Pacing algorithm test environment for simulating critical bleeding situations

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***Abstract*—Bleeding is most contraversal and dangerous trauma complications witch leads with no help to death. Every heart assisting system must be able to avoid malregulation in this critical event. Basic cardiovascular simulation together with novel pacing algorithms are verified in "bleeding" model. Bleeding of blood is simulated in two basic types: arterial bleeding and venous system bleeding. For both mode simulations blood loss graph versus heart rate has been modeled.**

Keywords—modeling; simulation; artificial pacing; cardiovascular system.

I. Introduction

Today's artificial pacemaker is coming as one of most important anti-arrythmic device to correct and generate pacing rate for heart if its natural system are failing.

Historically pacemakers are evaluated from simple constant rate pacing devices to modern very sophisticated monitoring and treatment devices. Most often external pacing are needed when patient own heart rate generation (sinus node) or impulse propagation ways are damaged – result is very often low heart rate (bradycardia) witch can't fulfill body demand for fresh oxygen rich blood.

Today is implemented various pacing algorithms for optimal heart rate estimation. Most of them are simple gate based system where minimal and maximal allowable heart rate are fixed and signal from sensors are just correlative value to calculate exact pacing rate.

As the software-based algorithms used in implantable medical devices become more complex, the design of bug-free or "paradox free" medical device software is becoming an increasingly difficult problem.

Safety recalls of pacemakers and implantable cardioverter defibrillators between 1990 and 2000 affected over 600,000 devices. Of these, 200,000 or 41%, were due to firmware issues and their effect continues to increase in frequency [1-5]. The high-level diagnostic and therapeutic operations of artificial pacemakers requires a clinically-relevant and interactive testing methodology to fully validate their functionality. The model provides closed-loop interaction with both medical device hardware and software implementations. We presented bleeding as study on pacing algorithm crosstalk and cardiovascular model to demonstrate how this interaction can result in inappropriate and inefficient rhythm therapy. Such investigation allows for the development of better algorithms, techniques for safety pacing in the real patient.

Pacing rate algorithms (patent nr. US20080058882) is based on energetic basis (verifying of heart energy supply / demand balance) for heart rate calculation.

To monitor all personal data sophisticated differential equation based real-time model has been crated and implemented on PC computer.

II. Model description

A. General Aspects

Model has three basic compartments (venous system, ventricle, arterial system) and three connections (inlet valve, outlet valve, peripheral capillary resistance). Compartments are simulated like capacitors in electrical system. Connections are simulated as inlet resistances or time varying resistances for inlet and outlet valves for ventricle.

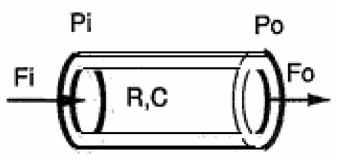


Figure 1. Vessel segment as compartment. Pi – inlet pressure; Po – outlet pressure; Fi – inlet flow; Fo – outlet flow; R – inlet resistance; C – segment compliance.

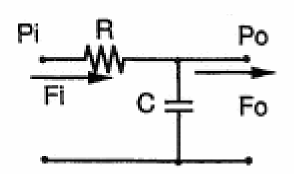


Figure 2. Vessel segment electrical equivalent. Pi – inlet pressure; Po – outlet pressure; Fi – inlet flow; Fo – outlet flow; R – inlet resistance; C – segment compliance.

Valve inlet and outlet conditions during simulation:

if (Pi > Po), then R(t) = Ri, else R(t) = Ro,

where Pi and Po are inlet and outlet pressures; R(t) – resistance; Ri and Ro are inlet and outlet resistances accordingly.

B. Simulation of Ventricle Elastance

Elastance is related to compliance by this simple relation: E = 1 / C, where, E -elastance; C – compliance.

Ventricle elastance is simulated by using time varying elastance model [6]:

if (t > = 0) and (t <= ts / 2), then E(t) = Ebase + 2 * Emax * ts / t,

else:

if (t > ts / 2) and (t <= ts) then

E(t) = Ebase + 2 * Emax * ts / (t – ts),

Else E(t) = Ebase,

where, E – ventricle actual elastance; t – cycle time span from start; ts – ventricle ejection (systol) duration; Ebase – base elastance of ventricle; Emax – maximal elastance during ventricle contraction.

III. COMPUTER BASED SIMULATION

Bleeding type simulations: arterial, venous.

For every type of bleeding simulation has been set up circulation volume reduction algorithms. Arterial bleeding resuts with more pronucated afterload reduction and blood pressure reduction. Venous bleeding has more effect on preload in late phases of simulation.

IV. SIMULATION OF BLOOD LOSS

Total circulating blood volume have been decreased over short time period from 5500 ml to 3000 ml, results are been presented as simulation graphs.

