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Improving Dialysis Services through Information Technology: From Telemedicine to Data Mining

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Abstract

This paper discusses the issues related to use of Information Technology (IT) solutions in dialysis, and describes the implementation of some of them in a medium size dialysis center. First, starting from the analysis of the organization of public-health nephrology services, the potential role of IT is highlighted. Second, the main directions for IT exploitation in dialysis, namely telemedicine and automated monitoring of dialysis sessions are discussed. Third, the on-field implementation of these services is described, together with some preliminary results. The work here presented shows how IT may improve dialysis services by ameliorating quality and reducing costs.

Keywords:

Dialysis, Information technologies, telemedicine, data mining

Introduction

Dialysis units deal with the treatment of patients with acute or chronic end stage renal failure. The incidence of chronic renal failures ranges from 242 to 348 per million in the US population [1] and 118 in Italy [2], the majority of them being related to glomerulonephritis and Diabetes Mellitus. The elective treatment of chronic renal failure is represented by renal transplant; dialysis treatments are provided as suitable alternatives to transplants for people in waiting list or for people that cannot be transplanted at all. Two main categories of dialysis treatments are nowadays available: hemodialysis and peritoneal dialysis. In hemodialysis, the blood pass through an extra-corporal circuit where metabolites (e.g. urea) are eliminated, the acid-base equilibrium is re-established and the water in excess is removed. Such process is performed by exchanging solutes through a semi-permeable membrane (dialysis) and by removing water with a negative pressure gradient (ultrafiltration); a machine called hemodialyzer regulates the overall procedure. In general, hemodialysis patients are treated for four hours three times a week. On the contrary, in peritoneal dialysis, water and solutes are removed within the patient's body, thanks to the introduction of the dialysis solution in the peritoneal cavity through a silastic catheter. The peritoneal membrane acts as a semi-permeable membrane and allows for the needed blood clearance and water removal. Peritoneal dialysis is performed at home by the patients themselves in a nearly continuous way. Two treatments are possible: CAPD (Continuous Ambulatory Peritoneal Dialysis) and APD (Automated Peritoneal Dialysis).

The dialysis treatment has very high costs and it is extremely demanding from an organizational viewpoint [3]. A medium size center may manage up to 60 patients per day in hemodialysis, i.e. an average of 120 patients, plus the peritoneal dialysis ones, that need to be visited roughly one time per month. This process requires highly specialized personnel, day hospital beds, and at least 30 hemodialyzers plus the disposable material.

Unfortunately, the number of patients that need dialysis is constantly increasing [1,2]. It has been recently recognized that payers of dialysis can only constraint costs by limiting access to dialysis, reducing the quality of the treatment (by, for example, reducing hemodialysis time) or placing constraints in the modality of distribution (by, for example, increasing the number CAPD patients) [3].

Rather interestingly, a potential solution to the increase in the costs of dialysis services, is represented by Information Technology (IT), that promises an improvement in the delivery of care at relatively low-cost. A number of applications of IT have been recently presented in the literature [4-10]. Summarizing, three main directions are emerging. First, it is now feasible to apply telemedicine solutions to control remote dialysis centers or to monitor home hemodialysis patients, thus maintaining the quality of care while reducing the travel and personnel costs [4-7]. Second, the advances in the implementation of hemodialyzers allow for an automated monitoring of dialysis session and for the early detection of problems in the quality of dialytic treatment [8]. Third, the transmission of data and messages from home by using telephone, fax,

computer telephony interfaces and Internet may strongly improve the delivery of care in APD and CAPD [9-10].

In this paper we will describe from an organizational viewpoint how IT may effectively automate Nephrology departments, and we will present the design and the first implementation of some IT solutions in the Nephrology service of the civil Hospital of Vigevano, Italy.

