COMPUTERIZED ARRHYTHMIA MANAGEMENT OF PATIENTS IN A CORONARY CARE UNIT

Allan Pryor, Ph.D., Ruth D. Goldberg,
Wayne F. Brown, M.D., and Jeffrey L. Anderson, M.D.

Department of Medical Biophysics and Computing
LDS Hospital, 325 Eighth Ave., Salt Lake City, Utah 84143

Introduction

The effectiveness of arrhythmia management for patients in a coronary care unit (CCU) depends on the ability of the physicians and nurses to function as a team when making arrhythmia management decisions, especially in emergency situations. The management decision is complicated by the fact the the arrythmia does not by itself suffice to determine what treatment is optimal for the patient but, together with other patient specific data, enable a list of treatment options.

This management problem, a complicated and dynamic condition involving a large mass of data clearly invites the use of a computerized management tool. This paper describes the development of a computerized arrythmia management system for patients in the CCU which allows for easy update of both, the patient's database and the computerized medical logic. CAM (computerized arrhthmia management) has been developed using the HELP (1,2,3) system at the LDS hospital in Salt Lake City, Utah. CAM has been programmed to automatically recommend a treatment plan immediately on entry into the system of a rhythm change in the patient. The arrhythmias managed by CAM are atrial flutter, atrial fibrillation, multifocal atrial tachycardia, paroxysmal supraventricular tachycardia, premature ventricular comlexes, non - sustained ventricular tachycardia, nonhypotensive sustained ventricular tachycardia, hypotensive sustained ventricular tachycardia and ventricular fibrillation.

The Medical Logic For Arrhythmia Management

The first step in development of a computer system for arrhythmia management was to formalize the medical logic used by the cardiologist in building a specific treatment plan for a patient into a knowledge base accessible by the computer. The creation of this knowledge base used a flowchart technique in arriving at the final treatment suggestion. The knowledge base thus created consisted of the discrete logic of each node of the flowchart and the control logic for traversing through the flowchart. The flowchart approach for knowledge representation was taken since, the data collection was independent of the application of the knowledge base and the ease in HELP for implementation of the node and control logic of a flowchart. Since the data collection was independent of the knowledge application and therefore assumed to be complete, evaluation of the appropriate treatment logic could in all cases proceed to a terminal node. The flowchart that resulted from this process was in fact a seven stage process to be followed by the computer in arriving at the treatment suggestion. The following are the seven stages of the knowledge base flowchart:

1) The arrhythmia is diagnosed by the physician and entered as original data when CAM is activated.
2) The clinical severity of the patient is evaluated for atrial flutter, atrial fibrillation and PVCs.
3) A list of possible etiological factors is checked.
4) The existance of contraindications to any of the drugs that could be included in the logic is checked.
5) A list of therapeutic goals of the specific patient is formed.
6) The effectiveness of each goal is assessed.
7) The treatment plans for each goal that has been assessed as useful are recommended to the physician in a practical sequence.

An example of formalizing a step in the medical logic is the assessment of the clinical severity of a patient with atrial flutter or atrial fibrillation. In this example the goal of the flowchart is to assess the patient's severity as emergent, urgent or elective. The logic entered in the CAM knowledge base for assessment of patient severity in the presence atrial flutter or fibrillation are presented in Figure 1.

The Patient's Database and Database Classification

Table 1 presents the data used for ventricular and atrial arrhythmia management. Because of the integrated medical record capability of HELP, this data is available to CAM through a variety of mechanisms. For example, the laboratory data is automatically entered into the system from the instruments used to measure those data. Hemodynamic data may be entered either automatically or manually depending on the presence of indwelling catheters. Medications are routinely entered by pharmacists at LDS Hospital. CAM makes use of this data availability by not requiring the cardiologist to enter unnecessary

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Figure 1.

