Expert Pacing System

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Summary

Within the last decade, knowledge-based computer systems have received a great deal of attention. Such expert systems are being increasingly used in medical applications and have proved to be helpful tools in solving an impressive array of problems in a variety of fields. This paper gives an insight into the challenges and chances that expert systems offer in the field of cardiac pacing systems. There are three types of integrated knowledge-based systems, depending on the kind of their interaction with the implant. Type 1 expert systems are used before or during implantation. They work on a large base of patients, medications and pacemaker/ICD data, possibly collected over years or decades. The knowledge acquired from these databases and from additional expert experience is used in order to optimize the pacemaker indication process and to find out the optimal pacing settings considering the patient's disease and physical condition. Type 2 expert systems interact directly with or within the working implant. They can be realized as implant embedded systems aiming at solving a specific, well-defined problem. External PC-based expert systems are mainly used during follow-ups for analyzing interrogated Holter data of the implant. By giving suggestions on how to change pacemaker parameters and by discovering possible mismatches they may be of a great support for the practitioner. Type 3 expert systems offer the greatest potential benefit. They are embedded in remote control systems communicating with the implant in predefined time intervals and operate on programmed parameters extracted from intracardiac signals.

Key Words

Pacing system, knowledge-based system, expert-based system, case-based system

Introduction

Cardiac pacemakers and ICDs are becoming increasingly sophisticated thanks to the progress in our electrophysiological and hemodynamic understanding of the heart and improvements in hardware and software technology. From the physician's point of view, the growing range of pacemaker types and the expanding amount of statistical functions and stored data in the implanted units increases complexity of the device and requires more time and training to manually achieve an optimal therapy. Hence, one of the main goals of current research and development activities is the simplification of device adjustment: The implant should soon become a self-explaining system with a high degree of automation in the follow-up.

In view of the development of future devices, the success of new and sophisticated therapeutic pacing concepts depends on their realization inside a self-learning active system that automatically adapts its functions to the patient's specific conditions while detecting and foreseeing critical cardiovascular states and applying the most appropriate of all possible therapies. Expert-based systems will play a key role on the way of reaching these targets. They can be applied in all areas where important decisions must be made effectively and reliably. The expert in these systems is a software module that contains stored knowledge and tries to solve specific problems in much the same way that a human expert would do. The expert systems can mainly be useful in two different ways:

- Decision support, e.g. by reminding the experienced cardiologist of options or issues to consider, by making suggestions, by offering alternatives, by listing similar patient cases and solutions, and by giving detailed documentation.

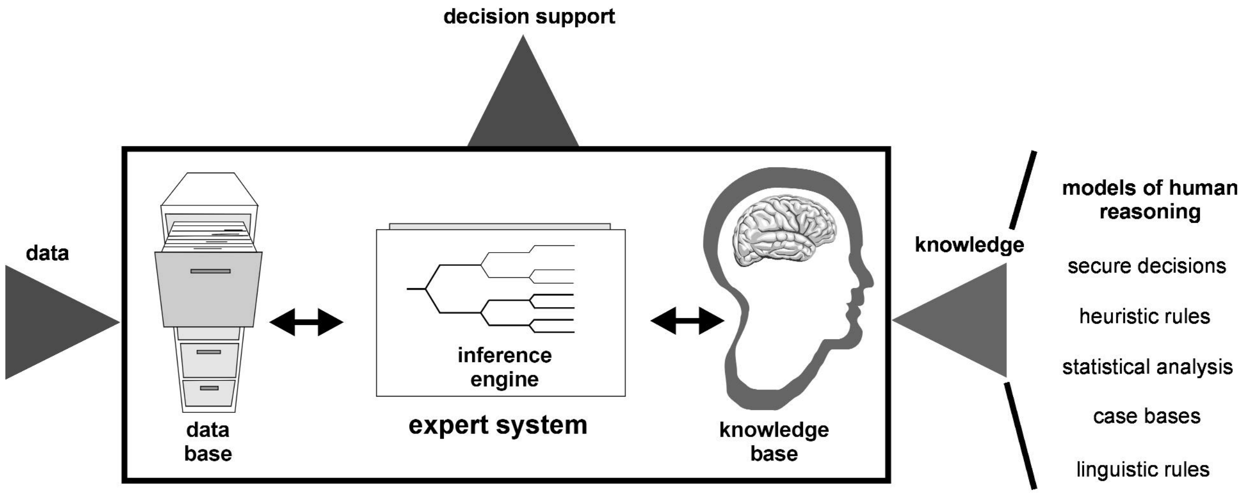


Figure 1. Structure of an expert system.

- Decision making, i.e. realized as an embedded specialized module that use secure knowledge-based on verified research results in order to automatically solve specific well-defined tasks.

The first one is the most common in the field of cardiology till now. The process of decision finding can be illustrated using the overall structure of an expert system (Figure 1). The inference engine as the main technical part of the system works on the specific task using a reasoning mechanism that draws conclusions from the given data base and the knowledge base. The latter is a collection of experts' knowledge of the particular domain that the expert system is dedicated to.

The quality of the collected knowledge is essential for a good performance of the system. That's the reason why the process of knowledge acquisition plays an important role in developing expert systems and requires an intensive cooperation between physicians and knowledge engineers.

The models of human reasoning show how different kinds of knowledge should be stored in order to classify patients. *Logic decisions* are usually represented in form of decision trees or tables (e.g. a special symptom leads to an accurate decision of how to solve the problem). *Heuristics* are often formulated in form of extensively corroborated rules of thumb (the background knowledge is of no interest). *Statistical* classifications are mainly based on large representative data bases storing the information on patients (clinical symptoms, ECGs, medication, diagnosis, etc.), drugs (dosage, effects and side effects, targets, etc.) and pacemakers (types, modes, settings, targets, etc.). *Case-based* classification systems collect as many patient case histories as possible using additional knowledge to compare different cases. *Rule-based* classifications represent the most common way of human reasoning and are formulated by simple if-then rules.

The mathematical formalization of knowledge inside the expert system is based upon these, shortly characterized, models of human reasoning. Thus, different types of expert systems differ in how the knowledge base is structured and how the inference engine works. One can distinguish between rule-based, frame-based, model-based and case-based systems or neural networks (see [1] for details). The question now arises how to apply these types of expert knowledge systems to the field of cardiac pacing systems.