The dialysis center: organization empowerment by Information Technology

In several Italian regions, such as Lombardia, the public health Nephrology service is structured as reported in Table 1:

Table 1 – Nephrology service organization in Lombardia

Process areas	Organizational areas
A. In patients	Nephrology unit Transplant unit
B. Day Hospital	Nephrology day hospital
C. Hemodialysis	Hospital Dialysis Center (HDC) Limited Assistance Dialysis Center (LDC)
D. Ambulatory Care	General ambulatory care (GAC)
E. Home Care	Home assistance service

In-patients usually comprise acute patients that may suffer from acute or chronic renal failure, and patients undergoing renal transplantation. If their stage of the renal failure does not require dialytic treatment, chronic patients are treated in the Nephrology day hospital and in the General Ambulatory Care (GAC); on the contrary, if they are undergoing hemodialysis, they are managed by the Hospital Dialysis Center (HDC). Sometimes, the dialysis service is provided with an ancillary section, called Limited Assistance Dialysis Center (LDC), that is a dialysis unit located in remote or rural areas; the LDC usually relies only on nurses as permanent staff. Finally, APD and CAPD patients are treated at home, and they are periodically visited in the Nephrology Day Hospital; they receive home assistance by specialized personnel. Moving from the description of the organizational areas described above, it is possible to outline the role of IT for supporting the care processes, as described in Figure 1.

The basic facilities for hospital admissions, discharge and patient management are provided by the Hospital Information system (HIS), which functionality can be increased by the implementation of proactive guidelines for day hospital and ambulatory care. From IT viewpoint, Dialysis Units should also manage: i) the data automatically collected during hemodialysis sessions, ii) the surveillance of the activities performed by LDC, iii) the surveillance and assistance of CAPD/APD and hemodialysis patients at home. Each of these three peculiar problems may be handled in different ways.

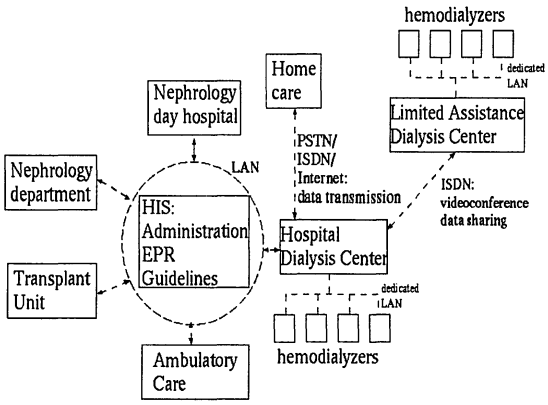

Figure 1

Automatic data collection

The most recent hemodialyzers allows for the automatic monitoring of the dialysis sessions. Moreover, the hemodialyzers can be connected to a Local Area Network (LAN) in order to monitor all the concurrent dialysis sessions. As an example, the INTEGRA© HOSPAL dialyzers coupled with the DIALMASTER© software for data acquisition, is able to monitor up to 28 parameters, with a configurable sampling time, which lower bound is equal to 100 msec.

It is clear that, if from one side the capability of monitoring all sessions is a potential advantage for the management of the dialysis center, on the other side the weekly accumulation of Gigabytes of data may hamper the use of the data themselves. Moreover, it must be stressed that, since the dialysis service works under cost pressure, any additional work overload is likely to be unacceptable by hospital personnel. For these reasons, it is impossible to rely on the inspection of the raw data, but it is necessary to automatically extract features and patterns that may be useful for assessing the dialysis sessions. This is feasible by realizing a suitable *auditing software* that should be able to summarize the dialysis sessions from a quality viewpoint. Such software should be customizable in dependence of the center requirements and should be integrated within a complete data mining service for health professionals, able to inspect the data at different levels of abstraction and time granularity. Finally, the same software should be able to automatically extract data to be used for the quality certification of the service.

Surveillance and management of LCD

The goal of a networking connection with the LDC is threefold: first, it is necessary to provide the required (synchronous) assistance to nurses for managing emergencies, including technical intervention on the

hemodialyzers; second, it is important to (asynchronously) control the dialysis adherence to the medical prescriptions; third, it may be important to maintain the patients motivations by a (synchronous) contact with the physicians. In this context, it seems that the presence of a video-conferencing system between the LDC and the HDC may effectively accomplish with the needs of synchronous communications, while the use of the previously mentioned auditing procedures on the dialysis data may solve the surveillance needs.

