A NEW SYSTEM TO RECORD RELIABLE PULSE OXIMETRY DATA FROM THE NELLCOR N-200 AND ITS APPLICATIONS IN STUDIES OF VARIABILITY IN INFANT OXYGENATION

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ABSTRACT. We have developed a simple system for internal validation of oximetry data collected over many hours from the Nellcor N-200 pulse oximeter (Nellcor, Inc., Hayward, CA). This system uses signals from the oximeter alone and a validation algorithm that is based in a computer connected to the oximeter. Unlike other validation systems, this system does not require connections to other monitors. The system was tested on 10 acutely ill newborns in an intensive care nursery over 16 hr of continuous recording for each infant (birthweight, 2.50 ± 0.73 kg; age, 3.4 ± 3.2 days). Oximetry data were accepted as valid using the new system if they surpassed a minimum level of quality (empirically derived, and equal to a 60% fractional success in pulse detection). The validated oximetry data were compared to data obtained using a conventional "compared to the electrocardiogram (ECG)" algorithm. For the new and the conventional algorithms, the distributions of validated SpO_2 percents were nearly identical, with data rejection rates of 28.9% for the new system and 37.3% for the conventional system. In the newborns, the new system was used to demonstrate that as the mean saturations decreased, there were striking increases in variability about the reported mean saturation ($p < 0.001$). While variability in infant SpO_2 is a well-known phenomenon, the amount seen here was unexpected. For example, the range of true saturations frequently recorded was quite wide at a reported mean SpO_2 of 90% (from 81 to 94%; but, the range was only from 92 to 98% at a mean SpO_2 of 96%). These findings demonstrate the usefulness of the new system and, if substantiated in more detailed studies, have important implications for the use of pulse oximeters to assess oxygenation in newborns.

KEY WORDS. Measurement techniques: pulse oximetry. Monitoring: oxygen. Equipment: pulse oximeters; computers. Oxygen: saturation.

INTRODUCTION

Clinicians caring for sick newborn infants usually attempt to keep SaO_2 within a designated optimal range. The upper and lower extremes of this range are chosen to minimize the risks of tissue hypoxia, retinal injury [1], bronchoconstriction [2], pulmonary vasoconstriction [3], and lung oxygen toxicity [4]. Unfortunately, there is little agreement on what the range of SaO_2 should be for acutely ill or convalescing infants [5]. Furthermore, even stable infants may have fluctuations in SaO_2 [6], over several minutes, that exceed the range of published recommendations (i.e., wider than, for example, 4 to 6%) [5, 7]. And, finally, during prolonged recordings, assessing the validity of the pulse oximeter data is necessary [8]; however, the validation system usually requires the use

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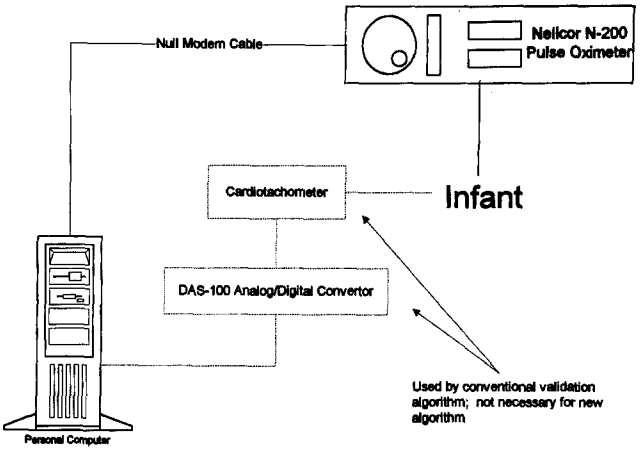

Fig. 1. The system used for data recording and validation. ECG data from the cardiotachometer was sent to the personal computer and was used for comparison to the conventional "compared to the ECG" algorithm. The system proposed requires only the oximeter connected to the personal computer.

of a separate cardiotachometer and comparison of the electrical heart rate and the pulse frequency [6, 9, 10, 11].

This paper addresses aspects of the latter two problems. First, we describe an automated system for collection and validation of pulse oximetry data using signals produced by the pulse oximeter alone. This system is simple, portable, and requires no calibration. Second, in 10 acutely ill infants, each studied continuously for 16 hr, we use the new system to document the variability in oximetry data within each consecutive 15-min period. Our validation process shows that the oximetry results selected as valid using the new method are equivalent to those from the conventional "compared to the electrocardiogram (ECG)" method. Thus, our system produces results similar to more conventional systems, but with a simpler apparatus.

