Integrating a knowledge-based system for parenteral nutrition of neonates into a clinical intranet

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Abstract

Daily renewed composition of parenteral nutrition for premature and full-term newborn infants in intensive care is tedious routine work. It needs a lot of expert knowledge and experience. Furthermore, it is a time consuming task and prone to inherent calculation errors. We have built several versions of the knowledge-based system VIE-PNN for prescribing parenteral nutrition supply. However, the clinical staff did not use these versions in their daily routine.

The recent version of VIE-PNN is a redesign using a HTML-based client-server architecture. It is integrated into the intranet of workstations which run the clinic's patient data management system. This integrated version is fully accepted by the clinical staff. It is used in daily routine at two neonatal intensive care units of the University of Vienna. All nutrition sheets are calculated by VIE-PNN. Reasons for the successful operation of the knowledge-based system in the daily routine work are ease of use, minimal required input, robustness of the system, explanation facilities, and most important time savings for the physician compared to the calculation by hand.

Keywords: Knowledge-based system, intensive care unit, parenteral nutrition, neonates, intranet application, integration with patient data management system.

1 Introduction

The planning and calculation of an adequate nutritional support for meeting the metabolic requirements of sick or premature neonates is an important

daily routine task. It is time consuming, needs practical expert knowledge and experience, and involves the risk of introducing possibly fatal errors [4]. We analysed the manual calculation of the nutrition schedule at our neonatal intensive care unit (NICU): the calculation is a routine task which is time-consuming and it bears the risk of overlooking important nutritional needs. The daily time required per patient is approximately 10 minutes. This sums up to more than one hour for the eight beds unit. Approximately 5% of all parenteral nutrition solution (PNS) sheets contain calculation or omission errors requiring recalculation or even remixture of the nutrition solution. This is costly and requires additional time of physicians and nurses.

Computer programs which support the calculation of parenteral nutrition are available at few hospitals. Most of them are designed for pediatric use (e.g., [6]) without giving specific consideration to the nutritional needs of small newborn infants. Sometimes a pediatric program for parenteral nutrition is extended to cover the group of newborn and premature infants [3]. However the low birth weight of neonates (500–1000 grams) at tertiary level NICUs makes it necessary to adapt to the individual metabolic and nutritional needs of the small neonate infant. Only few programs are tailored to the needs of neonates: [8] deal with the specific situation in a burn unit, and [7] implement simple food composition tables. The recently introduced tool `neofax-pn` for ordering parenteral nutrition solutions uses database technology to compute daily requirements. It allows the user to adapt yesterday's values. A recent study [9] indicates time savings and enhanced patient care for computerized parenteral nutrition orderings. We intended to create a program to support the daily routine in the NICU. This program has to combine standard textbook knowledge about neonatal nutrition with the practical knowledge of expert neonatologists.

In the year 1991 we started with the design and implementation of the knowledge-based system VIE-PNN (Vienna Expert System for Parenteral Nutrition of Neonates) with the following main aims:

- creating an interactive support system for planning the daily PNS,
- reducing the time needed for the calculation,
- creating a system able to combine parenteral with oral feeding,
- providing a continuous increase of the daily nutrition supply and a forced change from parenteral to oral nutrition. This requires reasoning methods taking into account the data of previous days,
- using the printed PNS schedule as part of the case history. The PNS schedule is further used by the nurses to compose the daily mixture of the nutrition solution,
- maintaining the hospital's standard for neonatal nutrition management and providing adequate control of fluid, electrolyte, fat, nitrogen, and caloric needs. The standard is defined in terms of rules of expert neonatologists,

and
– enabling the expert to keep the rules up-to-date.

2 The VIE-PNN system

VIE-PNN consists of three main modules: patient administration, computation of the daily PNS schedule, and maintenance. Patient administration is needed for adding new patients (name, sex, date of birth, venous access) and for archiving discharged infants. The maintenance module supports editing of nutrition rules, parameters' limits, rounding factors, and updating of oral nutrition preparations.

The main module of VIE-PNN interactively composes the daily PNS schedule. It starts with yesterday's PNS values of the infant (or plausible default values on the day of admission). These values determine the input parameters of the system (see table 1).

