MONITORING DIRECT BLOOD PRESSURE: ALGORITHM ENHANCEMENTS

Reed M. Gardner PhD, Susan M. Monis *, Paul Oehler *

LDS Hospital/University of Utah Salt Lake City, UT
*** Marquette Electronics Milwaukee, WI**

ABSTRACT

Enhancements have been made to algorithms for extraction of information from arterial pressure waveforms. These enhancements help eliminate a large number of the false alarms and prevent erroneous data from being logged in the trend memory of bedside monitors. The new algorithm was tested on data recorded from a variety of patients in the clinical intensive care environment. Registration of false alarms and erroneous data from arterial blood pressure waveforms was dramatically reduced while true alarms were properly detected.

INTRODUCTION

Monitoring direct arterial pressure provides timely, useful and important data to those caring for a critically ill patient [1-3]. The arterial pressure waveforms generally provides systolic, diastolic and mean pressure reliably. However, during a recent review of three bedside monitors with pressure monitoring capability [4], we found that none recognized and rejected the following artifact conditions: 1) zeroing the transducer, 2) fast flushing the system, and 3) drawing blood from the patient. These conditions occur several times a day during normal patient care and result in false alarms and erroneous data logging. To help eliminate these problems we have developed new algorithms for our bedside monitors.

METHODS

Characterization of the problem

The zeroing, flushing and blood drawing artifacts have the characteristics described below and shown in Figure 1 A to C.

Zeroing: At intervals nurses and physicians re-zero the pressure transducer. As can be seen in Figure 1A the pressure quickly drops to zero and stays there. Note in Figure 1A that the recorder displays the near zero pressure (AR2) of -2 mm Hg for systolic, diastolic and mean.

Flushing: The fast-flush is commonly used in clinical pressure monitoring situations to test the dynamic response of the catheter-tubing-transducer system and to flush out blood from the catheter and tubing. As can be seen in Figure 1B when a fast-flush occurs the pressure signal rapidly increases to the pressure in the flush bag and returns with oscillations to the patients pressure waveform. As can be seen in Figure 1B the pressure (AR2) sensed by the monitor is 349 systolic, -99 diastolic with 177 as a mean pressure--clearly not the patient's actual arterial pressure.

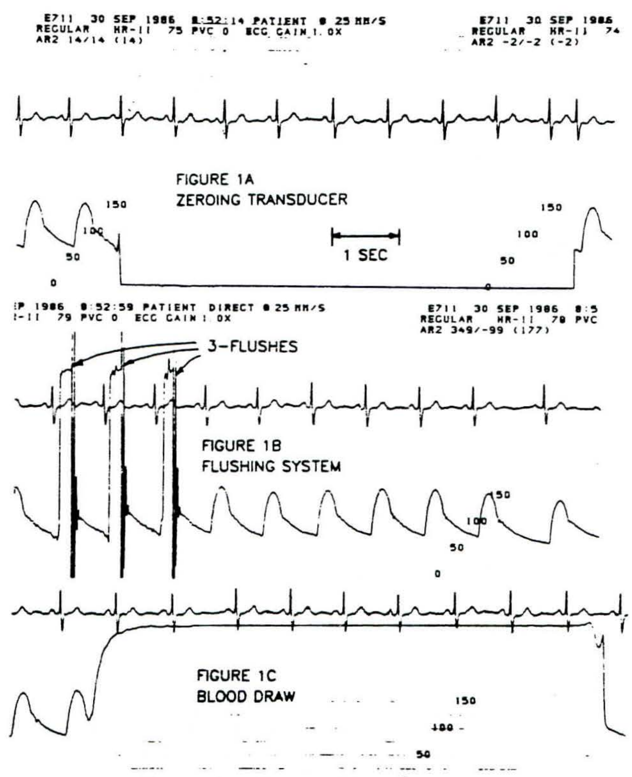

Figure 1. Strip chart recordings of zeroing, flushing and blood drawing artifacts.

Drawing: When the stopcock of a catheter-transducer monitoring system is turned to allow blood withdrawal for blood gas or laboratory sampling, the pulsatile pressure waveform is lost as shown in Figure 1C. Although the digital display is not visible in this figure, the systolic, diastolic and

0276-6574/87/0000/0607$01.00 © 1987 IEEE

mean pressures quickly go to the pressure inthe flush bag--usually near 300 mm Hg.

The solid lines and blocks in Figure 2 show the block diagram of the signal processing of a contemporary pressure monitor. Contemporary monitors do little to reject artifacts, and as a result, when these artifacts occur, the bedside monitor displays the erroneous data on their digital display, generate false alarms, transmit the erroneous data to the patient data management systems as well as log the erroneous data into the trend memory.

