

TITLE: NONINVASIVE BLOOD PRESSURE MONITORING USING NEURAL NETWORKS**AUTHORS:** P. D. Baker, Ph.D.; J. A. Orr, Ph.D.; D. R. Westenskow, Ph.D.**AFFILIATION:** Department of Anesthesiology, University of Utah
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Introduction: Most noninvasive blood pressure monitors use oscillometric algorithms for estimating diastolic, mean, and systolic pressures. However, conventional algorithms appear to be overly simplistic in interpreting the complex and nonlinear relationship between the oscillometric waveform (cuff pressure oscillations plotted as a function of cuff pressure) and blood pressure, as is evidenced by the fact that their performance is often dependent on variables such as blood pressure [1] and pulse pressure [2,3]. A neural network that calculates blood pressure from oscillometric waveforms has been developed and appears to overcome some of the limitations of conventional algorithms.

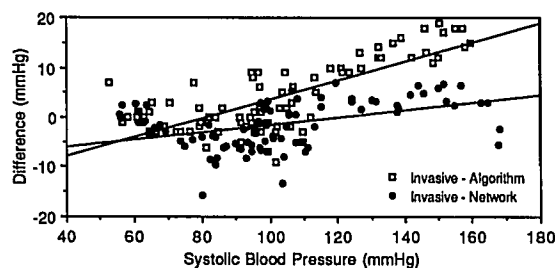
Methods: A total of 425 oscillometric waveforms and simultaneous invasive arterial blood pressure measurements were obtained from the contralateral forelimbs of five anesthetized mongrel dogs. The mean blood pressure of each dog was varied over the range of 40 to 140 torr by infusion of either sodium nitroprusside or norepinephrine. Three neural networks were trained to calculate either diastolic, mean, or systolic blood pressures using the oscillometric waveforms obtained from 4 out of the 5 dogs. The oscillometric waveforms from the 5th dog were then processed through the trained networks to obtain blood pressure estimates. The same waveforms were also processed using conventional oscillometric algorithms [1,2]. Training and testing was repeated 5 times until the data from all 5 dogs had been used once for testing.

Results: The first row in the table below contains the mean differences \pm the standard deviation of the differences between invasive measurements and noninvasive conventional algorithm and neural network estimates of blood pressure. These statistics were computed using data pooled from all 5 dogs. The second row contains the average of the means and standard deviations

computed separately for each dog (a better measure of intrasubject variation). The graph below, which contains systolic blood pressure data from dog 4, is one of the more dramatic examples of how the accuracy of the conventional algorithm decreased with increasing blood pressure, while the accuracy of the neural network remained relatively constant.

Discussion: The distributed and nonlinear processing capabilities of neural networks offer the potential of maintaining the accuracy of blood pressure estimates over a wide range of physiological conditions. Another advantage is that the use of neural networks, which can learn complex relationships by example, does not require a detailed theoretical understanding of the genesis of the oscillometric waveform.

Methods Compared	Diastolic	Mean	Systolic
Invasive - Algorithm	2.89 ± 4.49	1.84 ± 5.44	1.22 ± 6.05
Invasive - Network	-0.53 ± 5.14	-2.88 ± 4.97	-2.49 ± 6.33
Invasive - Algorithm	2.89 ± 3.53	1.84 ± 4.15	1.22 ± 6.05
Invasive - Network	-0.53 ± 4.18	-2.88 ± 3.30	-2.49 ± 4.21

**References:**

1. Geddes LA and Newberg DC: *Psychophysiology* 14:198-202, 1977.
2. Mauck GW, et al: *Trans ASME*; 102:28-33, 1980.
3. Yamakoshi K, et al: *Med Biol Eng Comput* 920:307-313, 1982.

A447**TITLE: RESPONSE TIME WITH SMART ALARMS****AUTHORS:** J. A. Orr, Ph.D.*; F.H. Simon, D.Ing.†; H-J Bender, M.D., Ph.D.†; D. R. Westenskow, Ph.D.***AFFILIATION:** *Dept. of Anesthesiology, Univ. of Utah,
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Introduction: Anesthesia alarm systems call attention to problems and minimize the time required to resolve such problems. Alarm firing times and human response times were measured for smart alarms and conventional alarm systems. While conventional alarm messages call attention to a single parameter such as "low airway pressure", smart alarms call attention to a specific problem such as "expiratory hose disconnect".

Methods: A simulator was used to measure the response time of smart alarms and of conventional alarm systems. The simulator uses pneumatic actuators to create breathing circuit faults remotely under computer control. When a problem was created, the time required for an alarm to fire (alarm time) and the time required for an anesthetist to correct the problem (human response time) are measured and recorded.

Smart alarms were generated using a neural network based smart alarm system [ref]. Conventional alarms were generated using Ohmeda model 5420 CO₂ monitor, model 5120 expiratory flow monitor, model 5201 O₂ monitor and the airway pressure monitor incorporated in the Ohmeda 7000 ventilator (Ohmeda, Madison WI). Default alarm thresholds

were used for CO₂ and pressure alarms and the expired minute volume alarm was set at two thirds of the set minute volume.

Eight anesthetists and anesthesia technicians were asked to answer questions from the ASA self test booklet. During the quiz, breathing circuit faults were created in the simulated patient breathing circuit. When an alarm fired, the anesthetist was asked to find the problem and correct it as quickly as possible. This process was repeated for both conventional and smart alarm systems. To remove bias, half of the subjects were tested using the smart alarms first and the other half were tested using conventional alarms first.

Results: The table below lists the alarm conditions created by the simulator. It gives the mean and standard deviation in seconds, of the time required for the subject to correct the problems after the alarm sounded.

Conclusion: While alarm firing times were approximately equal, for both alarm systems, human response times were much shorter using smart alarms. The results show that smart alarms should improve anesthesia safety by decreasing the time required to correct problems.

Alarm Condition	Smart	Conventional
E.T. Tube Obstruction	28.1 ± 19.5	56.6 ± 62.7
Exp. Hose Disconnect	16.1 ± 11.7	57.2 ± 57.5
Y-Piece Disconnect	9.4 ± 4.7	15.4 ± 6.7
Insp. Hose Leak	11.2 ± 6.4	31.3 ± 14.0
Exp. Valve Stuck Open	19.8 ± 12.8	56.1 ± 48.3
E.T. Tube Cuff Leak	7.9 ± 3.9	127.1 ± 61.3
Leak at CO ₂ Sensor	23.0 ± 21.9	76.7 ± 52.3
All Alarms	16.7 ± 13.6	60.1 ± 54.2

Reference: *Anesthesiology*; 71:339, 1989