VIE-PNN determines the PNS schedule by

– applying rules for the daily increase of nutrition components,
– applying rules for nutrition needs based on today's serum values, or if actual lab values are missing on normal values,
– applying rules for nutritional changes according to the specific health condition of the infant,
– decreasing parenteral nutrition components by the ratio of oral to total

Table 1
Input and output parameters of VIE-PNN.

Input parameters	*Output parameters*	*Statistical measurements*
Body weight	Enteral supply	Energy rates
Age	Parenteral supply	Infusion rates
Total fluid allowance	Glucose	Fluids supply
Scheduled enteral feedings	Proteins / amino acids	Energy supply
Bypass medication	Electrolytes	Nutrients supply
Serum lab values	Vitamins	Supply per kg per day
Health condition	Trace elements	
	Fat	
	Bypass medication	

supply (for components which are contained in enterally fed products),
- checking for components' range limits,
- applying rounding methods based on knowledge about the precision a solution is mixed,
- solving the problem if the total fluid allowance is too small,
- combining drugs for bypass medication.

The final PNS schedule consists of the output parameters shown in table 1. VIE-PNN is interactive allowing the physician to modify each of the input and output parameters.

The first four versions of VIE-PNN [5] were stand-alone PC versions. The initial three versions were implemented using an expert system shell ("Intelligence/Compiler (I/C)"). These versions were too slow to be useful in daily routine. The fourth version was a redesign in C++ with a user interface written in TurboVision. It was fast, but inflexible. It was not accepted by most of the clinicians due to the rigid way the user interface behaved. Further, it was impossible for the experts to adapt VIE-PNN's decision rules to changing nutrition standards. Such changes in the knowledge base required source code changes by the knowledge engineers and recompilation of the system. The system was introduced to the NICU including some initial training. It was evaluated successfully for its correctness [1] but it was used only by few physicians and not on a regular basis. The main reasons were its inflexible user interface and its installation on a stand-alone PC. The PC was located in a different room and it was often used for other tasks, like word processing.

3 Integrating VIE-PNN into the clinical intranet

The bad experiences with the stand-alone version of VIE-PNN motivated us to try a completely different approach. The NICU is equipped with an intranet of workstations. The workstations (two mirrored servers, a bedside workstation for each bed, and several workstations in the nurses' and the physicians' rooms) run the patient data management system Hewlett-Packard CareVue 9000. All patient records are handled electronically by this PDMS. Our goal was to integrate VIE-PNN into this system. Unfortunately, HP CareVue is a completely closed system. There is no chance to integrate knowledge-based modules which would be the ideal solution for a parenteral nutrition support system. We were therefore forced to choose the second best solution: using the workstations as display for our VIE-PNN system. We added an additional server to the intranet (see Figure 1). This server runs VIE-PNN on request of any client workstation. In this way VIE-PNN has migrated from a stand-alone self-contained advisory system to a client-server system [2]. The clients run the user-interface front-end to the VIE-PNN server.

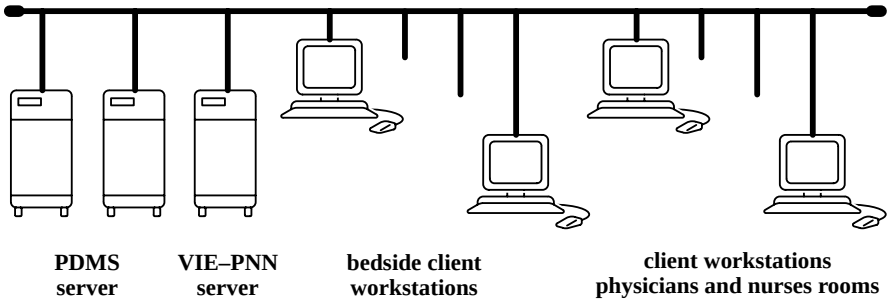


Fig. 1. The intranet of the neonatal intensive care unit.

The redesign of VIE-PNN (version 5) for a client-server architecture is based on the Hypertext Markup Language (HTML). A button in the HP CareVue system allows to invoke an HTML browser on any of the client workstations. This browser sends requests to the http-server of the VIE-PNN server workstation. All the reasoning and calculations are done by cgi-programs written in the programming language PERL [10]. Requests for data input and results of VIE-PNN are sent to the client workstation in the form of HTML pages. The final PNS schedule is printed on the NICU's laser printer. The system's knowledge is coded in PERL-like IF-THEN rules. It is revisable by the experts using the HTML browser.