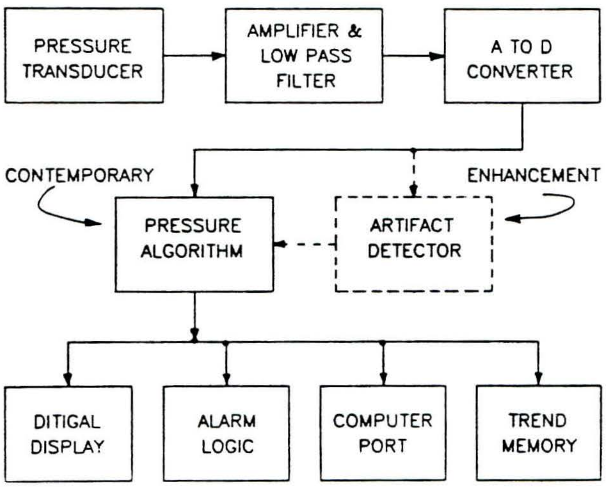

Figure 2. Block diagram of contemporary and enhanced pressure measurement algorithm system. The dotted box and lines indicate the addition made to the algorithm to reject the artifacts caused by zeroing, flushing and blood withdrawal.

Since it is important to record valid data for all the situations noted we set out to improve the pressure monitor's artifact detection algorithm. The goals for the enhanced algorithm were:

To **DETECT** and **REJECT** zeroing, flushing and blood withdrawal artifacts in the arterial pressure waveform and thereby eliminate false readings from:

A. Being displayed on the monitor.
B. Causing false alarms.
C. Being transmitted to the patient data base computer system.
D. Being stored in the trend memory of the bedside monitor.

Enhanced Algorithm

The enhanced artifact detection algorithm was added to the software of the Marquette 7000 series patient monitor shown in Figure 2. The artifacts were detected using the following logic (See Figure 1 A,B,C for strip recordings of each type artifact):

ZEROING: Zeroing is detected by having a large negative derivative followed by a very small summation of pressure values taken over a 2 second time interval.

FLUSHING: Flushing is detected by having a large positive derivative followed by a large summation of pressure values taken over a 2 second time interval.

DRAWING: Blood drawing is detected by having a 2 second period with no arterial pressure pulsation and having an increasing summation of pressure values taken over the same time interval.

As each artifact is detected within a 2 second window the digital display and other data output functions are held for the next 10 second period. The next data update after artifact detection, 4 seconds later, updates the display and other outputs for systolic and diastolic pressure the last valid data with a code for the artifact detected and the alarms are disabled. For example Figure 3 shows a "zero" artifact detection. The recorder shows the "held value" and then goes to the artifact detection indication of Z/Z (Z) for Zeroing artifact while indicating the mean pressure. The monitor display always indicates the mean pressure during any of the artifact detection situations. If a flush artifact is detected an F/F is displayed and for blood drawing a D/D is indicated. As soon as each artifact is detected the algorithm continues to search for the return of valid pressure pulse waveforms. As soon as 15 "authentic" pulse waveforms are detected the algorithm concludes that the artifact condition is remedied and re-initiates data display and recording. If no authentic pressure waveforms are detected, a maximum of 2 minutes of artifact are allowed. After 2 minutes the alarms and the display are updated regardless of the quality of the pressure waveform.

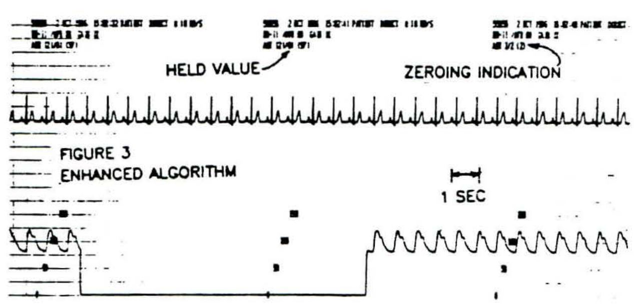

Figure 3. Strip recording output from the enhanced pressure algorithm during a zeroing session. Note that the system holds, then goes to Z/Z (Z) to indicate zeroing.

Validation

The ability of the artifact detection method to detect the zeroing, flushing and blood drawing was validated by comparing the results obtained from a contemporary monitoring system (Marquette 7000 series) with the enhanced artifact rejection algorithm. The data used to compare the systems were obtained from FM analog data recordings taken from two different clinical ICU settings (Massachusetts General Hospital in Boston, MA and LDS Hospital in Salt Lake City, UT). We evaluated 32 different 5 minute epochs of patient data tapes obtained from 17 different patients.

RESULTS

The results of the validation testing done on the 32 different 5 minute epochs of patient data with three types of artifact were analyzed. In addition three physiological conditions (asystole, cardiac failure, and physiological changes in mean pressure) when a "true" alarm should have been generated were tested. Further, tests of several hours of data from the patient data tapes were evaluated to ascertain that the algorithm did not falsely alarm or miss significant physiological events.

Results are shown in Figure 4. The solid lines show the results of the contemporary monitor while the boxes show the results obtained with the enhanced algorithm. The results shown are typical. There are two blood withdrawals followed by three groups of flushes and then a re-zeroing of the transducer. It can be clearly seen that the enhanced algorithm eliminates the artifacts in the contemporary monitor. Also, as can be seen, the true patient results are quite stable and the enhanced algorithm records a proper trend.

