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Abstract

Information found in the literature presents only marginal experiences concerning telemedicine in regards to peritoneal dialysis (PD). These experiences are limited to the transmission of data and/or images using new methods of communication. This article presents a new and innovative application of telemedicine in the field of PD and describes its characteristics in comparison to other telemedicine systems. In addition to optimizing the transmission of data via intra/internet, the DIATELIC (Interactive and Cooperative Monitoring of Dialysis Patients) system has an expert system designed to detect anomalies which can appear progressively and imperceptibly. This "intelligent" expert system uses six rules of interpretation simultaneously using basic initial data: Weight, blood pressure, differential blood pressure, orthostatic blood pressure, peritoneal ultrafiltration. These rules enable the system to give warning signs based on values which are pre-established or calculated using the averages of the previous 15 days. Routine use of this system operational now for over a year is conclusive. For the doctor, this system radically changes the way medical team follow-up on the patient. Daily access to the information concerning the patient resembles more a hospital-like setting and the integrated message service facilitates the contacts. For the patient, the sense of security derived from the expert system which notifies both the center and the patient in case of an anomaly is often mentioned. Telemedicine, which is in full development, will likely represent a major revolution for the public health system when the studies on the cost/benefit ratio reveal its utility.

Introduction and Definitions

Telemedicine, like many other emerging technologies, does not yet have any precise definition. The complexity of the communication systems, their rapid evolution, and the incessant technological innovations in the field of computers constantly open up new fields of applications for telemedicine. It is probably for this reason that the term telemedicine regroups, in fact, a multitude of applications as diverse as they are heterogeneous.
Telemedicine is defined by the Anglo-Saxons as the use of an electronic communication network for the transmission of data and information concerning diagnosis or medical treatments. As such, a simple transmission of medical data by fax (lab reports, medical mail, etc.) or by telephone enters into this definition. However, in common language, telemedicine concerns a more recent technology such as the use of a numeric communication network, internet and/or the transmission of data by means other than speech (images, sounds, files, numeric data). From this point of view, the field of telemedicine remains vast and encompasses all medical specialties. Logically, it would be useful to classify the applications of telemedicine not in function of the type of data and their mode of transmission but rather in function of its potential users. This distinction is owed to the particular characteristics which they have in common and is independent of the medical specialty concerned.

– telemedicine between health-care professionals. In this case, the technical and economic imperatives are undoubtedly less important than the quality and integrity of the information transmitted. Indeed, the relatively low number of professionals and their theoretical capacity of mastering computer skills does not necessarily warrant inexpensive and simple material. However, the quality and quantity of the transmission become the priority for a precise and rapid long distance analysis. Telemedicine between professionals is developing rapidly and can be applied to a large variety of domains such as the visioconference, tele-training, hospital-home networks, tele-experts, tele-diagnosis, etc.

– public telemedicine concerns the direct transmission of medical data between the patient and the health-care professional. The heterogeneity of the population concerned and the large number of potential users require more moderately priced, user-friendly systems which are adapted for patients who have no experience and no particular aptitude for computers. This type of telemedicine is developing less rapidly probably because easy to use systems are often the corollary to complex technology. This type of telemedicine will probably represent a major revolution for the public health system in the near future on condition that the cost/benefit study shows an economic advantage. The “public” telemedicine will undoubtedly revolutionize the medical profession and the doctor/patient relationship which may cause a certain amount of apprehension and thus impede its development even further.

The treatment and the monitoring of these chronic patients represent a potential field of application particularly interesting for “public” telemedicine. The first systems mentioned in the literature describe essentially the passive transmission of data from the patient to the doctor allowing different medical parameters to be monitored without requiring any particular action from the patient. In the order of development of these techniques, these interactive systems probably represent the next step. It will undoubtedly be followed by the appearance of intelligent interactive systems; in other words, systems which integrate an automated analysis of the data transmitted.