For model checking, we start from basic safety properties which should be satisfied by the pacemaker under all possible heart conditions. In this section, the most abstract cardiovascular model which covers all possible heart inputs to the pacemaker, is the most suitable heart model to use.

Simulation procedure:

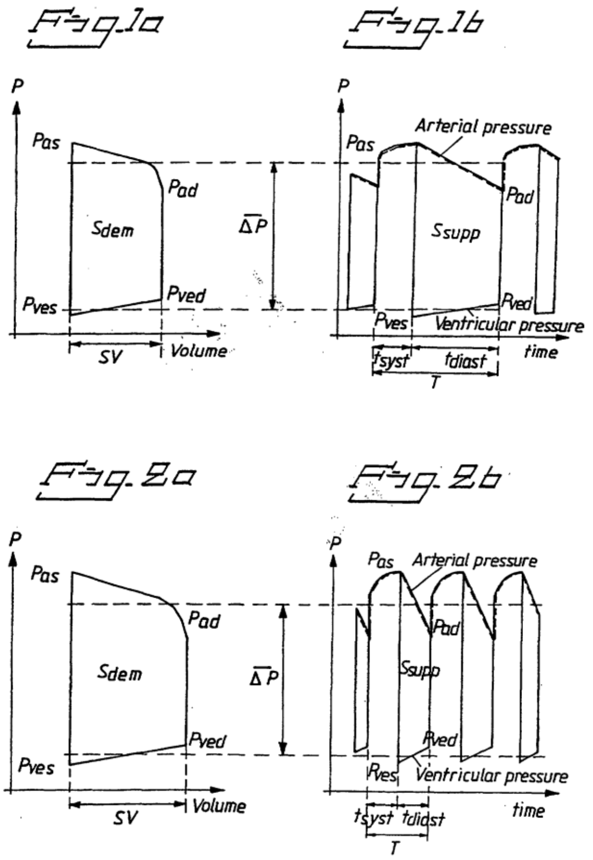
In real interaction cardiovascular model and bleeding simulation are started with some time sift about 5 seconds to get time for cardiovascular model to be stability state (all random parameters fluctuations are swiped out).

Blood bleeding is simulated in time-dependent mode, that every next time interval arterial or venous blood volume has been decreased by exact quantity.

Vart (t + dt) = Vart (t) – dVloss or Vven (t + dt) = Vven (t) – dVloss,

where Vart, Vven are arterial and venous circulating volumes, and dVloss is volume lost over certain time period.

Pacemaker model has been used to calculate heart rhythm for the next simulation step according to measured energetical parameters.



Figures 3a, 3b and 4a, 4b. Energy demand and supply representation on pressure volume graph and pressure time graphs.

V. Results

TABΛE I. SPECIFICATION OF MINIMAL AND MAXIMAL PACING RATE DURING ARTERIAL BLOOD LOSS

Circulating volume in model (ml)	**Min HR**	**Max HR**	**Mean art. BP (mmHg)**
5500	80	150	100
5000	85	152	100
4500	87	155	95
4000	89	156	90
3500	115	157	80
3000	140	157	50

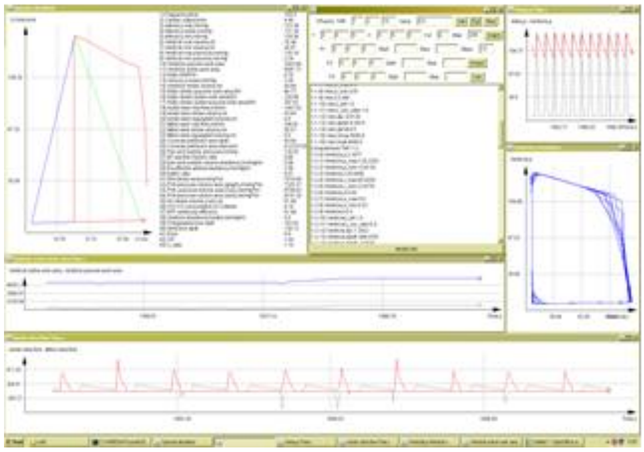


Fig. 5. Simulation windows with multiple functions: parameter window; graph windows; system window and data recording window.

A. *Discussion*

Devices with regulation capability like pacemakers had one common problem: they are “information blind” during fast changes in cardiovascular system like bleeding. To avoid malfunction of “smart devices” further investigation with more complex models and simulations are necessary.

VI. Conclusions

The result are quite controversial compared to heart rate normal reaction to bleeding. In intact organism heart rate has at least to phases: increasing heart rate and slow heart rate in critical blood loss conditions. The model was just bio-mechanical, without modeling central nervous system and blood constitution (Hgb concentration) responses to circulating blood volume reduction.

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