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VIRTUAL CENTER FOR RENAL SUPPORT: DEFINITION OF A NOVEL KNOWLEDGE-BASED TELEMEDICINE SYSTEM.

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Abstract – **The Biomedical Engineering Group of the University of Seville (GIB) is developing new strategies to apply the home health care paradigm within End Stage Renal Disease (ESRD) Patients. In this paper we first review the current status of ESRD patients in Spain, Europe and USA. In the second part, the formal definition of the novel Virtual Center for Renal Support (VCRS) is done. Design of VCRS relies on a model-based system analysis methodology. The knowledge-based assistance to be provided by VCRS is carried on the Patient Physiological Image Component (PPI Component). This is a computing component based on cutting-edge Modelling & Simulation Technology, which gives the physician the ability to predict clinical events, infer technical and physiological problems, compute no previously measured variables and is also an aid for diagnosis, prescription and supervision of therapies.**

***Keywords* – Remote healthcare, telemedicine, ESRD, peritoneal dialysis, hemodialysis, ESRD costs, knowledge-based assistance, modelling and Simulation.**

I. INTRODUCTION

The population of ESRD patients is growing in all developed countries. As a reference, in USA this growth is 7 % average per year from the beginning of 90's, although this slope is currently raising [1]. This is mainly due to the growth of the incidence rate and also to the improvement in the dialysis therapies and transplants outcomes. The low natality rate in Europe and USA and the higher life expectation will yield a very important increase of costs in the public health care system.

During the past decade, dialysis outcomes have notably improved, due mainly to the application of pharmacokinetic mathematical methods to quantify the delivered dialysis. However, renal replacement therapy outcomes, measured by means of morbidity and mortality rates are still very low [2].

Telecare or remote health-care systems based on Information Technologies are a new paradigm with high expectations to solve the current challenges. However, present-day telehealth systems are mainly focused to the monitoring and attendance of elderly people. The VCRS we scheme in this paper is a new architecture and methodology oriented to the monitoring and knowledge-based assistance to ESRD patients, with main focus in dialysis patients.

II. ESRD STATUS REVIEW

The total number of new ESRD patients in USA in 1998 was 85.520 (311 per million population), while the total of prevalence ESRD patients was 323.821 (1170 pmp), from which 233.211 (72%) were under dialysis treatment and the rest were transplanted patients [1]. More than 48 % of the incident ESRD patients were older than 65 years, while the analogous rate decrease to 34.4% for prevalence ESRD patients. Near all of these prevalent patients were submitted to dialysis treatment. On the other hand, the total of incident ESRD patients in Spain in 1997 was 3.814 (114 pmp), and the total of prevalence ESRD patients was 25.689 (745 pmp) [3], but 40% of prevalent ESRD patients had a functioning graft, 55% were in hemodialysis therapy and the rest were in peritoneal dialysis. The percentage of patients in dialysis is much smaller than in USA due mainly to the high rate of transplants in Spain.

The percentage of elderly people into ESRD population is an issue which must be highlighted. The trend in Spain and in the rest of Europe and USA is a growth in the average age of ESRD patients [1].

The USA ESRD population forecast is 661.330 prevalent patients and 172.667 incident patients for 2010, with 520.240 patients in dialysis therapy. The growth in prevalent and incident ESRD patients has occurred all over the world since 1989. The increase in prevalence ESRD population can be related to the improvement in therapies and also to a growth of the incidence.

Driven by the growth of ESRD patients, the economic cost supported by the USA ESRD program public health service has been increasing from $5.000 millions in 1991 to $12.000 millions in 1998 and it is expected that this cost will surpass $28.000 millions in 2010 [1]. In Spain, 40 % of the current total public health care expenditure is consumed by population with more than 65 years and it is expected a 30 % of people over 64 years old in Spain in 2050, with an increment of health costs in this group to 60.000 million euros, from the 12.000 million euros in 1997 [4]. The importance of these last data is due to the high and increasing percentage of elderly people into ESRD population.

III. ESRD CLINICAL REVIEW

The growth of percentage of incidence is first due to diabetes and second to hypertension. Diabetes incidence in primary diagnosis has duplicated from 1990 to 1998, while hypertension primary diagnosis has increased more than 10% in the same period. Diabetes is also the first cause in Spain and continues growing [5]. The same trend is observed in the rest of Europe. The essential hypertension is also a main cause of renal disease in Europe and a high rate of cardiovascular disease patients (50%) suffer progressive renal disfunction. In spite of these facts, only a 43 % of diabetic ESRD patients surviving a full year in USA were monitorized by the HbA1c test (Hemoglobin A1c or fraction of Glycosilated hemoglobin) in 1998 [6] and only a little percentage was routinely monitored. This is specially important since diabetics are the highest risk group for cardiovascular disease and also cardiovascular mortality in ESRD patients is much higher than in general population. It is now widely accepted the importance to control blood

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pressure upon a diagnosis of diabetes mellitus. In the line of cardiovascular risk factors monitoring, less than one of each three ESRD patients in USA who survived a full year had two or more lipid tests (lipid panel, cholesterol, HDL, LDL, VLDL, Triglycerides) performed in 1998.