We will present here one of the first interactive and intelligent public telemedicine systems applied to the treatment and monitoring of dialysis patients. This system, resulting from the collaboration between the CNRS (National Scientific Research Center), LORIA (Lorrain Reserch Laboratory of Computer Science and its Applications), and ALTIR (Lorrain Association for Renal Failure Treatments), was baptized DIATELIC.

Status of telemedicine for dialysis in 1999

1) The telemonitoring of dialysis machines.

Most dialysis methods (hemodialysis, hemofiltration, hemodiafiltration, automated peritoneal dialysis) require machines that are technologically evolved and which benefit from the latest technological innovations. With this in mind, the manufacturers of these machines currently used have anticipated the use of tele-transmissions by either incorporating a micro-chip, an integrated modem or a type RS232 output which enables the long distance recovery and transmission of information. Different tele-transmission systems are already operational (HEMODIAL™ by HOSPAL, GSS™ by GAMBRO, HomeChoice Pro™ by BAXTER) or on the verge of being operational (PD200™ by GAMBRO, SleepSafe™ by FRESENIUS). These systems allow the transmission of numeric data which are essentially technical (for hemodialysis, veinous and arterial blood pressure, ultrafiltration, other diverse characteristics of the hemodialysis session; for the automated peritoneal dialysis : number and characteristics of the cycles, ultrafiltration). The information is available in instantaneously or routinely through the intermediary of an integrated interface located in the computer of the medical center. Most of these systems are also able to transmit basic medical information (weight, arterial pressure, eventual incidents) through a specific interface located in the dialysis machine.
These innovations in the field of telemedicine do, however, possess characteristics which limit their utility:
-the systems developed by pharmaceutical laboratories are only compatible with dialysis machines from the same company. Even if the information transmitted is generally comparable, the interface and the transmission modes are different. Keeping in mind that medical centers rarely use machines that come exclusively from one pharmaceutical laboratory, this lack of compatibility of these systems is one of the reasons that their use remains limited.
- the technical nature of the data transmitted has undoubtedly a greater technical usefulness than a medical one. The maintenance of these machines, the long distance detection of

breakdowns, and the technical security of the sessions could present a particularly interesting application of these systems, on condition that the technicians can familiarize themselves with all the interfaces made by the different manufacturers of the all machines they use.
- the transmission of information is passive. There is no possibility of interaction or dialogue with the patient with these systems. This limits their use for the medical monitoring of patients.

In summary, the “telemedicine” systems actually offered by laboratories implicated in the different dialysis techniques allow mainly the long distance transmission of technical data of the dialysis sessions. This lack of interaction with the patients places these systems more in the category of telemonitoring of machines.

2) Telemedicine for dialysis

There are only few telemedicine experiences with chronic renal failure patients and, in particular, with dialyzed patients. The experiences published are rare, experimental and limited. These studies do not include clinical results nor do they generally include cost/benefit evaluations. The first experiences were initiated in 1995 and published in 1998 [1-3].

– A team in Washington D.C. [1-2] proposed an interactive telemedicine system. It consisted of placing an individual multimedia station in the home of each patient with two characteristics: a memory integrating a complete medical file (medical history, anamesis, physical and biological data, treatments, digitalized images (x-rays and others) and an on-line transmission of images and sounds. The images allow a private video-conference between the medical staff and the patient as well as the processing of more precise images (vascular access, exit site of the catheter, etc…) for a direct diagnosis. The sound is mostly used for cardio-pulmonary auscultation and sonar messages. This telemedicine system is thus interactive, polyvalent and has a potential field of application which is greater than that of dialysis. The first publication describing this system indicates a clinical study in progress which evaluates the quality of life of the patients, the morbidity, and the cost/benefit ratio.