Surveillance and management of Home patients

As mentioned in the introduction, CAPD and APD patients perform a self-management of their own disease. The clinical results are periodically revised during the patient's visits at the ambulatory care service. The capability of assisting such patients when they are at home seems important for improving the quality of care, for optimizing the visits time and for increasing the patient's compliance. Recently, several proprietary IT solutions have enabled the data transmission from home to clinic in APD; in this treatment a device located at home performs the dialysis solutions exchange over night. The device stores the parameters collected during the treatments in a local memory, and may send them via PSTN or may download them on a smart-card [11]. Unfortunately these IT solutions do not provide facilities to collect data on the general patient clinical status (such as the blood pressure); finally it seems hard to integrate them in an existing HIS. Other solutions comprises the provision to patients of general telemedicine services, including video-conferencing, Internet access and Computer telephony interfaces [9-10]. Finally, it has been recently tested the use of IT to assist patients undergoing home hemodialysis [4,5]. In this treatment, the patient is assisted during each dialysis session by telemonitoring; emergencies are supervised by the hospital center.

The implementation of IT solutions in a medium size dialysis center

Vigevano is a town of nearly 70,000 inhabitants located in Lombardia, 35 Km from Milan. The Vigevano dialysis service relies on 5 physicians, 17 nurses, a head-nurse and a technician. This personnel manages the organizational areas of the Nephrology unit, the Nephrology day hospital, the HDC, the GAC and the home patient's assistance. The Vigevano center is able to manage up to 48 hemodialysis per day, and nowadays treats 89 patients and 28 peritoneal dialysis patients. There is also a LDC, located in Mede, a rural town 40 Km far from Vigevano; the LDC has 5 nurses and manages 27 hemodialysis patients.

In this setting, IT has been exploited to i) connect the LDC via video-conferencing; ii) monitor the dialysis sessions of all patients and derive a set of quality indicators of the hemodialysis sessions monitored; iii) plan for a telemedicine assistance of CAPD and APD patients.
In the following we will briefly describe the technical details of each step, and the first results obtained.

Managing LDC via videoconference

A videoconference system has been successfully implemented and tested to accomplish with the need of synchronous communication between the LDC located in Mede and the HDC of Vigevano. In particular, it has been set up a system based on two VCON Cruiser 384 Videoconference boards, installed on two PCs, following the architecture shown in Fig. 2. The connection between the two centers is realized through 2 ISDN lines (4X64 Kb/sec). The video camera used at the HDC was a standard Philips analog camera, while the two rooms of the LCD were provided with a Pan Tilt Zoom Sony Camera EVI-D31, with optical zoom X12, resolution 752 X 585 and illumination range of 7-100000 lx. The two remote cameras were controlled by the HDC. In both LDC and HDC two Tabletop microphones have been installed; moreover, in order to allow for a better mobility between the two rooms in the Mede service, a radio-microphone has been also provided.

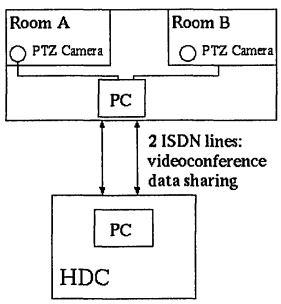

Figure 2. The videoconference service that connects the Mede LDC and the Vigevano HDC.

The Videoconference sessions have been managed by the VCON Meeting Point© software. The performance of the system has been evaluated accordingly to the procedure published in [12-13]. This method allowed to measure audio, video and file transmission delay. The audio and video transmission delays were estimated to be 0,4 sec that is considered to be acceptable for this application. The file transmission delay was tested with files of different size, and ranged from 39,22 sec (121 Kbytes) up to 3 mins and 37 sec (1,2 Mbytes). In this case, the users considered the delay very high. However, since the data transmission speed was not the main goal, it was decided to start the clinical usage of the system. The system is currently being used since August 1999, with a minimum of one video-conferencing session per week plus emergencies and special requirements of the LDC. Up to now, thanks to the the video-conferencing system, several major changes occurred in the organization of the HDC assistance to the LDC service:

- the visits of the HDC head-nurse to LDC have been

limited to not-routine intervention, such as the introduction of new operational techniques that require face-to-face teaching;
- the majority of technical intervention on the hemodialyzers have been carried on using the telemedicine system; therefore, the technician is not anymore required to travel to Mede to provide assistance;
- the head of the dialysis unit reduced his trips to Mede from one visit every two weeks to one visit every six weeks.