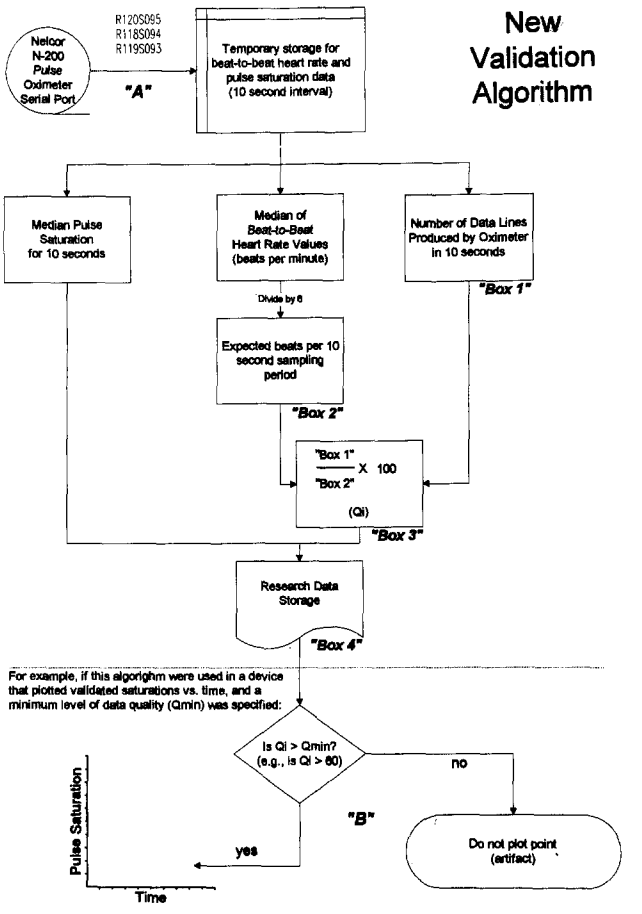

Fig. 2. Validation algorithm for new system. Lines of data (A), composed of heart rate calculated beat-to-beat and SpO_2, are acquired from the oximeter and stored for 10 sec. Next, the computer calculates and records the median SpO_2, median heart rate in beats/min, and the number of lines of data for each 10-sec interval (Box 1). The number of heartbeats expected per 10-sec interval is calculated from the median (Box 2). The ratio of Box 1 to Box 2 is calculated (Q_i in Box 3) and stored (Box 4). If the ratio exceeds the threshold Q_{min} (B) being tested, the data are accepted.

METHODS AND MATERIALS

Evaluation of data obtained from oximeter alone

The Nellcor N-200 (Nellcor Inc., Hayward, CA) pulse oximeter detects pulsatile waveforms, and can calculate estimated heart-rate and pulse saturation data for each detected pulse. These data packets can be collected at the standard serial port on the back of the monitor.

The data packets produced by the oximeter follow the format:

RxxxSyyyCRLF

where xxx is the heart rate, yyy is the pulse saturation, R and S are capital letters, CR is a carriage return, and LF is a line feed [12].

For these studies, the Nellcor N-200 was adjusted to output the "beat-to-beat" data packets described above by setting its DIP SWITCH to the appropriate positions (2, 4, 7, and 8 down; 3 and 5 up). The output from the monitor was sent via a serial null modem cable [13] at 1200 baud (8 data bits, 1 stop bit, no parity) to an IBM PC-compatible microcomputer. The optional ECG input to the oximeter was not used; cardiotachometer signals used for comparison purposes were sent directly to the microcomputer (Fig 1).