– A team in Tokyo [3] describes an interactive telemedicine system based exclusively on the transmission of images (Image Transfer System). The patients are equipped with cellular telephones and a portable computer on which is connected a numeric camera. The images are transmitted (duration: 4 min per image) to a server situated in the hospital and can be accessed by the doctors either directly or by their personal computers. The images are of good quality (1024 X 768 pixels; 16 700 000 colors) which permits a diagnosis on a portion of the body through a visual monitoring of the peritoneal dialysis treatment (color and aspect of the bags, inspection of the equipment). The Japanese study included 10 patients and emphasized the compactness of the equipment which facilitated the mobility of the patients.

– A team in Texas [4], historical pioneers in the field of telemedicine, have been using telemedicine for dialysis since 1992. Initially, they proposed a video-conference system linked to the telemonitoring system of the hemodialysis machines (Texas Telemedicine Project) by equipping the dialysis centers far from the medical team. Since 1997, they have been proposing to equip the patient with individual stations containing a rather complicated ensemble of electronic captors which permit a perfunctory consultation from a distance: stethoscope, opthomologic camera, fiber optic monitor, additional close camera. The entire station (cost: 34 000 USD) is connected through a numeric network to a server which is constantly monitored by a doctor.

The appearance in 1995 of a new dialysis technique, the daily home hemodialysis, opened up a new field of application for telemedicine for the individual, integrating simultaneously the telemonitoring of dialysis machines and the interaction with the patients. Until now, two experimental projects have been described:

– Pierratos [5] equipped his patients treated at home with a personal computer linked to a hemodialysis machine which transmitted the technical data to a server through the telephone network (modem). The medical team accessed this server through internet technology and can consult the data in real time or differed time since the data is stored by the server.

– Agroyannis [6] described a project (Homer-D) financed by the European Community. He used the numeric network (ISDN) to establish a bi-directional communication between the doctor and the patient. A UNIX station with a multimedia PC located in the hospital is permanently accessible. Each patient is equipped at home with a multimedia terminal linked to a hemodialysis machine which permits the monitoring and long distance control of this machine. Additional captors permit an automatic monitoring of a patient during dialysis sessions: arterial tension, cardiac rate, electrocardiogram, and transcutaneous oxymetry. A preliminary study which involved two patients, four months, and 100 dialysis sessions will be enlarged to encompass three European centers and will probably include a cost/benefit evaluation.

These telemedicine studies described above involved the instantaneous transmission of a large amount of data, allowing for the long-distance monitoring of the patient and the equipment. However, all these systems depend upon a doctor to analyze the data in order to make a diagnosis. In other words, the transmission of data simply eliminates the geographic distance between the patient and the medical team.

The DIATELIC project

1) Objectives

The main objective of the DIATELIC project is to improve the quality of the CAPD treatment. Optimization of the treatment quality first requires three main telemedicine characteristics:

The prevention of disorders due to chronic or acute hydration (hyperhydration or deshydration). These anomalies often appear progressively and insidiously in patients treated by home PD. It can be responsible for incidents leading if not to death then, at the very least, to a poorly tolerated treatment in a semi-urgent context and which can undoubtedly contribute to the rate of morbidity.

An improved long-distance relationship with the medical team. The telephone, invented in 1854 is still the only means of interactive communication between the dialysis patient at home and the medical team. Meanwhile, on the eve of the third millennium, the telephone has shown its limits in comparison to what actual technology can offer: the dialogues are subjective, the parameters transmitted are limited, the frequency of the calls is haphazard, and the availability of the medical staff is variable. These deficiencies in the quality as well as the quantity of the telephone calls can lead to problems with which the medical teams are familiar. Consequently, these problems often lead to the precipitated transportation to the center in order to establish a diagnosis and eventual hospitalization if the call was delayed.

A system which, through daily use, does not lead to a constraint which could underscore its benefits. This implies a quick and easy to use system. The patient interface should be sufficiently “universal” to be practical for all patients and quick enough to avoid any additional constraint on an already imposing treatment. The medical interface should permit the monitoring of a large number of patients without demanding a large amount of time from the medical team.