Basic Strategies for Using Expert Knowledge in Pacing Systems

The cardiologists' expert knowledge is, beyond doubt, of prime importance in all phases of clinical patient care concerning diagnosis and therapy strategies. Both decision data (e.g. symptoms, risk factors, diagnostic findings, costs etc.) and possible decisions have to be identified in these distinct phases. Therefore expert pacing systems have to support cardiologists' reasoning within multiple fields: diagnosis of basic disease, staging of basic disease, prediction of disease progres-

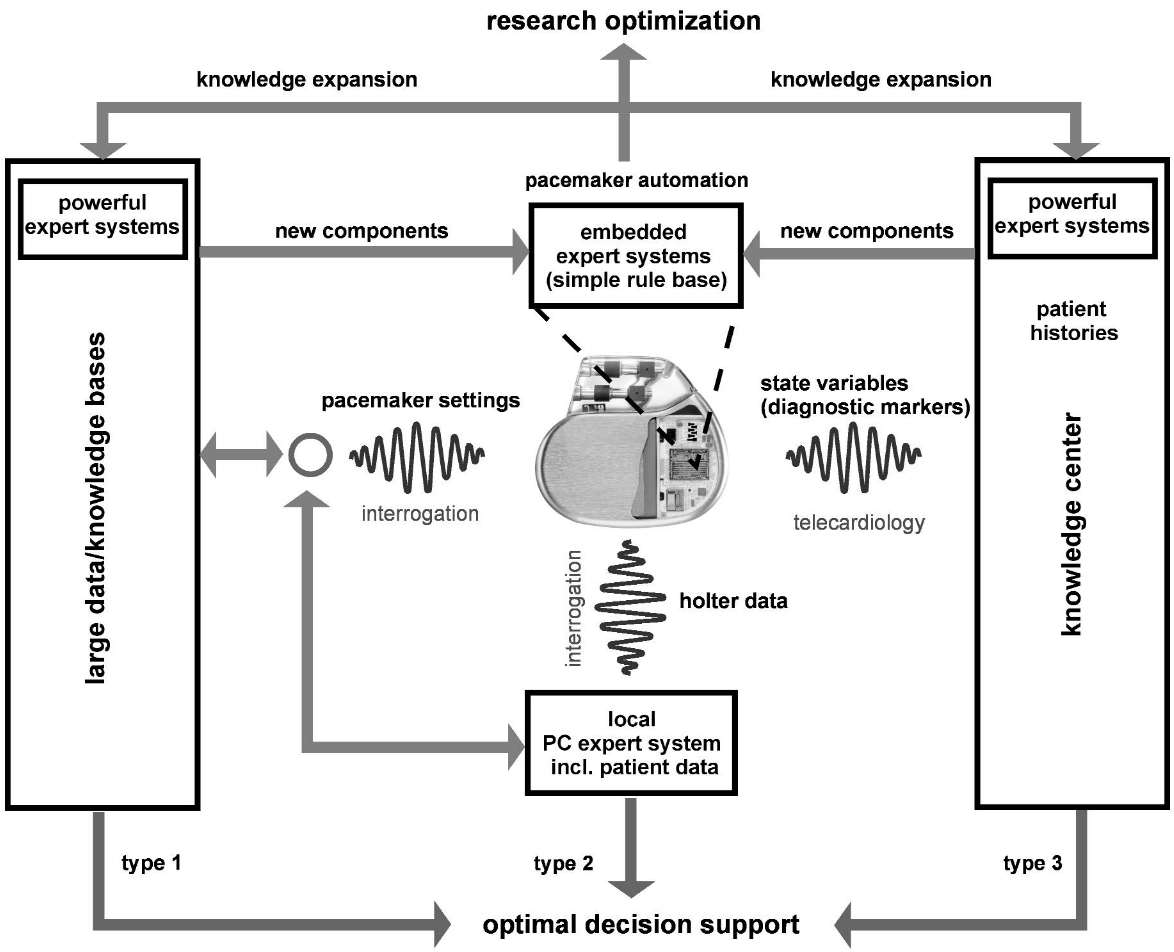


Figure 2. Expert pacing system in a general view.

sion and possible aftereffects, prevention of disease, risk stratification and deductions considering the following drug and pacemaker therapy strategies. A general view of an expert pacing system (Figure 2) let us differentiate between three types of integrated knowledge-based systems dependent on the kind of their interaction with the implant.

Type 1 expert systems are used before or during implantation. They work on a large base of patients, medications and pacemaker/ICD data, possibly collected over years or decades. The knowledge acquired from these databases and from additional expert experience is used in order to optimize the pacemaker indication process and to find out the optimal pacing settings considering the patient's disease and physical condition.

Type 2 expert systems interact directly with or within the working implant. They can be realized as implant embedded systems aiming at solving a specific, well-defined problem. External PC-based expert systems are mainly used during follow-ups for analyzing interrogated Holter data of the implant. By giving suggestions on how to change pacemaker parameters and by discovering possible mismatches they may be of a great support for the practitioner.

Type 3 expert systems offer the greatest potential benefit. They are embedded in remote control systems communicating with the implant in predefined time intervals and operate on programmed parameters extracted from intracardiac signals.

The complexity of an expert pacing system increases from a Type 1 to a Type 3 expert system. The realization of each expert system type involves many challenging tasks as well as promising opportunities to improve clinical practice. However, this requires close co-operation between cardiology clinicians and knowledge engineers toward achieving expanding knowledge.

	AVB	SSS	Brady-Tachy-cardie	AF + Afl	SSS + AVB	Others
VVI	13.7	22.1	22.5	62.4	0	27.9
VVIR	3.4	6.9	10.8	33.1	3.9	11.9
DDD	43.5	27.3	25.6	1.3	42.3	27.5
DDDR	20.3	36.3	36.0	3.2	46.2	23.3
AAI	0.0	4.4	3.1	0.0	3.8	1.7
AAIR	0.0	2.6	1.6	0.0	0.0	1.0
VDD(R)	19.1	0.4	0.4	0.0	3.8	6.7
Sum	100	100	100	100	100	100

Table 1. ECG indications for, and pacing modes used in, initial pacemaker implants in new federal states of Germany (all numbers in %; the numbers are taken from [2]).

Statistic and Case-Based Expert Systems

Powerful expert systems can be used before the implantation of the ICD or the pacemaker, accessing valuable information from large data pools or case bases (Type 1 systems). Pools containing a large number of documented implantation data are of special interest, e.g. the databases of the German Pacemaker Registry offering detailed information on ECG indications for pacing such as AVB, SSS, bradycardia, tachycardia, AF, etc., the distribution of pacemaker systems and modes, the distribution of etiologies, etc [2]. Such data are usually presented in a statistical manner using raw numbers and their percentage distribution or matrices combining different variables (Table 1). Other databases contain similarly structured information about drug therapy or appropriate settings of pacemaker parameters (AV delay, base rate, mode switch rate, thresholds, lead configuration, etc.).