Quality of life of patients is related to their morbidity, which is an important issue to control. This is specially important with patients with more than 65 years old. Morbidity is usually measured by means of length and frequency of hospitalization [1]. Although both parameters have decreased, they still support high values. The main diagnoses for prevalent hemodialysis patients in USA during 1998 were infections, cardiovascular complications and vascular access problems (infections and others) [1]. For prevalent peritoneal dialysis patients the situation is similar, substituting the vascular access by catheter complications. These results are similar in Spain and Europe.

Infection is an important cause of death in ESRD patients, so it is important their periodic control by means of blood analysis. Another relevant problem is the stenosis in the vascular access, which is related with an access function impaired [7] due to the recirculation of dialyzed blood. This topic has been widely studied and the formal Urea Kinetic Modelling is an important instrument to help the physician to predict it [8].

Disorders of calcium, phosphorus, D vitamin and parathyroid hormone, are usually prior to the initiation of dialysis therapy and are the main responsible of the emergence of "adynamic bone disease", a condition diagnosed by bone biopsy [9]. To maintain the parathyroid hormone concentration near normal level it is important to control dietary phosphorus, calcium salts and calcitriol. Use of calcium salts with meals may require adjustments in the concentration of calcium in the dialysate fluid to prevent hypercalcemia and consequent deposition of calcium phosphate salts, which may imply damage to heart, blood vessels, and other tissues.

Another pathology that appears in long-term dialysis patients is amyloidosis. In ESRD patients, this pathology is due to the increased release of beta-2-microglobulin (B2M) protein as amyloid from macrophages and to the reduction in destruction of B2M that normally occurs in functioning kidneys. It is necessary an adequate monitoring of B2M by means of periodic blood analysis in risk patients. Some studies have shown a reduction of B2M level with high flux hemodialysis and biocompatible membranes.

It is widely accepted nowadays that the improvement of renal therapies outcomes are highly related to the dialysis dose that can be measured by the urea or creatinine Kt/V index [8]. Other important indicators related to morbidity and therapies outcomes are erythropoietin (EPO) dose and hemoglobin (HGB) and hematocrit (HTO) levels [1].

The significance of Kt/V is not understood enough yet, and there exist different procedures and also different results on computing Kt/V [10]. Although the prospective HEMO study, designed to evaluate Kt/V with current high flux membranes and highest Kt/V levels, is near to finish, and therefore the situation will be enlightened, the physicians will need a computational and telemedical support which aids them to compute doses and prescriptions and to compare numerical results with clinical patient outcomes.

Although the hemodialytic procedure has been much improved, this technique requires an adequate education of patient and staff members, especially in current home-HD. The main limitation of present-day home dialysis is the supervision and control gap between the patient and the physician. Home dialysis began to be studied as a viable alternative to the Center dialysis in the 70's [11]. The major barriers for the large-scale effectiveness of home dialysis treatment considered in that study were: lack of criteria for selection of candidates and lack of a continuing supportive service system. Nowadays, nearly the same barriers continue active [12].

III. DESIGN GUIDELINES

From this brief review we can state that it is necessary a change in health-care paradigm which may be led by novel technologies on information and communications. The VCRS telemedicine system has been projected to eliminate the historical barriers in order to achieve an open, broad and successful implantation of home dialysis.

The previous ESRD review sketches a too complex scene to be solved by a telehealth system only based on a sophisticated data and voice telecomunication system. To guarantee a remote and secure dialysis therapy it is necessary an automated system able to predict in short and medium term the clinical and technical complications that the patient may develop and suffer. The system must also aid the physician to propose and modify the patient therapy, even in an interactive manner. With that aim we have defined the novel concept of ***patient physiological image*** (PPI), which is a computer component, accessible in a remote way, that the VCRS uses to compute a knowledge in depth about the patient. The PPI is created, constantly adjusted and stored by the telehealth system by means of modelling and simulation techniques. The analysis mode and the physiological systems that the mathematical model comprises itself, depend on the patient and the medical staff requirements.

In essence, the PPI component must be understood as a computer representation of a patient. Once a new PPI component is created and linked with a patient, it will be continuously changing and adapting to this patient by means of monitored biomedical data. In this way, the evolution of the component follows up the evolution of the patient.

Starting from these previous concepts, the VCRS is defined as a remote knowledge-based assistance and monitoring system for clinical support of renal patients. VCRS will be applied to two types of patients:

- ESRD patients submitted to regular dialysis or with a functioning graft.
- Renal patients prior to Renal Replacement Therapy (RRT) submission.

The main goals to be achieved by the VCRS are now described.

1. **Reliable Patient Access to VCRS**.

The communication link must be secure and avoid any temporary unavailability. The privacy and intruder attack are two main difficulties to overcome. Modularity, scalability and open design, allowing different standard protocols and biomedical sensors, are other important issues related to patient access to VCRS. The patient interface must be friendly, easy to learn and prepared to be used by physically disabled patients. Finally, the VCRS must allow a Home RRT access for the most ESRD population in non-acute phase.

2. **Improving therapy outcomes**.