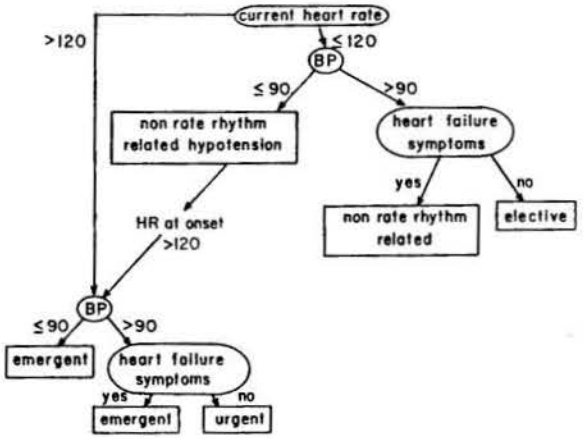

Table 1

THE DATA USED FOR EVALUATING THE VENTRICULAR AND ATRIAL MANAGEMENT OF THE PATIENT

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arrhythmia
coronary heart disease
existence of cardiac disease other than coronary artery disease
heart failure
ischemia
myocardial infarction
coronary spasm
vital signs
electrolyte abnormalities from smac tests
acid base abnormalities from blood-gas tests
drugs given close to the onset of the arrhythmia
contraindications to drugs
drugs given since the onset of the arrhythmia
medical history:
- hyperthyroidism
- hypothyroidism
- alcoholism
- prostatic hypertrophy
- systemic lupus
- rheumatoid arthritis
- hypertension
- asthma
- chronic obstructive pulmonary disease
- angina pectoris

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data at the time of consultation. There is available, however, a set of data entry screens presented to the user at the time initiation of CAM. The only required entry at this time is the arrythmia to be managed, however, additional data may be optionally entered at this time. This optional data includes updated results of physical examinations, updates in the patient's history and treatments that may have been given to the patient in the physicians' office, by the paramedics or emergency room staff. The potential for entering such data through the menus allows CAM to have the most recent patient information. Table 2 presents the data that can be entered at the time of execution of CAM through these menus.

Table 2a

DATA ENTERED TO THE PATIENT'S FILE USING CAM'S MENU

A VENTRICULAR ARRHYTHMIA
AN ATRIAL ARRHYTHMIA
MEDICAL HISTORY:

myocardial infarction	systemic lupus
unstable angia	rheumatic arthritis
hyperthyroidism	hypertension
hypothyroidism	asthma
alcoholism	diabetes

prostatic hypertrophy
chronic obstructive pulmonary disease
organic heart disease other than coronary heart
TREADMILL AND ECHO TESTS
a treadmill test was done today
abnormal ST depression was found from treadmill test
leaflet prolapse from echo test
mitral stenosis from echo test
INEFFICACY OF DRUGS (NEW PATIENT)*
CONTRAINDICATIONS TO DRUGS (NEW PATIENT)*
CONGESTIVE HEART FAILURE FROM PHYSICAL EXAMINATION
audible S3
rales, more than 50% lung fields and moist inspiratory
interstitial/alveolar edema
appears dyspneic
cold peripnery skin
appears fatiqued
abnormal level or conciousness
low urine output
cyanotic nails
ASSOCIATED FINDINGS:
chest pain, rule out myocardial infarction
poor perfusion
anxious (as a sign for excess of catecholeamines)
hepatic dysfunction
diarrhea within the last 24 hours
VITAL SIGNS:
current arterial systolic pressure
current arterial diastolic pressure
current neart rate
heart rate at onset of the arrhythmia

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* Drugs included are: lidocaine, procainamide, bretylium, verapamil diltiazem, nifedipine, quinidine, disopyramide, phenytoin, digoxin, propranolol, bronchodilators, alpha sympathomimetics, beta sympathomimetics, tricyclic antidepressants, beta sympatholytic agents, phenothiazines and lithium.

Although many data items may be entered, only one of them is indispensable - the entry of the arrhythmia. Two to four entries, however, are usually sufficient in order to receive the desired management recommendations. The decision on which data need be entered for an optimal consultation is left to the cardiologist. This procedure of final data entry is used to minimize the terminal time required by CAM and have it make use of the rich online database already available in HELP.