These changes did not have a negative impact on the treatment quality; on the contrary a measurable impact on the direct costs was observed, in terms of time gain in traveling and assistance. Such costs can be easily calculated. Following the figures reported in Table 3, in one year the number of trips saved were 17, 4 and 4 for the head of unit, the head nurse and the technician, respectively. Each visit is estimated to last 6 hours for the physician and eight hours for the other personnel. Since the number of hours per year is taken to be 1512 (210 days X 7.2 hour per day), the save in personnel cost in one year may be evaluated as 9.5 Keuros. This mean that within two years the equipment (15 Keuros) and telecommunication costs (1 Keuro/year) will be covered, even considering depreciation.

Table 2. Cost savings with Video-Conferencing (VC) systems

Personnel	**Trips without VC**	**Trips with VC**	**Hourly cost**	**Cost savings over one year**
Head of the Unit	26	9	74 Euros	7.548 Euros
Head nurse	5	1	32 Euros	1.024 Euros
Technician	5	1	32 Euros	1.024 Euros

Monitoring dialysis sessions. Nowadays, the assessment of the hemodialysis sessions is performed by the so-called KT/V analysis. The parameter KT/V roughly expresses the blood volume that is cleared from urea at the end of the dialysis treatment. Its assessment is usually performed monthly by measuring urea blood concentrations before and after the treatment. The first goal of the use of monitoring data was therefore to extract from the data automatically collected during hemodialysis sessions some indicators that may indirectly express KT/V, together with some other indicators that may reveal the non-adherence to the dialytic prescription established before the treatment. Relying on the data collected by the DIALMASTER© software for HOSPAL devices, we develop an Auditing software, written in Microsoft Access, that performs data analysis on the time series of six parameters:

- The average level of Blood Bulk flow in each dialysis (QB)
- The average hemodialyzer venous pressure in each dialysis (PV)
- The average hemodialyzer arterial pressure in each dialysis (PA)
- The time difference between the prescribed dialysis time and the effective one in each dialysis (Δtime)
- The weight loss difference (in percentage) between the programmed and the real one in each dialysis (Δweight = |real weight –programmed weight|/programmed weight)
- The presence of a nurse intervention during each dialysis session (Int)

The average levels were calculated after automatic outlier removal from the original time-series. Each value was compared with a reference value, to obtain a quality index of the overall dialysis, and the reasons of unsuccessful treatments. A generic index of success has been derived by judging as positive a treatment in which all the following logic conditions are satisfied:

Parameters	Condition
QB	Greater or equal to the prescribed QB
PV	Less or equal to 350 mmHg
PA	Greater or equal to –250 mg
Δtime	Less then 15 min
Δweight	Less or equal to 1.1%

Four patients have been monitored for 1 month and a half (for a total of 71 dialysis sessions) and a preliminary evaluation of the service performance has been obtained. The general results were the following: 68% of the dialysis sessions were positive, 24% were negative and 8% were positive but with personnel intervention.

After the analysis of the "failures", it turned out that the 55% of the negative cases showed an insufficient weight loss, the 33% of the cases had problems with the blood bulk flow and the 12% of the cases had an insufficient dialysis time. Rather interestingly, all negative cases had only one cause of "failure". Such experience clearly showed the feasibility of using monitoring data for quality assessment, since no extra effort was required to personnel for data input, and the automatic procedure for data analysis was easy and useful. Moving from this experience, we plan to implement a data mining system, that should be able to summarize dialysis outcomes and to automatically highlight the intra- and inter-dialysis sessions variability of the clinical parameters.