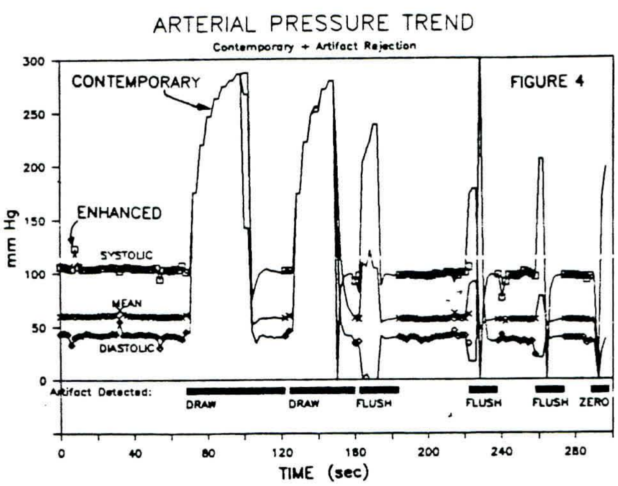

Figure 4. Trend plot of data derived from a patient arterial pressure signal illustrating the consequences of blood drawing (DRAW), fast flushing (FLUSH) and zeroing the transducer (ZERO). The smooth "contemporary" curves are the data derived from the 2 second display updates of a Marquette 7000 series monitor. The discrete marks are the corresponding values obtained for the same patient waveform data with the enhanced artifact rejection algorithm. The bars below the plot show which type of artifact was detected and the time interval the artifact occurred. The sequence seen is DRAW, DRAW, FLUSH, FLUSH, then ZERO for a 300 second (5 minute interval) displayed.

Figure 5 shows the systolic trend data for the same patient for the same time interval for the contemporary monitor and the enhanced algorithm. For the alarm limits set as shown, 7 different alarms (6 of them false) would have been activated during this 5 minute period. For the enhanced algorithm only one alarm was activated—at 240 seconds.

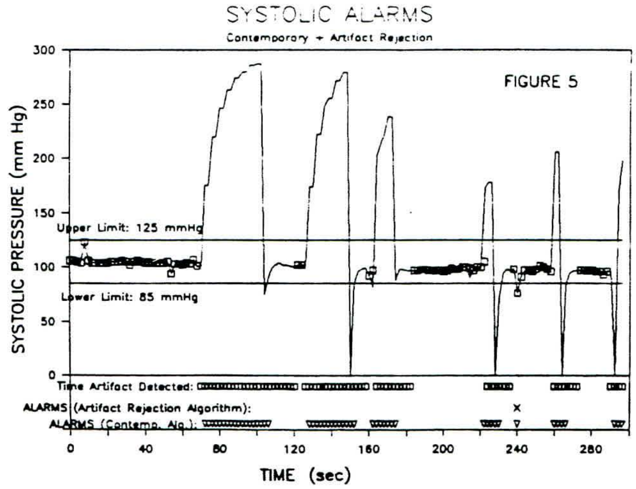

Figure 5. Shows only the systolic pressure information from Figure 4. Superimposed are the upper (125 mm Hg) and lower (85 mm Hg) alarm limits for systolic pressure. On the bottom part of the figure are indicated the time intervals when artifacts were detected. The next line identified by ALARMS (Artifact Rejection Algorithm) shows the alarms identified by the enhanced artifact rejection algorithm. Note there is only one "low" alarm at 240 seconds. The bottom line shows the alarms which would have been generated by the contemporary pressure monitor.

Table 1 summarizes the results from the 32 different episodes of artifact detected from the clinical patient tapes.

TABLE 1

Results of evaluating 32 different episodes of pressure waveform artifacts

Truth \ Artifact Rejection Algorithm	Artifact	Physiologic (True)
Artifact	29	3
Physiologic	0	3

Sensitivity= 90% Specificity = 100%

DISCUSSION

Clearly the enhanced algorithm produced dramatic improvements in the bedside monitor's ability to evaluate clinical data. In summary the following are the most important conclusions:

1. Present monitoring systems allow far too much artifactual data to reach the monitors' display, trend buffer, and alarm logic.
2. The enhanced artifact rejection algorithm eliminates most of the false alarms caused by zeroing, flushing, and blood drawing.
3. The trend displays of the new algorithm are more representative of actual patient conditions.
4. Data sent from the bedside monitor to the computerized patient data management system is more valid and thus patient data management computer systems can be programmed to automatically acquire patient data.

REFERENCES

1. Bleicher W, Epple E, Kopp M, Junger H. Artifact processing in a computerized intensive care unit. Computers in Critical Care and Pulmonary Medicine. Springer, Berlin 1985 p 102-115.

2. Bleicher W, Frey R. Zahn S, Steil E, Budwig G, Epple E. Characteristic Trend patterns in Computerized intensive care monitoring. Computers in Cardiology 1981; p 423-426.

3. Bleicher W, Epple E. Uberlegungen zur Alarmgebung in der Intensivmedizin und in der Narkoseuberwachung (Alarm processing in Intensive Care and Anaesthesia), Anasth Intensivther Notfallmed 21:132-136, 1986.

4. Maloy L, Gardner RM. Monitoring systemic arterial blood pressure: Strip recording versus digital display. Heart & Lung (In Press — October 1986).