Using eight HTML pages VIE-PNN asks for input and verification of the nutrition parameters. Minimal input is required from the physician. Manual input is mandatory for serum values from the laboratory (if new values are available today), for changes in the amount or kind of oral feeding and for changes in the bypass medication. If there are no changes, the physician may accept all pages by clicking the `OK` button. The system recommends values for nutrition components based on its knowledge rules. Figure 2 shows such a page for electrolyte values. The physician may change a value in case the nutrition requirements differ from standard rules due to a problem of the neonate which is not included in the knowledge base of VIE-PNN. Pressing the `I`(information) button gives an in-depth explanation about the computation of the recommended value (including basic values, rounding factors, and rules used). The final page shows the complete PNS schedule (see Figure 3). The user may accept it and print the PNS sheet or modify single parameters again.

4 Daily routine use of VIE-PNN

We installed the client-server intranet system of VIE-PNN at the NICU by the end of June 1996. It was accepted immediately by the physicians of the NICU. Only a few minutes of training was required. During the last six months 895 PNS schedules have been computed. There are no more PNS sheets calculated by hand (except for a few sheets done by external weekend staff).

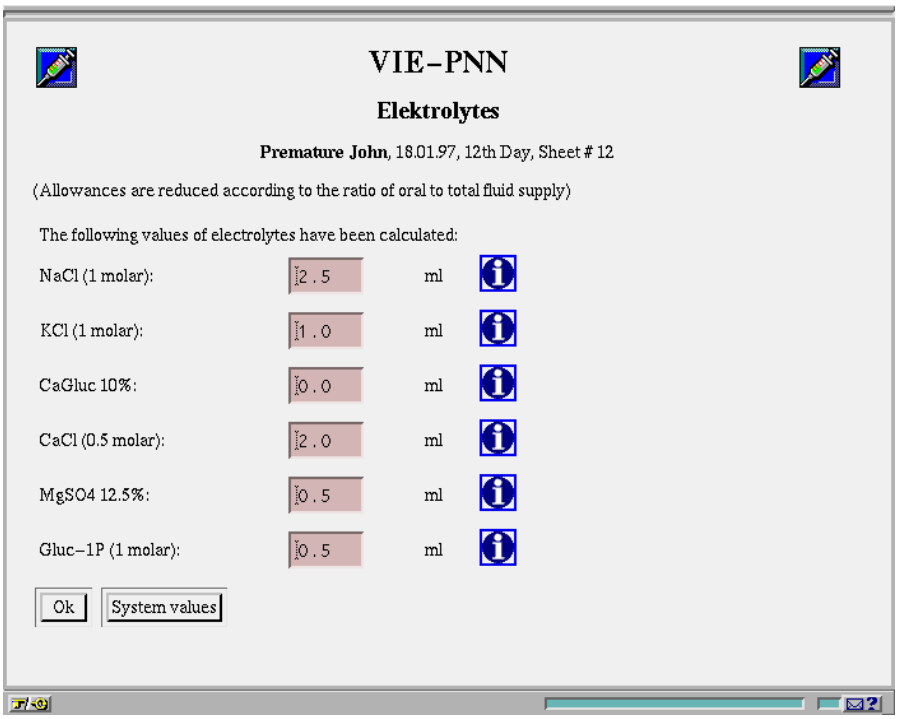
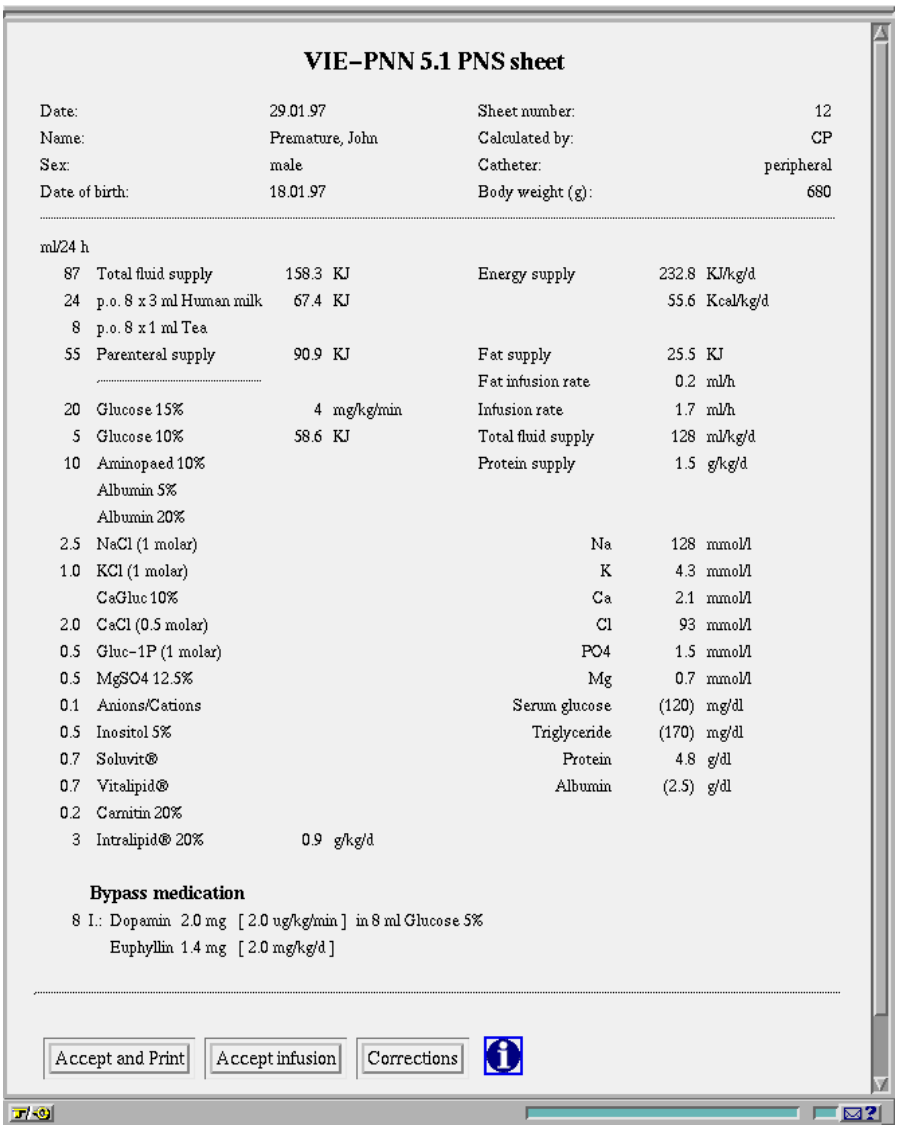