For example, further valuable databases are offered by the industry standard Ann Arbor electrogram libraries that provide benchmark wideband unipolar and bipolar intracardiac electrograms of cardiac arrhythmias for scientific investigation. These recordings allow scientists and ICD developers alike to utilize identical data for device design [3]. Each recording consists of surface ECGs and intracardiac bipolar and unipolar electrograms of diverse cardiac arrhythmias (Figure 3).

It is the knowledge engineer's task to build knowledge bases out of all these statistical data. In cooperation with a number of experienced physicians the engineer can create rule-based knowledge, e.g. by formulating more or less complex rules (combining any desired input parameters) like

IF (ECG-Indication = SSS & AVB) THEN (pacing mode = DDD(R)) is a good decision.

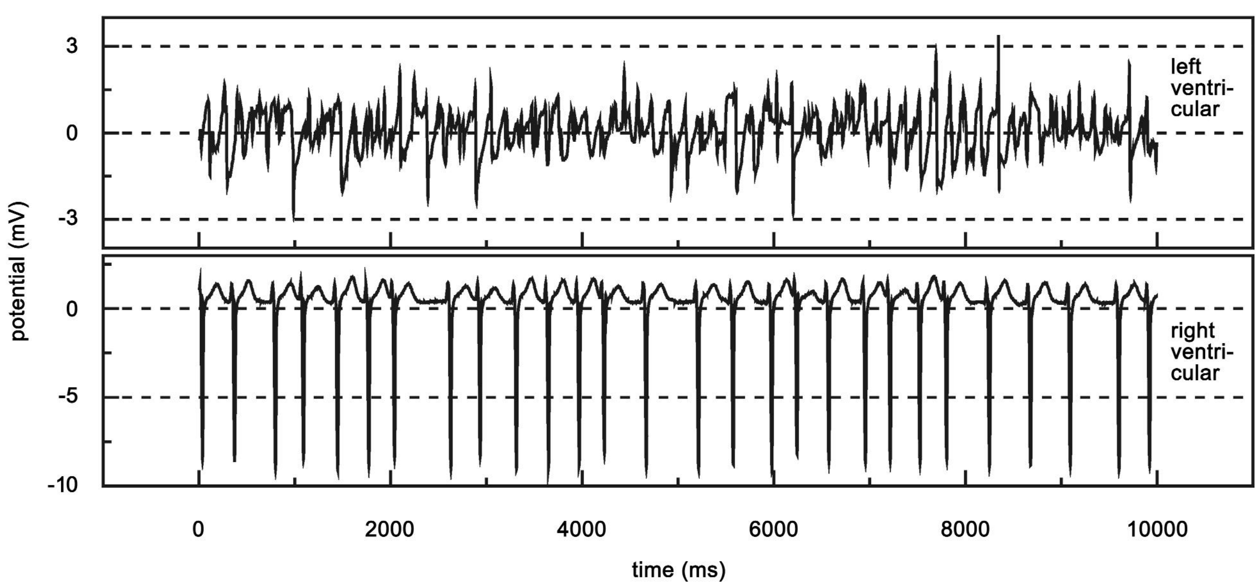


Figure 3. Ann Arbor IEGM record of atrial fibrillation [3].

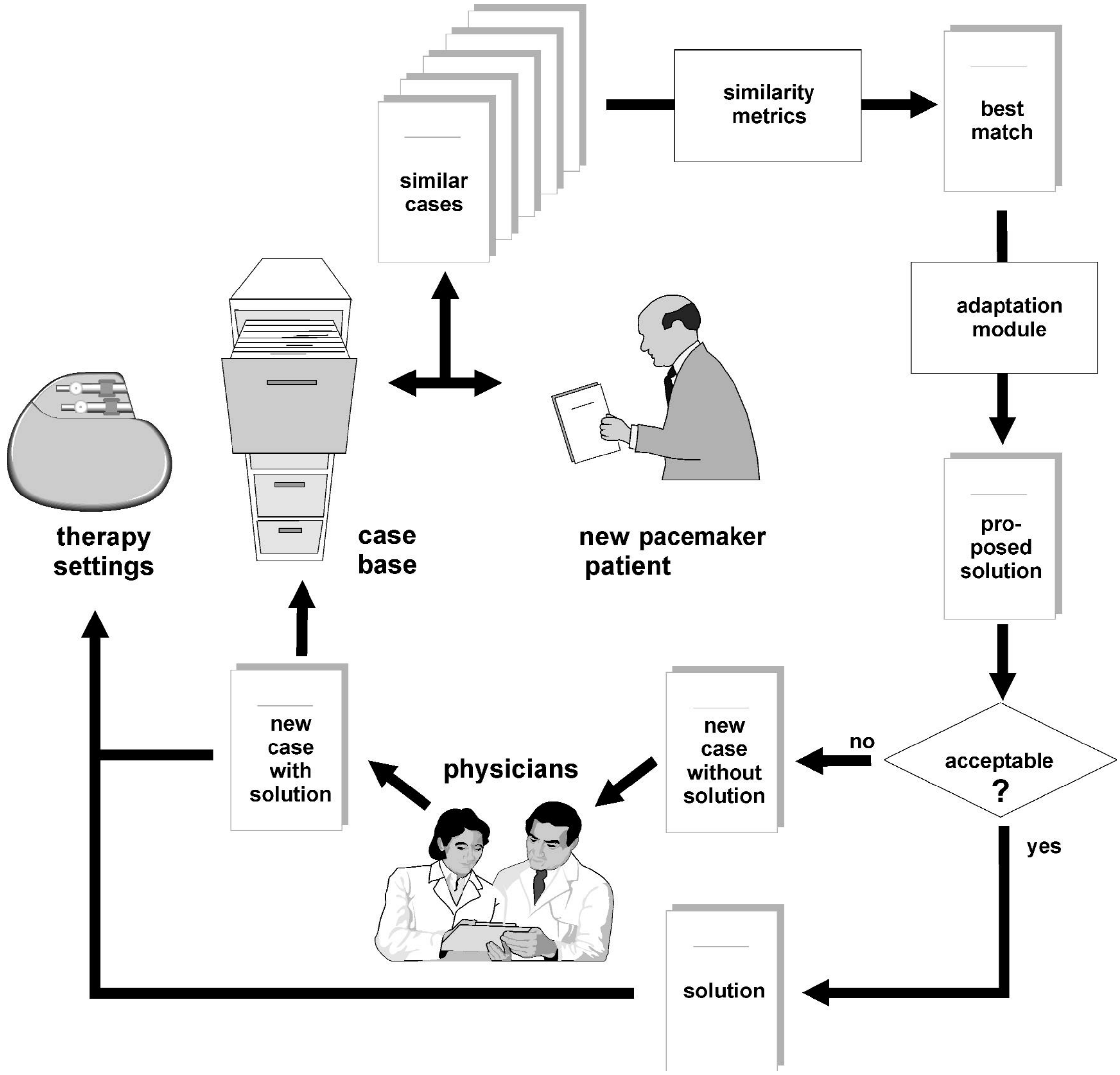


Figure 4. Case-based expert systems.

