization of the clinic. There is almost no need to elucidate how important the results are with reference to the final design of human tasks, to the introduction of an information processing system and to the man-computer communication.

4. A PRELIMINARY MAN-COMPUTER-COMMUNICATION STUDY.

In order to get more insight in the direct problems related to the introduction of a computer system in this particular situation, it was decided in an early stage to set up a simulation so that practical experiences in a clinical setting could be gained. The most important reasons can be stated as follows:
- It was necessary in an early stage to test the dialogue design, when working with naive users.
- In literature it is emphasized that it is very important that from the beginning the final users of a system are involved in the project. Their feedback is very essential, and their involvement is crucial for a successful introduction of a computer system.

For a dialogue between man and computer several possibilities exist. Several authors distinguish between a number of different techniques, ranging from fully Computer initiated to fully Operator-initiated \(^5,6\); or as seen from the operator ranging from passive to active dialogues. For choosing a particular kind of dialogue the following criteria are given: Level and kind of education of the users of a system; frequency the system is used and kind of computer application.

For the case of the rehabilitation center the so-called menu-selection seemed
to be an appropriate choice. This is a passive dialogue, where the user has to choose from lists of possibilities presented on the screen, in order to find the information requested. This menu-selection is an easy-to-learn dialogue style, but it will become boring for experienced users. Hence, for them possibilities to reach the information, bypasses, have to be provided. Important other aspects in the design of a dialogue for naive users are: The system has to be foolproof, the quantity of input-data should be minimised, and the application of abbreviations for data input is very desirable, if and only if, strict rules are given to which an abbreviation is formed. Important ergonomic aspects are: The fact whether the information is presented line by line or page by page, the use of capitals and lower case letters; the use of special features such as reverse video; the use of special-purpose terminals as often is advised; the quantity of information per page and the standardization of the lay-out on the pages.

Based on the literature reviewed a small demonstration test system has been realised on the university's IBM 370 system with a Beehive-terminal. This terminal had a reverse video facility, only one programmable function key could be applied. The dialogue was developed in CPS, an interactive subset of PL/I. The structure of the test system is shown in Fig. 7. Every block in this figure represents a page on the screen. On the first page the user has to identify him- or herself.

Figure 7: General lay-out of the demonstration system.
(Privacy protection), then one has to state whether one wants to follow the bypass or the menu. The menu consists of: A list of patients, a list of files of every patient, and a list of chapters of a particular file. As an example the goal check list as mentioned in paragraph 2 was worked out. Then, finally one had to indicate whether one wanted to fill out or just to observe the goal check list. The reason for distinguishing two versions of the goal check list in the menu is the fact the observation of the list as shown in Fig. 8 is easy to interpret, whereas during the fill out phase the positioning of an X, P or T (Fig. 8) by a cursor takes more time and leads to more mistakes than just typing in a code from 1 through 5. Hence in the observe version the data are printed in columns, and in the fill out version the data typed in code. Besides this menu selection method the system was set up in such a way that via the bypass one also could reach the data. In this interactive program one could use abbreviations.

As mentioned before; an important aspect in computerizing the data handling is privacy protection. Rules have to be formulated as answers to the questions:

- Who is allowed to enter a new patient in the data base, and who is allowed to enter a particular data about a patient? How can one prevent that people who are not authorised to do so, will change data?
- Who is allowed to read the information, and how can we prevent possible misuse of the system?

![COAL CHECK LIST]

**Figure 8:** The display format of the goal check list.
The first question implies that the system must recognize who is on the staff of the center, both questions imply that the system must identify who is who. A safe method is to make use of pass-words, a frequently used method in banking operations.

21 subjects, equally distributed over the different disciplines of the clinical staff tested the system voluntarily. Their opinions about the system were collected by watching the subjects during the training sessions, and by questioning them by means of check lists. Two classes of opinions were gathered, i.e. one class about the use of computers in a rehabilitation center in general, and another about the use of this particular system. The first check list had to be filled out before the training session, the second one at the end of the test period.

The inquiries showed that the group, although representative with reference to the distribution over the disciplines, was certainly not representative with reference to their attitude to computers. The majority judged positively about automation of the data handling, whereas it was known that a large group was more reluctant. The results can be summarized as follows:

- Speed of data transport should be in the order of 9600 baud; the system response time should certainly be in the order of a fraction of a second and in the case it takes longer it should be indicated by a message like "Your data are now being processed"; the reliability of the system should be high, and an indication whether the system works or not is essential for the use with naive subjects.
- The idea of working with pass-words appeared to be working well, although flexibility due to shifting staff members is very important; menu selection is a very attractive method for infrequent users and beginners, or as reference possibility, good bypass possibilities are certainly required for the experienced user; although only one special function key was available, the application of more function keys such as, a Begin-, Stop-, Correction-, Next Page- and a Break- key seems to be valuable; the dialogue should be user-friendly.

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