Table 2b

DATA RELATED TO THE ARRHYTHMIA

ATRIAL ARRHYTHMIAS

onset of atrial arrhythmia
atrial flutter
atrial fibrillation
multifocal atrial tachycardia (MAT)
paroxysmal supraventricular tachycardia (PSVT)
attempt conversion in patient with unclear conversion prognosis
do not attempt conversion in patient with unclear conversion prognosis

VENTRICULAR ARRHYTHMIAS

tend to give prophylactic lidocaine for acute MI
onset of ventricular arrhythmia
ventriclar fibrillation
hypotensive sustained ventricular tachycardia
non hypotensive sustained ventricular tachycardia
nonsustained ventricular tachycardia

PVC > 5/mn	PVC <= 5/mn
multiformed PVCs > 2/mn	multiformed PVCs <= 2/mn
paired PVCs > 1/hr	paired PVCs <= 1/hr
early beats > 1/mn	early beats <= 1/mn
triplet PVCs	

PVC < 10/hr

Two generic forms of data are available to CAM for inclusion in the decision logic. The first form referred to as original data is that data which is the direct result of some measurement. They would include pressures, heart rate, physical findings, history, laboratory data, etc. The second form of data is derived data. This data is the result of some form of intermediate decision processing. The results of any other decision systems in HELP are examples of derived data. Derived data may also be entered by the cardiologist as diagnoses such as heart failure, renal failure, etc. Thus within CAM there is the capability to use data to formulate decisions as well as the capability to incorporate previous decisions (manual or computer) into the logic of the arrythmia management.

The Implementation of the Medical Logic of CAM

The CAM logic was written for implementation on the HELP decision system. HELP makes available to the developer of medical decision logic a set of tools, constraints and a decision oriented language. The major operational construct of HELP is the block or subsystem. Within the block the problem is broken into a series of discrete decisions. Each of these discrete decisions are constructed as a unique decision labeled in HELP as a "sector". Each "sector" has an output which can contain not only a formatted message, but up to 10 numeric values which result in decision specific information being entered into the formatted message. In the example of a HELP "sector" of figure 2 the sector has two numeric values as output In this example the values are indices to other formatted messages which are inserted into the formatted "sector message". The final consultation of CAM, therefore, is the set of all formatted messages generated by the execution of the "sectors" in the CAM HELP block.

In implementation of a flowchart knowledge base HELP provides two mechanisms for control of the execution flow of the "sectors". The first allows the user to test the outcome of any "sector" and provide a list of non executable "sectors" if the specified branching logic is satisfied. The second mode of control is in reality a post processing contol mechanism. Using this mode the developer actually supresses the outcome of certain "sectors" based on appropriate control logic. In the example of figure 2 there are two instances of contol flow logic listed under the heading SKIP LOGIC. In those instances if the logic is evaluated as true the list of sectors following the logic is not executed.

The main features in the HELP language which make it easy for the developer of medical logic are the search, arithmetic and function statements provide in the language. In particular the search constructs available make it easy to develop logic requiring sophisticated data definitions and temporal constaints.

In the implementation of CAM as has been noted a flowchart approach was taken. A separate flowchart was constructed for the ventricular and atrial rhythms. These flowcharts which were developed by the cardiologists were then implemented into HELP "sectors" with the appropriate control criteria. Since HELP results in a very modular design, modifications, deletions and additions were easily accomplished by editing, deleting or adding a HELP "sector".

Validation of CAM

In order to properly validate logic of CAM two series of experiments were performed. The first was to enter simulated data into CAM for initial verification of the flowchart logic of CAM. This was easily accomplished by using the general data entry tool provided as the front end to CAM. In consultation with the cardiologists of the project a series of hypothetical test cases were formulated and entered into CAM. The output of CAM was then evaluated to verify the following: that the order of the treatment protocol was appropriate, that the outcome followed the path dictated by the data, that the temporal considerations of the logic was appropriate, and finally that the treatment suggestion was consistent with the desires of the cardiologist. Numerous logic errors were discovered as a result of this testing and corrected.

The second experiment was to prospectively compare the treatment suggestion of CAM with the actual treatments prescribed by the cardiologist.

Figure 2.