IF (ECG-Indication = AF) AND (COUNTER for AES = HIGH) THEN (pacing mode = overdrive) can be considered.

IF (ECG-Indication = AF chronic) THEN (pacing mode = VVI) may be the best option.

or by simply considering the "probabilities" of statistics to guide possible decisions. Plausibility factors represent the confidence one has that a fact is true or a rule is valid. The additional knowledge of several human experts in different fields can be combined to give a system more breadth and accuracy.

Another way of establishing a knowledge-based system is based on the premise that human beings use analogous or experiential reasoning. Therefore the engineer creates a case-based system, in which individual patient case histories are indexed according to the presenting signs (ECG-strips) and symptoms, the laboratory findings, the treatments (drugs and pacemaker settings) used, and/or any other factors that the physician might later find interesting. The process of case-based reasoning is illustrated in Figure 4. The similarity metrics in these systems are used to measure the degree to which the given patient case matches past cases. The adaptation module creates a solution either by modifying past solutions or creating a new solution. If no reasonably appropriate prior case is found then the physician has to find a new solution that can be added to the case base, thus allowing the system to be improved. That way expert systems are established to support the physician's decisions on for example

- the choice of pacemaker type;
- the pacing mode to program;
- the additional drug therapy;
- whether standard pacing parameters should be changed;
- which parameter values may fit the patient's conditions best.

The optimal settings for pacemakers offering advanced features, e.g. prevention of arrhythmias by biatrial pacing, overdrive pacing, optimized AV-delay pacing are of special interest [4,5].

An ideal Type 1 expert system asks the physician for detailed data about the patient's state and, after running its knowledge and the physician's input through its inference engine, suggests a certain pacemaker program that can be downloaded from the programmer. Furthermore the system provides a detailed documentation on all data reflecting the particular patient case and the process of decision making.

Local Expert Systems for Holter Data Analysis during Follow-up

Beyond doubt an automatic analysis by an external PC or laptop expert system (Type 2 system) can help the physician while analyzing the diagnostic memory data interrogated during follow-up examination of pacemaker patients (Figure 5). The diagnostic information memorized by the pacemaker and transferred to the computer is particularly helpful for a clinical evaluation of the patients' status and of the functions of the implant. A further aim is again to make suggestions for specific changes of the programming parameters deduced from Holter data, current settings and, if applicable, by considering the physical condition of the patient. An additional benefit of these systems is the permanent documentation of therapy including additional graphical features on data and knowledge representation. For these purposes the expert system uses rule-based knowledge in order to analyze the available diagnostic information, compare with limiting values or reference distributions, give hints on peculiar findings and make proposals regarding possible countermeasures. The practical value for the physician will decisively depend on the completeness, correctness, practical relevance and other quality attributes of the implemented clinical expertise, which is stored as tables of rules.

The physicians' feedback on the results of the expert system plays an important role for further development. The main aim of the first clinical evaluations is to assess, complete, and extend the table of rules. Therefore such systems have to include a kind of learning component giving the physician the possibility to complement and extend the base of knowledge. The broader the spectrum of the patients' pacing indications, programmed modes, age and other miscellaneous characteristics, the more meaningful the output of the expert system is expected to be. Following this way of verification of the rule tables and extending the knowledge base, the expert system grows up to a more and more valuable tool during follow-up examinations. A first clinical evaluation study using such a system led to very interesting and promising results [7]. The

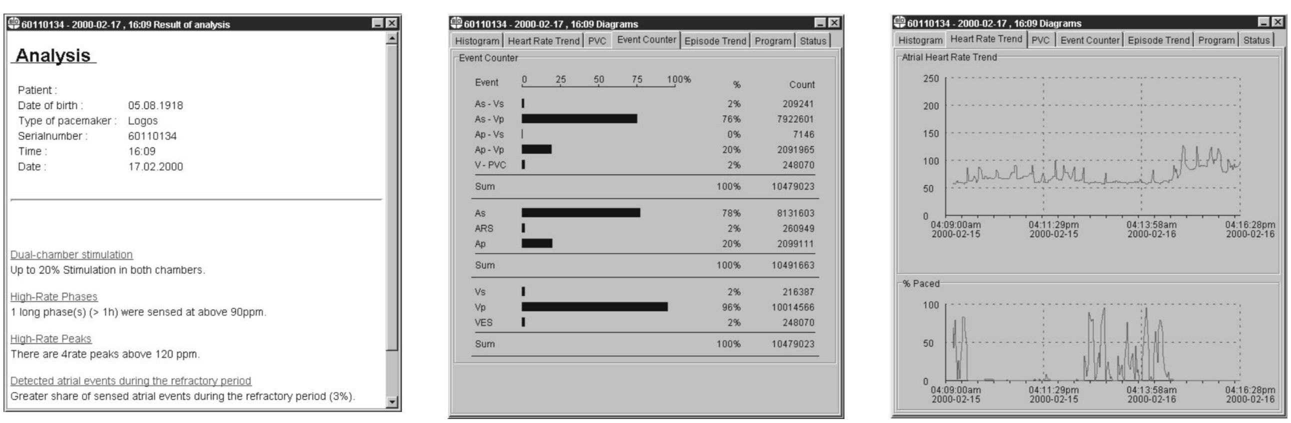


Figure 5. Analysis of Holter data during follow up by use of an external expert system [6].

research group pointed out the potential clinical benefits through:

- the full diagnostic potential provided by modern pacemakers, which can be exploited without additional effort;
- the detailed technical and medical expertise, offered by knowledge-based support to the physician;
- the possibility of an early and precise detection of the progression of diseases and other risk factors;
- the expected long-term optimization of the therapy;
- the consequent overall improvement of the quality of follow-ups.

Furthermore such automated systems can be regarded as the first step of remote control systems (Type 3 expert systems).