2) Description

a) Principle

The DIATELIC system allows the transmission of medical data in real time, the analyses of the data, and the return of the raw data indiscriminately in the form of a representational graphic or an analysis of the data with an automated diagnosis. This second function answers the need for economy of time when monitoring a large number of patients by the same medical team. DIATELIC contains, then, an original expert system in several respects. DIATELIC uses the Markov model to calculate the probability for a patient to be in a predetermined hydration condition. Five conditions of have been established: normal hydration, hyperhydration, deshydration, dry-weight under-estimated and dry-weight over-estimated. In order to calculate the probability of being in one of these five conditions, the system uses six complex rules simultaneously, and analyses simultaneously the absolute values of weight and blood pressure (differential and orthostatic) as well as their variations over the two previous days and taking, as points of reference, the averages of the previous fifteen days. So, for example, a patient with a permanent moderate systolic hypertension due to a cardiovascular disease will not be classified “hyperhydrated” if his state has been stable for at least fifteen days. Another example, a diabetic patient with a secondary orthostatic hypotension presenting a vegitative neuropathy will not be diagnosed as “deshydrated” if his condition is stable.

A warning message will automatically be sent to the patient as well as to the medical center as soon as the system detects a change in condition which could be a potential anomaly. In the case of a false alarm, the diagnosis of the expert system can easily be modified by the doctor and these corrections are taken into account in future diagnosis of the patient: the expert system is a self-learning. Finally, other rules have been introduced concerning the variations of ultrafiltration which are analyzed daily, exchange by exchange. An integrated e-mail service, simple and easy to use, completes the system. This feature is frequently used by the patients.

b) Functional description of the experimental system

The DIATELIC system is composed of three sub-systems. The first is a sub-system in the home of the patient, the second is a server which integrates the data base and the intelligent systems’ detection of anomalies, and the third is a medical sub-system. These three sub-systems are actually interconnected through several networks as shown in figure 1. The patient’s terminal is connected to the server by a commuted telephone network. The server is connected to the Lorrain Reserch Laboratory of Computer Science and its Applications (LORIA); this is accessible through the local internet network (STANNET), permanently connected to the CHRU and ALTIR (Lorrain Association for Renal Failure Treatments) network. (Fig.1).