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BLOCK #3.12    TREATING RHYTHM (ANY SECTOR)
SECTOR 2   =  TREATMENT.  =
      SCT MOD 1:
      SCT MOD 2:   EMERGENT
      SCT MOD 3:   URGENT
      SCT MOD 4:   ELECTIVE
      SCT MOD 7:   RHYTHM DIAGNOSIS MISSING
      SCT MOD 10:  DATA MISSING FOR EVALUATING
      SCT MOD 11:  CONSIDER HYPOVOLEMIC HF TO TREAT WITH FLUID.
      SCT MOD 12:  CONSIDER CAUSE FOR HYPOTENSION NOT RELATED TO ENTERED ARRHYTHMIA
      SCT MOD 14:  CONSIDER CAUSE NOT RELATED TO ENTRED ARRHYTHMIA
      SCT MOD 20:

      OWNER:  STUDENT,RUTH   SECURITY:  AAAA   PRIORITY:  0
      ALWAYS SEND  DESTINATION LIST: TO CALLING PROGRAM, TO INFA FOR DEBUGGING

      FINAL EVALUATIONS:
      A  SCT MOD:  A
      B  SCT MOD:  B

      SKIP LOGIC:
      A  IF VAL ITEM A EQ 1 THEN SKIP(3 to 33)
      B  IF VAL ITEM A EQ 3 OR VAL ITEM A EQ 4 THEN SKIP(30 to 33)

      SECTOR LOGIC:
      A  ARITH:     A = 1
      B  ARITH:     1
      C  SEARCH:    (A) (FC) ECG DATA (MANUAL ENTRY), (N) RHYTHM DIAGNOSIS, (ADJ) VENTRICULAR MECHANISMS, (ADJ) HEART RATE
                    AT ONSET OF THE ARRHYTHMIA
         FROM:      TIME SEARCH B,     TO: NOW
      D  SEARCH:    (A) (FC), (ITEM) HEART RATE (MANUALLY CCU),    MOD:  LAST,  FROM:  5 MN BEFORE NOW
         IF ex:     VAL SUBITEM A NE 0
      E  SEARCH:    (A) (FC), (ITEM) ARTERIAL SYSTOLIC PRESSURE,   MOD:  LAST,  FROM:  5 MN BEFORE NOW
         IF ex:     VAL SUBITEM A NE 0
      F  ARITH:     IF NOT ((C OR D) AND E) THEN B = 10 GOTO FE
      G  SEARCH:    (A) (FC) ********** CHEST **********          (ANY SECTOR), (SCT) ===INTERSTITIAL/ALVEOLAR EDEMA=
         FROM:      VAL SEARCH B
      H  SEARCH:    (A) (FC) TREATING RHYTHM(ANY SECTOR), (SCT) = HEART FAILURE = =,  FROM: NOW
      I  SEARCH:    (A) (FC) ECG DATA (MANUAL ENTRY), (N) RHYTHM DIAGNOSIS, (ADJ) VENTRICULAR MECHANISMS, (ADV) CONGESTIVE
                    HEART FAILURE (CCU)
         FROM:      10 MN BEFORE NOW
      J  ARITH:     IF G EQ 1 OR H EQ 2 OR H EQ 4 OR EX ITEM I THEN  J = 1 ELSE J = 0
      K  ARITH:     IF D LE 120 AND E GT 90 AND J EQ 1 THEN B = 14
      L  ARITH:     IF D LE 120 AND E LE 90 THEN B = 12
      M  ARITH:     IF (C GT 120 OR D GT 120) AND E LE 90 AND J EQ 1 THEN A = 2 GOTO FE
      N  ARITH:     IF (C GT 120 OR D GT 120) AND E LE 90 AND J EQ 0 THEN A = 2 GOTO FE
      O  ARITH:     IF (C GT 120 OR D GT 120) AND E LE 90 AND J EQ 1 THEN A = 2 GOTO FE
      P  ARITH:     IF (C GT 120 OR D GT 120) AND E LE 90 AND J EQ 0 THEN A = 2 GOTO FE
      Q  ARITH:     IF (C GT 120 OR D GT 120) AND E GT 90 AND J EQ 1 THEN A = 2 GOTO FE
      R  ARITH:     IF (C GT 120 OR D GT 120) AND E GT 90 AND J EQ 0 THEN A = 3 GOTO FE
      S  ARITH:     IF C LE 120 AND D LE 120 AND E GT 90 AND J EQ 0 THEN A = 4 GOTO FE
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A total of 27 consecutive patients with presenting rythmns evaluated by CAM were used to validate the logic of CAM. For each of these patients the appropriate data were entered into the computer after reviewing the chart and consultation with the attending physician to ensure the data base were accurate for the patient before CAM was executed. On this subset of patients only 49 of the possible 138 messages available in the CAM logic were needed for the treatment suggestions of this sample of patients. Table 3 presents the distribution of treatment suggestions for patients with ventricular rhythms and Table 4 is the distribution of treatment suggestions for the patients presenting with atrial rhythms. Included in tables are the basic treatment suggestions made by CAM. Figures 3 and 4 are examples of a complete consultation for a patient with nonsustained ventricular tachycardia and a a patient with atrial flutter. While the set of all possible rhythmns and the number of patients studied was small, the results were encouraging in that the treatment suggested by CAM for all 27 patients was felt appropriate by the cardiologists responsible for the care of the patients.