Embedded Expert Systems for Specialized Problem Solving

The computational power of microprocessors as well as the memory capacity in currently used pacemakers and ICDs limit the range of algorithms possible to use inside the implant. For that reason, specialized and less complex systems can be presently embedded to solve certain well-defined tasks. Having in mind the great amount of different tasks that the software of a pacemaker or an ICD has to do, a wide spectrum of possible applications for expert systems is offered, above all regarding the fields of arrhythmia detection, arrhythmia prediction, arrhythmia prevention, arrhythmia classification, automatic optimization of implant parameters (AV delay, thresholds, etc.) or control parameters (stimulation rate, amplitude, duration, etc.). The process of decision making by using available knowledge in these fields is reflected in form of easy decision trees and tables (clear logic) or by formulating simple rules and inference engines, building a fuzzy logic system.

The implementation of the first idea is simpler and more common because of less computational demands. For example, dual chamber ICDs operate with discrimination-algorithms in order to reliably discern the origin of the tachycardia episodes. The SMART™ (Biotronik, Germany) detection algorithm implemented in the Phylax AV (Biotronik, Germany) is based on the concept that the chamber with the higher rate denotes the origin of the tachycardia [8]. To differentiate in cases of equal heart rates in both chambers, additional criteria are analyzed, namely sudden onset, ventricular and atrial rate stability, and regularity of the P-R intervals (Figure 6a). A successful discrimination leads to an appropriate therapy sequence (Figure 6b).

Fuzzy systems are surely more complex to realize. However, they reflect human reasoning in a better way than conventional methods do. Furthermore, the progress of electrophysiological and hemodynamic understanding of the heart will require more intelligent and powerful algorithms in ICDs and pacemakers of the next generation.

Figure 7 shows the structure of a fuzzy expert system that consists of a fuzzifier, inference engine and

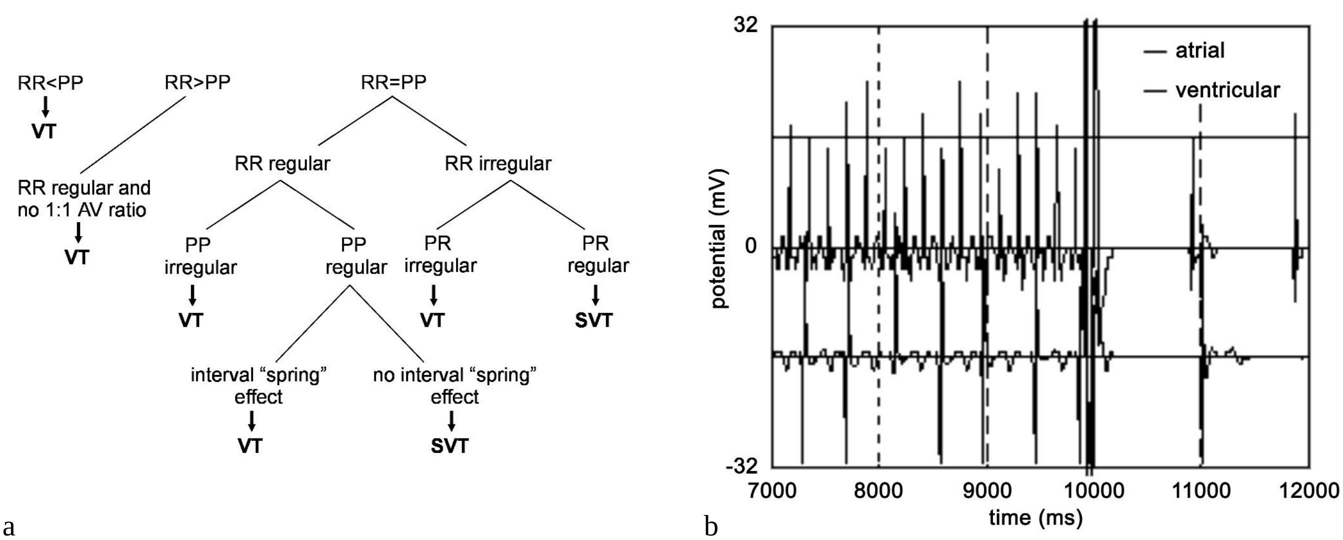


Figure 6. SMART™ algorithm for discrimination of tachycardia. Panel a: Decision tree. Panel b: Atrial and ventricular IEGM records in a successful discrimination of atrial flutter and effective termination by a 1-J shock [8].

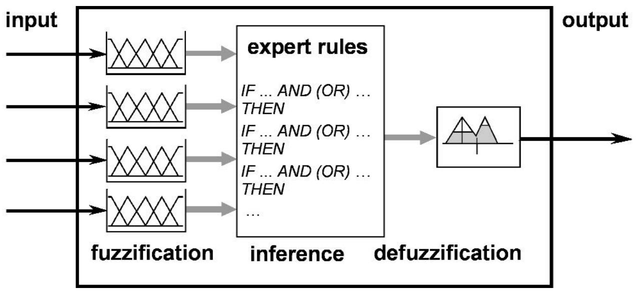


Figure 7. Structure of a fuzzy system with multiple input and single output.

Parameter	Prediction threshold
nMAPd90	reduction by 20 %
MAPd90-25	increase by 20 %
Δcycle length (ms)	increase over 75 ms
ΔMAPd90 (ms)	increase over 20 ms

Table 2. Parameter limits for prediction of atrial fibrillation in patients following aortic valve replacement [10].

defuzzifier. Fuzzification is a form of quantification in which the input data are assigned to so called membership functions. The latter give their input a special degree of membership to a fuzzy set using linguistic variables that reflect human thinking. The inference engine translates the fuzzy input sets into fuzzy output sets running the input through the if-then rule base of the system that was obtained by expert knowledge. In the end, the results of all rules are combined and the defuzzifier derives an unfuzzy output. Interesting applications of fuzzy systems concern again for example the classification of tachycardia for use in ICDs [9] or the estimation of stimulation rate in fuzzy-logic-based rate adaptive pacemakers with multiple sensor information [10].