The second important goal of VCRS is the improvement of patient quality of life, reducing morbidity and mortality rate and achieving a better patient rehabilitation. This goal is related to the first secondary goal written down below.

3. **Enhancing physician efficiency**.

This goal can be achieved by means of an easier access to patient's data and a knowledge-based clinical decision support. Machine interface design must be adapted to working methods of physicians, regarding their actual computer tools and data structures. With that aim physician-VCRS interface will have cross-platform execution capability.

4. **Inexpensive system with low maintenance**.

This feature mainly applies to the patient's access devices to VCRS.

We also define two secondary goals. Firstly, VCRS will serve as support for academic and clinical investigation about renal disease, allowing its connection and thus the information transfer to other telemedical environments. Last, VCRS system will be used as an electronic platform to make easier the management of health resources to health providers.

To achieve these goals, we have designed an architecture formed by three types of elements: remote access units (RAU) for biosignal acquisition and communication from remote patient’s location, client interfaces for the professional access (CIPA) and computing and resource provider of the virtual center (RPVC).

With the aim to facilitate a non-restrictive access to ESRD patients and to insure the reliability of the access, we have initially projected to use the standard X.25 protocol between patients and RPVC. This protocol has been largely used by financial entities because of its high reliability. The main telephonic operators, in all countries, provide services and modules which allow the connection between an asynchronous (RS232) or synchronous device and the X.25 telematic network, from a basic telephonic access. This is a trade-off communication solution between a direct basic telephonic connection and other advanced communicactions links as ISDN, for instance, which are non-accesible for the majority of patients. Of course, by means of a modular and open design, this system will be easily able to migrate towards a more novel communication technology.

Another feature of the VCRS connectivity architecture is the separation between the RPVC and CIPA. This scheme is different from the other ones developed by other renal telemedical projects as HOMER-D [12][13]. HOMER-D System (Home Rehabilitation Treatment – Dialysis) has been supported by the 4th Framework Programme of the European Union. This system has overcome the technical tests imposed [14] and the clinical outcomes seem good [15]. The ultimate goal of HOMER-D project was to develop telematic monitoring services (TMS) for supporting patients who need home hemodialysis (HHD) or satellite hemodialysis (SHD). HOMER-D is later discussed.

Attending to the actual technology state, the requirements in bandwidth, security, availability and data privacy between CIPAs and RPVCs could be achieved by means of virtual private networks (VPNs) connecting CIPAs-RPVCs and different parts of RPVCs. Nevertheless, the design will not be restricted to VPN connection, allowing other networks as Internet.

The knowledge-based assistance is supported by the PPI components. These objects are currently being investigated by GIB and they can be considered as mathematical models available to be executed in a distributed manner and with advanced features from web-simulation technologies. The PPI development is taking into account the recent modelling methodologies standards as Modelica [16], besides open design concepts, as reusability and interoperability.

Finally, the VCRS design and evaluation methodology we are using is a model-based system analysis similar to the methodology used by Carson et al [12] [14].

IV. Discussion and conclusion

Information technologies are presented as a reliable paradigm which seem able to improve healthcare services quality, ESRD programs access and cost efficiency. Several modern works have been published in accordance to these statements. For instance, Vecchi et al [17] present an international comparative about costs and funding in different ESRD therapies, showing the lowest costs in Home Hemodialysis and Continuous Ambulatory Peritoneal Dialysis (CAPD). Mc Phatter et al [18] have shown that Home Dialysis may be chosen as a viable alternative to Center Dialysis. Taking into account the advantages of integrative care approaches, such it has recently been published [19], the VCRS design will allow both, peritoneal dialysis and variable frequency hemodialysis, as renal replacement therapies.

Information and communications technologies are increasingly used in the renal healthcare field. HOMER-D is perhaps the most important project in this investigation line. However, the ultimate HOMER-D goal is different from VCRS goal. HOMER-D tries to fill the “supervision gap” of the HD treatment by means of signal monitoring, for which the patient's access is done by means of an ISDN port and a multimedia-PC, placed in the patient's site. VCRS uses signal monitoring as a resource to feed its knowledge-based assistance system, which is supported by PPI components.

In addition, we think that the HOMER-D communication requirements are excessive to get a massive implantation of a homecare dialysis technology. However, a basic telephonic connection (without conversion to telematic network) is not adequate to fulfil the reliability requirement. Although wireless and Internet technologies seem to be the future, it is now necessary a more tested and reliable communication technology.

As summary, we have presented the project design guidelines of a novel tele-healthcare architecture for ESRD patients. First of all, we have reviewed the ESRD patients state, showing their forecast evolution and the charge of this ill-population over public health providers. From that background we have proposed a Virtual Center for Renal Support (VCRS) which presents two major differences respect other renal telehealth architectures. A remote assistance based on a knowledge in more depth of the patient and a communication link, which provides together a reliable telematic architecture and a widely used communication access: a basic telephonic point.

The first and major key-issue of this system is achieved by a physiological mathematical model simulation of each patient. This issue has propelled the development of the new concept referred to as patient physiological image or PPI. The GIB is actively working in the methodology, computer representation and management of this concept.

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