Table 3.

FREQUENCY DISTRIBUTION OF VENTRICULAR ARRHYTHMIAS TESTED

number of patients	arrhythmia	treatment	Figure *
3	occasional PVCs	lidocaine or procainamide	17
1	multifocal coupled PVCs	lidocaine or procainamide	18
4	nonsustained ventricular tachycardia	lidocaine or procainamide	19
2	nonhypotensive sustained ventricular tachycardia	lidocaine	20
1	hypotensive sustained	cardioversion	21
1	ventricular tachycardia	and lidocaine	
1	hypotensive sustained ventricular tachycardia	cardioversion and quinidine	22
1	ventricular fibrillation	cardioversion and lidocaine	23

* The figures are therapy suggestions for specific patients.

Table 4.

FREQUENCY DISTRIBUTION OF ATRIAL ARRHYTHMIAS TESTED

number of patients	arrhythmia	treatment	Figure #
2	emergent atrial flutter	cardioversion & drug therapy menu	24
2	elective atrial flutter	drug therapy menu	25
3	emergent atrial fibrillation	cardioversion & digoxin iv & drug therapy menu	26
1	urgent atrial fibrillation	digoxin iv & drug conversion menu	27
2	elective atrial fibrillation	digoxin po & drug therapy menu	28
3	elective atrial flutter & atrial fibrillation	drug therapy menu	29
1	atrial flutter & atrial fibrillation	condition not related to rhythm or rate	30

success or failure of the logic is dependent on the accuracy of the data available at the time of execution of the logic. This is particularly true with respect to the knowledge of success or failure of previous treatments, historical data including cronic nature of the rhythms, and pertinent physical findings. Thus while the logic may be straightforward and easily understood its ability to aid may be much more dependent on the data acquistion methods than its internal logic. In the current form of the logic of CAM as noted the assumption is that all data have been entered before execution. The completeness of the data is ,therefore, dependent on what is either naturally entered into the computer through the automated programs or is entered manually by the cardiologist at the time of execution of CAM. Since much of the key logic of CAM may be dependent on previous response of the patient to a particular treatment, knowledge of that previous treatment is critical to the utility of CAM. For those treatment episodes during a single stay in the hospital the computer will have information on the treatment results, but if the episodes were from previous admissions the knowledge of these results is dependent on the entry of that information by the cardiologist. This is typical of the situation where the data entry may be more time consuming then the

Figure 3.