Regarding the field of arrhythmia prediction, clinical and theoretical studies have shown that the monophasic action potential (MAP) may be used to predict the imminent onset of supraventricular as well as ventricular arrhythmias [11,12]. It appears that the morphological changes of this signal reflect the electrophysiologic cellular processes and represent an indicator of the probability for the heart rhythm to become unstable. Therefore the beat-to-beat parameters of this signal play an important role for either risk stratification of the patient or prediction of tachycardia. A morphological alteration of this signal precedes observed episodes of supraventricular arrhythmias in patients following aortic valve replacement [10]. Figure 8 demonstrates the changes of MAP recorded from atrial human epicardium prior to AF. In terms of predicting the onset of arrhythmias in this patient group, the rate corrected MAP duration, the difference MAPd90-25 and the average change of cycle length and MAPd90 may all be used. The suggested prediction threshold is depicted in Table 2. By creating a fuzzy system using these parameters as input values, it is possible to determine a risk factor for estimation of the probability of tachycardia occurrence (Figure 9). The advantage of such a system is the integration of human reasoning. Whereas conventional systems would act on exact values and fixed thresholds, fuzzy logic gives the chance to interpret its input in a more human manner by defining fuzzy sets implemented as linguistic variables. This procedure also considers the fact that it is often very difficult to set or find appropriate threshold values as they may differ between individual patients. This is a typical fuzzy problem where the use of more or less heuristic rules is of great help. The difficulty is surely the formulation of rules where further knowledge is to be acquired from future studies.

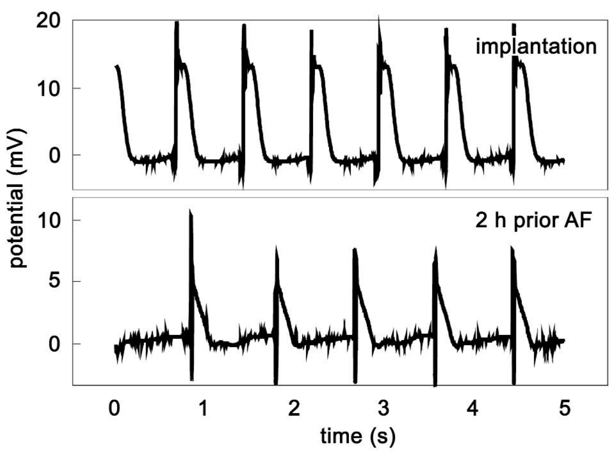


Figure 8. Atrial monophasic action potential prior to atrial fibrillation [10].

Besides a change in the shape of monophasic action potential, other parameters are reported to be possible predictors or risk stratifiers, e.g. occurrence of extrasystoles, heart rate variability, electrical alter-

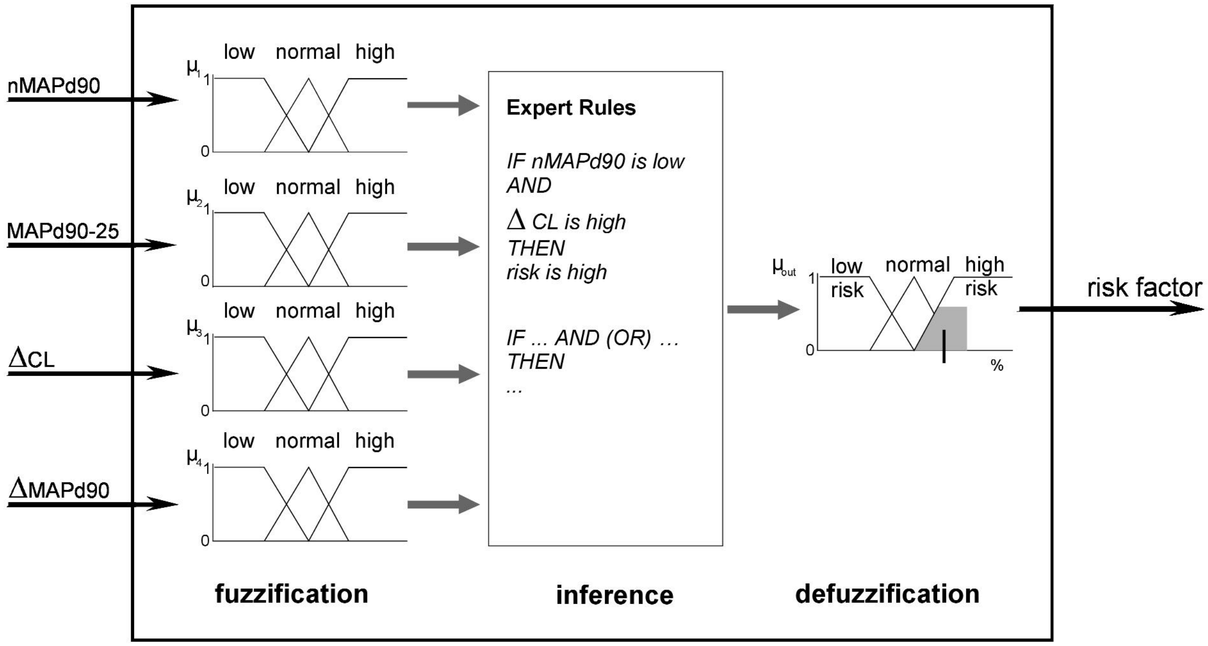


Figure 9. Fuzzy expert system for prediction of supraventricular tachycardia.

nants, heart rate turbulence, parameters using the ventricular evoked response (VER) and many others. The idea is to choose a large set of those parameters, combine them by formulating simple rules and thereby establish a diagnosis system for monitoring cardiac state. This approach also includes a possible monitoring of medication [13]. Beyond doubt, this is a challenging target that can only be reached step by step. The application of automated systems embedded in the implant software that allow incorporation of human or expert-knowledge-based decision making will surely expand. But the question arises whether technical progress allows an implant embedding of even more powerful and more intelligent systems using deeper knowledge or whether it would be more suggestive to establish them as external systems including the additional benefits that large databases yield. The second solution seems to be very promising, above all considering the immense advances in telecardiology.