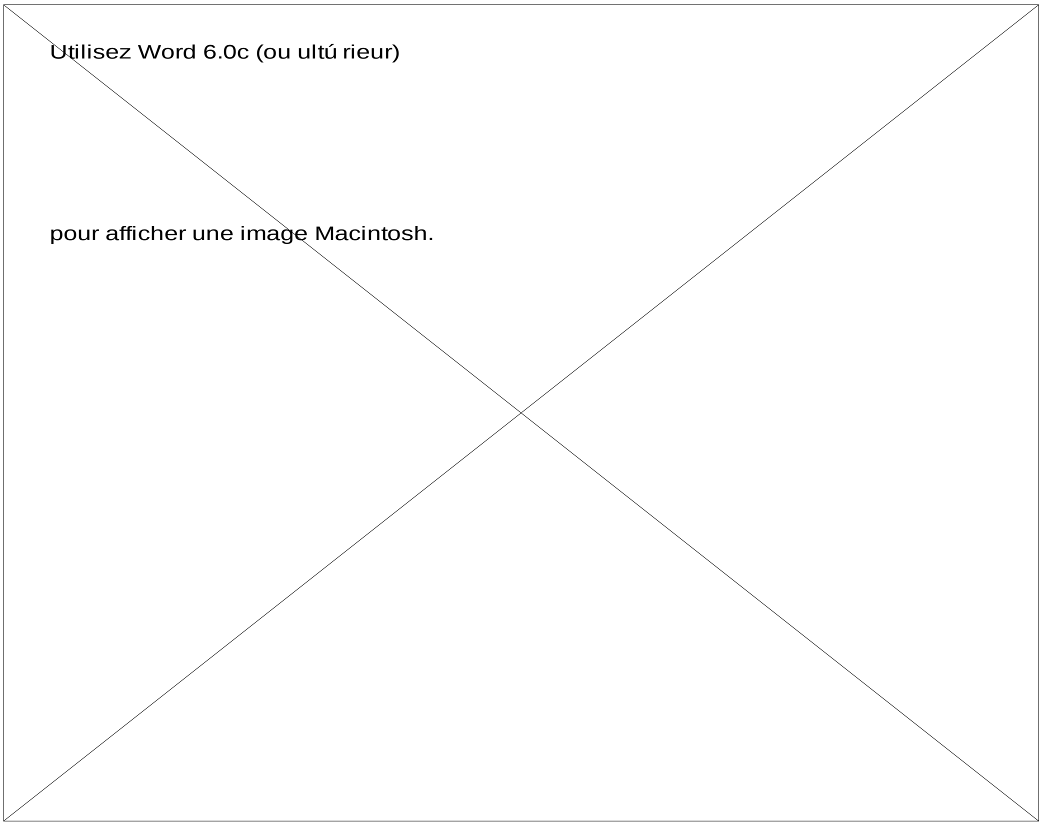

Fig 1: Architecture of the experimental platform

Data confidentiality is preserved according to the recommendations of the CNIL: a password is required each time the server is accessed and the data is codified. Only the doctor is familiar with the patient's identification code. In addition, the connection on the patient's side is made through a call-back system with the server having in memory the telephone number of each patient.
In the present system, the data entry is done manually by the patient who has already done this on paper. An exploitation in posteriori revealed that certain complications could have been avoided if the information had been transmitted earlier. The patient must get accustomed to entering the data into a computer and the transmission procedures. He can also take advantage of a graphic feed-back system showing the evolution of the data, which may contribute to his compliance. The clinical experience (technical test) has shown that the data entry does not present any great difficulty for the patient who, on the contrary, shows a certain enthusiasm and is reassured by the fact that the information he sends will be analyzed rapidly.

3) Advantages

DIATELIC, thanks to its expert system, analyzes the given information before transmitting them. In doing so it is undoubtedly a precursor of a new generation of telemedicine systems. This essential and original characteristic allows the sorting of information. Such a system is then applicable to a large number of patients monitored by a single doctor: routine consultations of the global data being reduced to those presenting anomalies.
Other characteristics which distinguish the DIATELIC from other telemedicine systems currently used:

– an optimized doctor/patient interaction: the data is no longer passively gathered but is entered and transmitted by the patient himself. This interaction is reinforced by an integrated e-mail service which permits a bi-directional exchange of information. The patient now has an active role which reinforces his sense of responsibility with regards to the treatment and its adherence

– a feedback directly to the patient of the analyzed data by the expert system. This security function stimulates and motivates the patient to adhere to his treatment and to use the patient interface.

– an expert system precisely adapted to the surveillance parameters of the dialysis technique for which it was developed (CAPD) for DIATELIC. This characteristic of the expert system allows a specialized monitoring and a detection of anomalies adapted to the CAPD.

– finally, the data transmitted is essentially medical and concerns the patient's health. DIATELIC is not a system of monitoring of machines or dialysis equipment. It can thus be used for all peritoneal dialysis patients, regardless of the material used.

Conclusion

Encouraged by the development of the communication network, the decrease in the cost of transmission, and the simplification of the computers, telemedicine will probably develop in the next few years and profoundly modify the medical profession. It will represent a major revolution in the public health system when the current studies undoubtedly reveal a favorable cost/benefit ratio. Concerning DIATELIC, such a study was started in may 1999. It is a propective, randomized study including at least 30 patients, in order to evaluate the quality of life, the mortality, the morbidity and the cost of the therapy between patients followed by telemedicine compared to patients without telemedicine. Preliminary results will be published in year 2000.

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