Fig. 2. Sample page showing recommendations of VIE-PNN for supply of electrolytes. The physician may change the values. The I(nformation) button activates an explanation page with details about the computation of the electrolyte.

There were no reports about errors in the sheets. One may suspect that this is due to the interactiveness of the system: the physician eliminates all erroneous computations of the system. However we have no reports about changes required on standard cases. We are convinced that knowledge-based modules like VIE-PNN have to be interactive. There is no possibility to cover all extreme situations which require modification of the nutrition schedule. After six months of continuous operation the system is trusted and used in the daily routine.

The success of the HTML-based system has to be explained mainly by the ease of use and the benefits in terms of time savings. Comparing the standalone PC version and the client-server version there are no essential changes of the program flow and the knowledge used. Even the final printout of the PNS schedule is the same. Identifiable factors adding to the success of the HTML-based version are:

- VIE-PNN is run in the routine computer environment of the local PDMS;
- physicians using the system classified the HTML browser as an *intuitive* user interface. It is immediately clear to the user which box accepts an input, which buttons to press and which links to follow. There is no special training required;
- the HTML browser provides the required flexibility for the user. Especially



VIE–PNN 5.1 PNS sheet

Date:	29.01.97	Sheet number:	12
Name:	Premature, John	Calculated by:	CP
Sex:	male	Catheter:	peripheral
Date of birth:	18.01.97	Body weight (g):	680

ml/24 h						
87	Total fluid supply	158.3	KJ	Energy supply	232.8	KJ/kg/d
24	p.o. 8 x 3 ml Human milk	67.4	KJ		55.6	Kcal/kg/d
8	p.o. 8 x 1 ml Tea					
55	Parenteral supply	90.9	KJ	Fat supply	25.5	KJ
				Fat infusion rate	0.2	ml/h
20	Glucose 15%	4	mg/kg/min	Infusion rate	1.7	ml/h
5	Glucose 10%	58.6	KJ	Total fluid supply	128	ml/kg/d
10	Aminopaed 10%			Protein supply	1.5	g/kg/d
	Albumin 5%					
	Albumin 20%					
2.5	NaCl (1 molar)			Na	128	mmol/l
1.0	KCl (1 molar)			K	4.3	mmol/l
	CaGluc 10%			Ca	2.1	mmol/l
2.0	CaCl (0.5 molar)			Cl	93	mmol/l
0.5	Gluc–1P (1 molar)			PO4	1.5	mmol/l
0.5	MgSO4 12.5%			Mg	0.7	mmol/l
0.1	Anions/Cations			Serum glucose	(120)	mg/dl
0.5	Inositol 5%			Triglyceride	(170)	mg/dl
0.7	Soluvit®			Protein	4.8	g/dl
0.7	Vitalipid®			Albumin	(2.5)	g/dl
0.2	Carnitin 20%					
3	Intralipid® 20%	0.9	g/kg/d			

Bypass medication

8 I.: Dopamin 2.0 mg [2.0 ug/kg/min] in 8 ml Glucose 5%
Euphyllin 1.4 mg [2.0 mg/kg/d]

Accept and Print | Accept infusion | Corrections

Fig. 3. VIE-PNN's HTML page showing the final composition of the parenteral nutrition solution. The top part gives administrative data. The left column shows the components of the PNS. The right column gives statistical measurements and today's serum values.

the `BACK` and `FORWARD` buttons allow to review and revise pages;

- the explanation facility (using the `I`(nformation) button) adds much to the confidence in the conclusions of VIE-PNN. Often a parameter looking unplausible appears correct after looking at the explanation page. An example of such a complicated calculation is the proportional subtraction of components from the parenteral nutrition which are contained in the enteral product. Such a calculation is usually not done by hand.
- most important, the time savings for the physicians are considered very high. We have logged the connect time for each PNS schedule computation (measuring the time between the start of a patient's PNS sheet and its final

acceptance). The analysis of this log does not show a dramatic effect on time savings (the median of the connect time per patient was 6 minutes 13 seconds). But the connect time is somewhat misleading since the physician is often interrupted during the calculation process (phone calls, emergency and routine actions, lookup of data in the patient record). From the subjective physicians' view the savings are dramatically: no one would calculate any more PNS sheets by hand due to the time required.

The integration of VIE-PNN into the intranet of workstations running the patient data management system was an important step in bringing a knowledge-based system into daily routine use. However, it is far from perfect. We would like to integrate the PNS schedule composition as a module into the HP CareVue PDMS. At the moment this is impossible due to the operation of the PDMS as a closed system. More seriously, it is at present not possible to get the laboratory values required by VIE-PNN from the PDMS at the time required. The automatic inclusion of the ten serum values into VIE-PNN would be a great step forward in minimizing manual input. We are, however, trying to find solutions by interfacing laboratory equipment and by acessing the PDMS database via the recently introduced ODBC interface.

A second problem is inherent to the client-server architecture and the operation of the http-server. Composing a PNS is a step by step procedure. Each page on the client browser presents a group of components of the PNS. Computation of the PNS schedule requires the pages to be in correct order (e.g., we can not compute carbohydrates without knowing the total fluid supply). After completing the input on one page the client sends the input to the server. But the http-server is stateless, i.e., all the information about the state of the client has to be included in hidden input variables (e.g., the patient id, the user id, the page number, the next page we want to see). Further, the server has to store all information about computations done at prior steps and reuse this information as a starting point for the current computations. Another complication arises from the possibility a user may step back in the browser, modify an old input page and send it to the server. This requires doing proper recalculations of parameters. Finally, the server has to enforce a locking mechanism hindering two physicians working on different client workstations to calculate the same sheet for one patient. We have solved these problems by implementing a locking scheme and patient records which store all the information entered at a client and computed by the server. But this is rather tricky because it is not the way a http-server is intended to be used. An alternative solution would be a reimplementation in Java. The whole PNS schedule would be computed at the client side using Java code. This code includes the current nutrition rules and the PNS data of the previous days. We keep this Java option open for a future release of VIE-PNN.