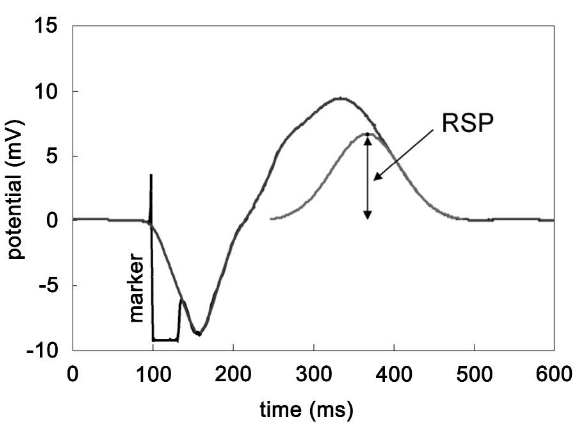
Optimal Therapy Monitoring and Decision Support by Expert-Based Remote Control

The rapid developments in the field of modern telecommunications and wireless data transmission will surely enable physicians to take full advantage of the benefits of enhanced diagnostics [14]. Implants of the next generation comprise improved telemetry features and thus enable the establishment of home-based outpatient monitoring systems. They will be integrated parts of an enhanced service system, including various grades of services to patients and physicians. Besides financial benefits this approach facilitates immense support for the physicians and thus optimum care for their patients. Patient monitoring will no longer be restricted to just the follow-up. Shorter monitoring cycles should result in early detection of situations requiring intervention by the attending physician, therefore contributing to enhanced patient safety and reduced subsequent costs. The main benefit of these systems is definitely the complete exhaustion of diagnosis features that an implant can offer. Permanent and automatic monitoring of the state of the patient by transferring defined state variables will lead to further improvements of diagnosis as well as enhanced therapeutic strategies by discovering more efficient ways of treatment. Considering the last aspect, large databases that are integrated in the service system offer a great help in analyzing the transferred data by the use of expert knowledge. Thus modern telecardiology involves the possibility to use the advantages of powerful expert systems.

One important example, which is already in clinical use, relates to rejection monitoring after cardiac transplantation: the computerized heart acute rejection monitoring system (CHARM). Rejection monitoring provides the possibility to weigh the dosage of immunosuppressive medication against the rejection process. Within the CHARM project [15], non-invasive recording of intramyocardial electrograms is performed using fractal-coated epicardial leads and a pacemaker with high-resolution intracardiac electrocardiogram transmission (Physios CTM 01, Biotronik, Germany). The changes in the intracardiac electrical signals are used to supplement the histologically observed structural tissue changes in monitoring the rejection process (Figure 10a). The patient is examined for rejection indications at the transplant center at predefined intervals. During measurements, the implant transmits the VER through a high-resolution telemetric connection to an external data acquisition system. Via the Internet, the data are sent to a central data analysis workstation and evaluated automatically. The results are sent back to the physician at the transplant center who decides whether and by how much the dose of medication should be changed or whether to perform an endomyocardial biopsy (Figure 10b).

At present, every rejection measurement requires the patient to visit the transplant center. The next stage of telecardiology development supports a home monitoring system that allows the patient to remain home during automatic measurements and enables the automatic transmission of rejection monitoring data to a central station. The use of expert systems at this stage helps to discover the significant correlation between the results of endomyocardial biopsy and VER analysis. Furthermore, rule bases are established in order to optimize the adjustment of medication dosage. The process of knowledge acquisition is here of great importance, especially in the first phases of development. A central station for data storage and evaluation involves several advantages: patient histories enable case-based comparison of different or similar situations. Improved knowledge about how to change control parameters can be embedded by adding new rules. Furthermore, the expert systems ensure a permanent documentation of the ongoing therapy in the patients. The deeper the knowledge and the more data are stored in the service base the better the chances for an ongoing optimization of evaluation procedures. Following these tasks the "electronic biopsy" is about to become a viable alternative to the endomyocardial biopsy, possessing advantages that include a lesser burden to the patient and overall lower costs to the health care system.

Besides the expert-based use of telemonitoring of transplant patients the same tasks have been set for enhancing the safety, quality of life, and service for all patients with a pacemaker or defibrillator implant. The idea of an ideal pacing system is to monitor the cardiac state with an implanted pacemaker or ICD (Figure 11).



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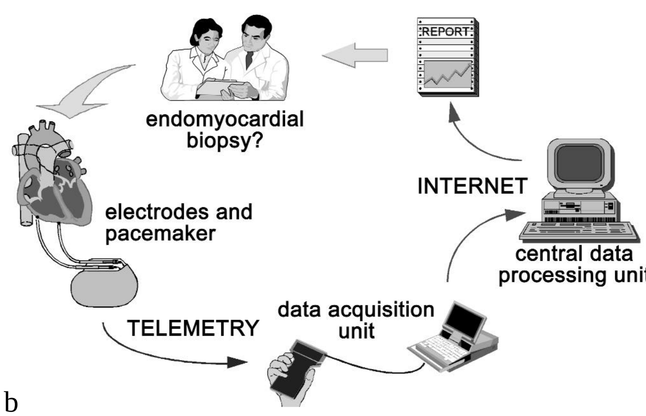

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Figure 10. Computerized heart acute rejection monitoring. Panel a: Typical averaged ventricular evoked response as obtained from an intracardiac electrogram sequence during pacing. The rejection sensitive parameter (RSP) is calculated as the amplitude of a normal distribution, which was fitted to the terminal part of the repolarization phase using least square techniques [14,15]. Panel b: Overview of the system.

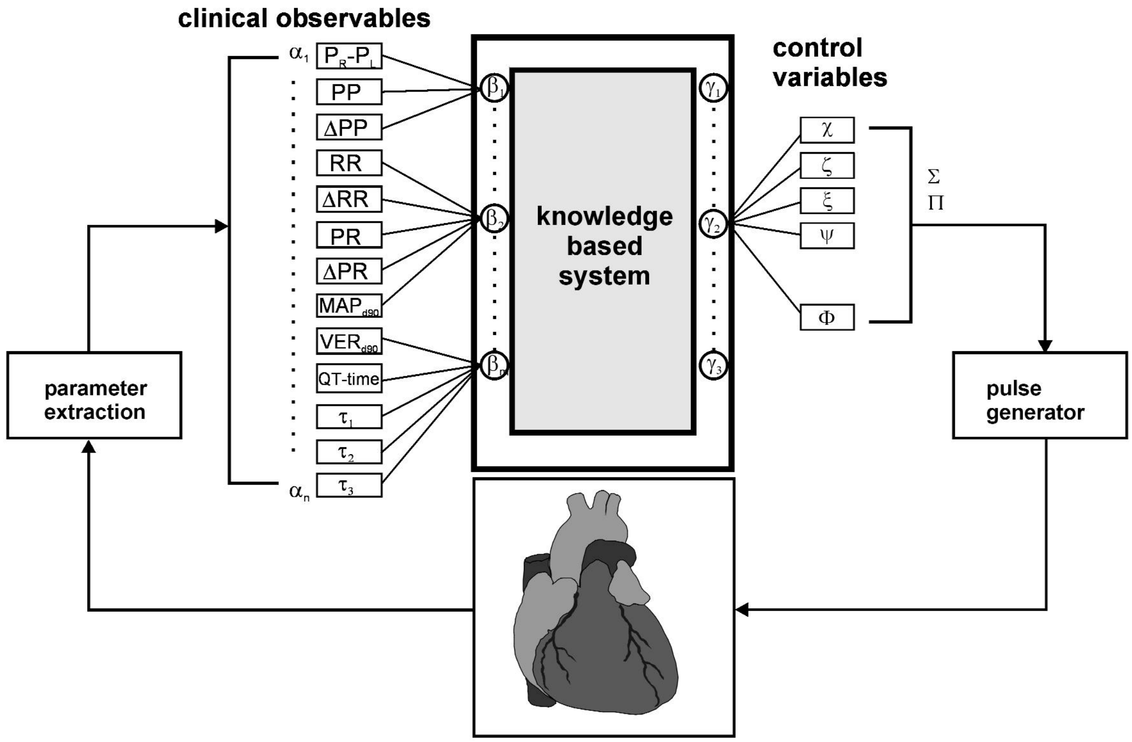

Figure 11. Observation and evaluation of cardiac state parameters using expert knowledge.