Towards telemedicine services for assisting home care in APD/CAPD patients

It is planned to set up a service for assisting APD/CAPD patients via the integration of Computer Telephony Interfaces and Internet-based services, within a project funded by the National Ministry of Health, and under the scientific leadership of the Policlinico S. Matteo Hospital of Pavia. Such service will be designed to provide a better link between the patient's home and the hospital clinic. A small set of basic clinical parameters will be monitored and transmitted by patients either using the telephone or the Internet; the data and the messages will be therefore made

available to physicians for a more frequent monitoring and therapy revision. Although the integration with existing telemedicine solutions for downloading data from the APD devices is currently not possible, due to the strict proprietary policy of APD device providers, it is also foreseen to extend the auditing software previously presented, to allow for an automatic data analysis of APD sessions. The telemedicine system is now under preliminary evaluation in the different clinical sites involved in the project.

Conclusions and future work

Information Technology now offers a large spectrum of useful solutions for increasing the efficiency of health care provision. The use of IT can be particularly valuable in medical departments that are overwhelmed with costs and time problems. To provide an effective impact in this context, the design of IT systems should be based on a careful analysis of the organization of the health care service [14]. Such analysis should highlight the potential IT-based solutions to real problems, and, even more importantly, how the organization should be changed to fully exploit such solutions. In this paper we have shown the potential impact of IT in dialysis and nephrology services, and we have shown how the use of telemedicine and automated data mining system may provide time-saving, low cost effective solutions to some current problems. In the future, we plan to achieve a better integration of the work herein described with the existing legacy systems; moreover, we will investigate the data mining aspects related to the automatic evaluation of the patients status, relying only on the data collected during dialysis sessions. Finally we will test the telemedicine system that has been designed and implemented for assisting CAPD and APD patients.

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References

[1] The United States Renal data system, http://www.usrds.org

[2] Registro Italiano di Dialisi e Trapianto, http://www.sin-italia.org

[3] McFarlane PA, Mendelssohn DC. A call to arms: economic barriers to optimal dialysis care. Perit Dial Int 2000: 20: 7-12.

[4] Agroyannis B, Fourtounas C, Romagnoli G, Skiadas M, Tsavdaris C, Chassomeris C, Tzanatos H, Kopelias I, Lymberopoulos D, Psarras. Telemedicine technology and applications for home hemodialysis. J. Int J Art Organs 1999: 22: 679-683.

[5] Moncrief JW. Telemedicine in the care of the end-stage renal disease patients. Adv Ren Replace Ther 1998: 5: 286-291.

[6] Mitchell JG, Disney AP. Clinical applications of renal telemedicine. J Telemed Telecare 1997:3: 158-162.

[7] Homer-D project: Home rehabilitation treatment – Dialysis. http://www.etho.org.

[8] Ronco C, Brendolan A, Bellomo R. Online monitoring in continuous renal replacement therapies. Kidney Int 1999: 56: S8-14.

[9] Nakamoto H, Hatta M, Tanaka A, Moriwaki K, Oohama K, Kagawa K, Wada K, Suzuki H. Telemedicine system for home automated peritoneal dialysis. Adv Perit Dial 2000: 16: 191-194.

[10] Stroetmann KA, Gruetzmacher P, Stroetmann VN. Improving quality of life for dialysis patients through telecare. J Telemed Telecare 2000: 6: S80-83

[11] PD link software for home choice Pro. http://www.baxter.com

[12] Klutke PJ, Mattioli P, Baruffaldi F, Toni A, Englmeier KH. The Telemedicine benchmark – a general tool to measure and compare the performance of video conferencing equipment in the telemedicine area. Computer Methods and Programs in Biomedicine 1999: 60: 133-141.

[13] Klutke PJ, Gostomzyk JG, Mattioli P, Baruffaldi F, Plasencia A, Borrel C, Pasarin M, Di Crescenzo E, Pipitone E, Mancini C, Toschi A, Morshedi M, Strintzis MG, Englmeier KH. Practical evaluation of standard-based low-cost video conferencing in telemedicine and epidemiological applications. Med Inform 1999: 24: 135-145.

[14] Carson ER, Cramp DG, Morgan A, Roudsari AV. Clinical decision support, systems methodology: their role in the management of chronic disease. IEEE Trans IT in Biomedicine, 2, 1998: 2: 80-88.

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