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References

[1] M.Dobner, S.Miksch, W.Horn, C.Popow, "VIE-PNN: An Expert System for Calculating the Composition of Parenteral Nutrition Solutions for Neonates" (in German), *Wiener Klinische Wochenschrift*, 107(4)128–132, 1995.

[2] H.Eriksson, "Expert Systems as Knowledge Servers", *IEEE Expert/Intelligent Systems & Their Applications*, 11(3)14–19, 1996.

[3] J.Kuchenbecker, L.Urbina, M.Müller, "The Revised PEDINFUS Computer Program for Total and Added Parenteral Nutrition in Children" (in German), *Infusionstherapie und Transfusionsmedizin*, 23(1)35–40, 1996.

[4] J.D.Legler, "Physician's accuracy in manual computation," *MD Comput*, 7:155–159, 1990.

[5] S.Miksch, M.Dobner, W.Horn, C.Popow, "VIE-PNN: An Expert System for Parenteral Nutrition of Neonates," in *Proceedings of the Ninth Conference on Artificial Intelligence for Applications (CAIA-93)*, IEEE Press, New York, pp.285–291, 1993.

[6] C.Ochoa-Sangrador, M.F.Brezmes-Valdivieso, C.Gil-Valino, "Pediatric Parenteral Nutrition Mixtures Design Program: Validity and Stability Study," *Comput.Biomed.Res.*, 28, 271–281, 1995.

[7] D.Picart, B.Guillois, L.Nevo, D.Alix: "A Program for Parenteral and Combined Parenteral and Enteral Nutrition of Neonates and Children in an Intensive Care Unit," *Intensive Care Medicine*, 15(4)179–182, 1989.

[8] M.Piert, D.Kistler, R.Hettich, "Computer-assisted Infusion and Nutrition Planning in an Intensive Care Burn Unit," *Intensive Care Medicine*, 15(2)121–125, 1989.

[9] M.A.Puangco, H.L.Nguyen, M.J.Sheridan, "Computerized PN Ordering Optimizes Timely Nutrition Therapy in a Neonatal Intensive Care Unit," *J Am Diet Assoc*, 97(3)258–261, 1997.

[10] L.Wall, T.Christiansen, R.L.Schwartz , "Programming Perl," 2nd edition, O'Reilly and Associates, Sebastopol, CA, 1996.

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Werner Horn, Ph.D., is Associate Professor of Artificial Intelligence at the Department of Medical Cybernetics and Artificial Intelligence of the University of Vienna. He studied Computer Science at the Vienna University of Technology. Since 1984 he has been head of the Knowledge-Based Systems Group of the Austrian Research Institute for Artificial Intelligence. From 1992 onwards he acted as a Representative in the European Coordinating Committee on Artificial Intelligence.

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Silvia Miksch, Ph.D., is Assistant Professor at the Institute of Software Technology, Vienna University of Technology. She studied Information Systems at the University of Vienna and the Vienna University of Technology with concentration on: Applied Statistics and Artificial Intelligence. She received her master of Social and Economic Science from the University of Vienna in 1987 and her Ph.D. in 1990. Afterwards she joined the Knowledge-Based Systems Group at the Austrian Research Institute for Artificial Intelligence (ÖFAI) as scientific researcher and was visiting scholar at Knowledge System Laboratory (KSL), Stanford University, CA, USA (FWF-Erwin Schrödinger

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Her general research interests are temporal representation and reasoning, task-oriented design, protocol- and guideline-based care, planning, scheduling, time series analysis and filtering techniques, visualization, and evaluation of knowledge-based systems in real-world environments.

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Andreas Seyfang studied Computer Science at the Vienna University of Technology. His field of specialization was artificial intelligence. He finished his studies in 1996 with a masters thesis about the VIE-PNN system.

Related resources

- **VIE-PNN**: `http://www.ai.univie.ac.at/oefai/kbs/vie-pnn.html`
- **Neonatology on the Web**: `http://external.csmc.edu/neonatology/`
  `http://www.neofax.com/`
- **PERL**: `http://language.perl.com/`