For this purpose a set of defined electrophysiologic parameters would be extracted from the electrical signals using enhanced features of implant electronics and electrode sensors. The clinical variables taking into consideration will depend on the functions of the implant and encompass arrays of different event rates, time delays reflecting conduction times, parameters of variability, depolarization and repolarization times, characteristic parameters of the MAP and VER signal as well as time constants that are evaluated by system identification algorithms and reflect dynamic changes of cell behavior [11,12,13]. Knowledge-based systems are established in cooperation with clinical experts. By use of fuzzy logic these systems can combine their input variables in a manner of human reasoning and deliver control variables for an ongoing optimization of pacemaker or ICD therapy. Thus the implant can be seen as an adaptive control element that compensates for pathologies in an optimal way.

As the expandable computational requirements of the mentioned algorithms cannot be abandoned, an external realization of the knowledge-based system is preferred using the power of telecommunication. This incorporates the additional benefit of the access to large amount of data and the use of deeper knowledge. The implant receives the role of a diagnostic monitor observing the cardiac function. It stores the measured data and extracts the diagnostic markers. By applying telemetry equipment as indicated in Figure 12, these markers are transferred to a center of knowledge via a patient base station. Here the state of the patient is permanently stored, compared with historical patient data and analyzed by the use of expert knowledge, including the possibility to monitor the success of pacing as well as medication therapy. Evolutionary fuzzy algorithms (e.g. genetic algorithms) may enable self-learning features of the system by, for instance, automatic evolving shapes and types of the membership functions as well as the fuzzy rule sets. The evaluated data are summarized in a cardioreport that provides the physician with detailed information on the state of the patient and possible suggestions how to adjust the therapy.

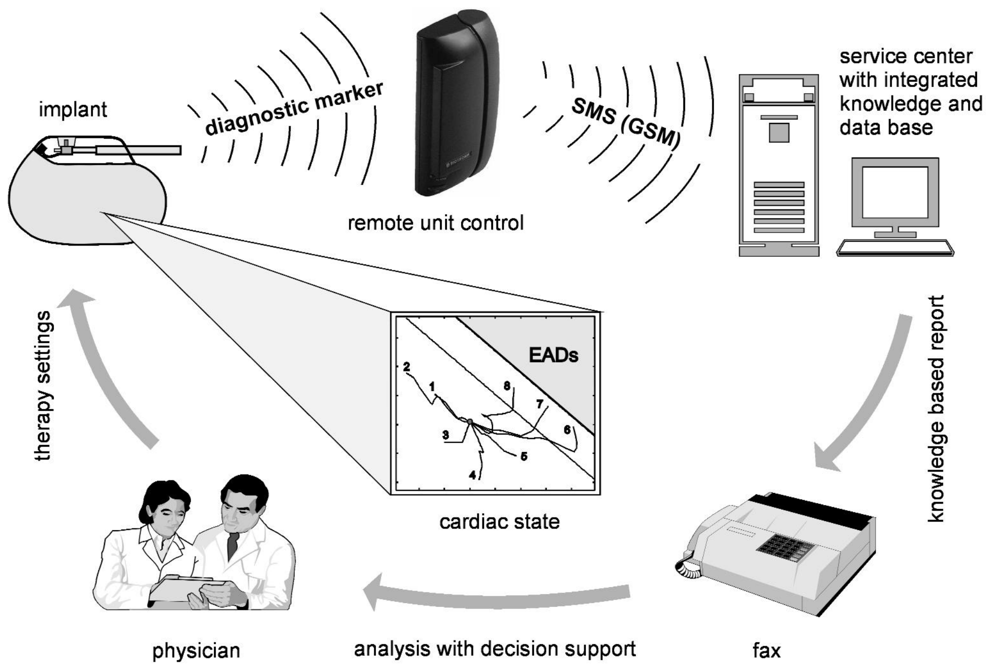

Figure 12. Expert-based monitoring of cardiac state and therapy control by use of modern telecommunication.

Discussion

For medical tasks, the range of acceptable error is small because of ethical concerns and malpractice risks. Beyond doubt, however, expert systems in combination with the proceedings of modern telecardiology offer a wide spectrum of possible applications for pacing systems. Patient benefits include at first arrhythmia prediction and prevention, disease detection and classification, medication monitoring, rate adaptation, optimization of parameters leading to enhanced quality of life, risk stratification, and many other more specialized functions.

In view of computational efficiency it is preferable to source out expert knowledge in the first phase of development and establish external powerful knowledge-based systems as part of a multi service center for the physicians. Additional benefits are provided through the use of modern telecommunication. Also the application of automated systems embedded in the implant software that allow incorporation of human or expert-knowledge-based decision making will expand. Cardiac pacemakers and ICDs will become more and more sophisticated with the progress of more profound electrophysiological and hemodynamic understanding of the heart, using intracardiac signals, such as VER or MAP, as well as advances in the fields of sensors, leads, batteries, microprocessors, memories, and signal processing techniques. Extra effort will be required for extracting the valuable diagnostic information out of the mass of measured data.

The process of knowledge acquisition by interviewing physicians, learning from past experiences, and unifying the know how of as many experts as possible will promote the use of computational intelligence in cardiac applications. Knowledge accumulation leads to further progress in diagnosis and therapy of cardiac patients resulting in new diagnostic information from which the experts can acquire knowledge again. The justifiability of the expert system increases with deeper knowledge leading to less rules and a less complex system. Keeping this point in view, there are chances for realization of intelligent knowledge-based systems as embedded implant software modules in the near future. Nevertheless, much work remains to be done to provide patients and physicians with the full range of extended facilities that expert systems promise.

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