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          DIAGNOSIS: HYPOTENSIVE SUSTAINED VT
          ACUTE MI
SUGGESTED TREATMENT:
GIVE ELECTRICAL CARDIOVERSION AT 100-300 WATT-SEC. ON SYNCHRONIZED MODE: TO PREVENT RECURRENCE FOLLOW UP WITH LIDOCAINE
GIVE LIDOCAINE:
LOADING DOSE: 3 MG/KG TOTAL (DOLUS METHOD) INITIALLY 1 MG/KG. THEN 0.5 MG/KG EVERY 2-5 MN UP TO 3 MG/KG TOTAL OVER
10-20 MN.
SIMULTANEOUSLY, A 2-4 MG/KG INFUSION (AVERAGE 3 MG/MN) IS BEGUN AND CONTINUED
FOR THE PERIOD OF THERAPY, MINIMUM OF 24
HOURS SUGGESTED. CHECK FOR TOXICITY
ORAL CONTINUATION IF NEEDED: RECOMMEND QUINIDINE BECAUSE FIRST DRUG OF CHOICE.
GIVE QUINIDINE SULFATE :
INITIALLY:FOR AGE GREATER THAN 70 OR WEIGHT LESS THAN 50 KG :200 MG Q6H
OTHERWISE: 300-600 MG.
INCREASE
AS NEEDED UP TO 400-600 MG.Q6H. FOLLOWING RESPONSE TO ECG
(QRS<QT) AND BLOOD LEVELS
ALTERNATIVE SALTS INCLUDE GLUCONATE AND POLYGA
LACTURONATE
COMMENTS:
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Figure 4.

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EMERGENT TREATMENT
ATRIAL FLUTTER : SUGGEST CARDIOVERSION.CONSIDER RAPID ATRIAL PACING FOR FOLLOWING CONTRAINDICATORS
DRUG THERAPY: GIVE DIGOXIN IV BECAUSE OF HEART RATE GREATER THAN 100
 -- ELECTRICAL CARDIOVERSION:FOR FLUTTER 50 WAT-SEC, INTIALLY  USING STANDARD TECHNIQUE
 -- START CLASS I ANTIARRHYTHMICS:
       QUINIDINE SULFATE 300-400 Q6H 4-6 DOSES
    OR PROCAINAMIDE 375-500 Q4H 4-6 DOSES
    OR DISOPYRAMIDE 150 Q6H 4-6 DOSES
 -- START ANTICOAGULATION: GIVE REPARIN IV OR SQ. (TO PREVENT THROMBOEMBOLYSM ON CONVERSION)
RISK OF REVERSION IS LOW. RECOMMEND THAT IN 2 WEEKS D/C :
 -- ANTICOAGULATION.
 -- DIGITALIS.
 -- CLASS I ANTIARRHYTHMICS
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Discussion

The experience gained to date on the use of computerized logic for the management of arrythmias has indicated that such aids provided by the computer may have a positive effect on the care of patients. In review, however, of the logic developed for CAM it is evident that the cardiologist is willing to expend. More importantly it may be unknown which previous data may be relevent to the arrythmia now being managed. Thus, the cardiologist may forget to enter critical data or be required to enter a series of unnecesssary data. To evaluate the effects of this independent data entry mode a version of CAM is being written wherein the entry of data is controlled by the CAM logic itself. In

this mode only the presenting rhythm is entered before CAM is executed and those data items which are required by CAM and not available in the patient's database are requested at the time of CAM execution. However, because of the interaction with CAM and repeated evaluation of its logic as new data is entered this mode may be as time consuming as the first method.

Several features have been incorporated into CAM which have aided in its acceptability by the medical profession. The first is inherent in the HELP system itself and relates to the ease of updating the logic. With HELP's inherent modularity little effort is required to create new or change old criteria. Thus CAM can easily adapt to changing needs in treatment regimens. Another feature which has been found useful is the flexibility of the instructions provided. They have been capable of providing alternative choices when clear cut plans are not known and also explanations concerning the reasons why certain treatment protocols have been suggested. This not only aids the physician, but gives him the confidence that the suggestions are based on reasonable criteria.

Current effort is now underway at LDS Hospital to instrument every bed in the CCU with a computer terminal. This terminal which will be used for data review, nurse charting and order entry, will also be available for execution of CAM at the bedside. We anticipate that this availability of terminals and increased ease of data entry will promote continued use and enhancement of CAM.

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Figure Legends

1. Flow chart of logic used to determine patient's severity for atrial flutter or atrial fibrillation.

2. Text messages of a sector that represents the clinical severity of a patient with atrial flutter or atrial fibrillation.

3. Example of a treatment plan suggested by CAM for a patient with myocardial infarction and hypotensive sustained ventricular tachycardia.

4. Example of a treatment plan of a patient with atrial flutter.