Figure 2 demonstrates how the acceptability of the

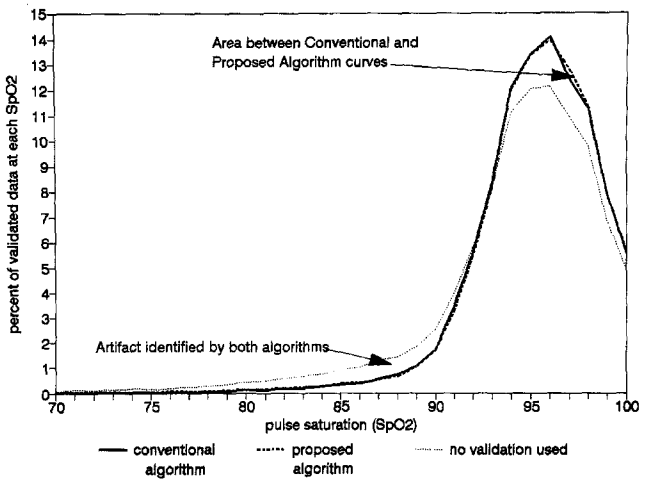

Fig. 3. Distribution of validated oximetry data using conventional and proposed algorithms. The X axis is the median SpO_2 from the 10-sec data acquisition intervals. The Y axis is the percentage of all validated SpO_2 corresponding to each median SpO_2. Using either the conventional or the proposed algorithm, e.g., 14% of all data validated occurred with a mean SpO_2 of 95%; 2% of all data validated occurred with a mean SpO_2 of 90%. Data represent points from 36,130 10-sec intervals validated using the conventional algorithm [57,600 − (57,600 × 0.373)] and the 40,926 10-sec intervals validated using the new algorithm [57,600 − (57,600 × 0.289)]. For comparison, a curve representing all data (not screened by any validation algorithm) is also given.

SpO_2 recorded is validated using the new algorithm. Each time a pulse is detected, a line of oximeter data (see "A" in Fig 2) is produced by the oximeter. The equation used for evaluation of oximetry data quality (Q) is:

$$Q_i = [(P \times 60) / (H \times I)] \times 100,$$

where Q_i = quality of oximeter data collected during the time interval, P = number of lines of data (pulses) received per interval (see Fig 2, Box 1), H = median value of the heart rates provided via the oximeter port for each time interval (see Fig 2, Box 2), 60 = seconds per minute, and I = the data collection interval. We used a 10-sec interval length, because this duration has been shown to be adequate for pulse oximetry data [14].

Q_i is similar to the monitor's pulse detection efficiency; a value of 100 indicates that 100% of pulses were detected and deemed adequate for saturation calculation during that interval of time. However, since the monitor rarely detects all pulses, simply validating only those intervals with Q_i = 100 would cause rejection of an excessive amount of useful data. Therefore, we sought a minimum acceptable Q_i, which we will call Q_{min}.

An acceptable Q_{min} for the proposed technique would lead to oximetry data sets that, over a long period of time, would have a distribution of saturation values similar to the distribution obtained using the conventional algorithm (Fig 3). We empirically determined the optimal Q_{min} value by repeatedly evaluating the pulse saturation distributions using the new technique and comparing them to the distributions obtained using the conventional technique.

Since Q_i is an indicator of the monitor's ability to detect a useful pulsatile signal, we calculated this value for each 10-sec interval. All data from each 10-sec interval that produced a Q_i below the trial Q_{min} (or otherwise did not meet the secondary criteria described below) were considered artifact.

Two examples, following the outline shown in Figure 2, may better illustrate the steps used to obtain and apply the Q_i. Box 1 in Figure 2 represents the number of pulses detected based on the lines of data generated by the oximeter. Let us assume that 20 lines (pulses) were recorded for a given 10-sec interval. Let us also assume that the median of the beat-to-beat heart rate was 120 beats/min. Dividing 120 by 6 (see Box 2 in Fig 2) yields a value of 20. Q_i (see Box 3 in Fig 2) for this 10-sec interval would be 100. For the second example, let us assume that the Box 1 value is only 10, but that the median heart rate is still 120 (this would occur when the oximeter is not detecting pulses well, due to, for example, motion artifact). The Box 2 value would still be 20; but, Q_i would be only 50. For this example, if Q_{min} were $\geq$51, then the data from this second interval would be considered artifact.

The proposed algorithm is analogous to watching the "bouncing bar" or plethysmographic display on the oximeter. If the bar "bounces" rhythmically, the oximeter is said to be "picking up" a good pulsatile signal. Each pulse detected results in a beat-to-beat data packet. Therefore, in general, the better the quality of the pulsatile signal, the greater the number of beat-to-beat data packets (at a given heart rate). Hence, a count of these beat-to-beat data packets becomes the basis of the proposed validation algorithm.

Heart-rate data from cardiotachometer to be used for comparison to conventional validation technique

The conventional method to verify pulse oximetry data compares the heart rate from the pulse oximeter to the heart rate from a bedside cardiotachometer [10,15]. In general, when these heart rates differ by 5 beats/min or less, the simultaneously obtained pulse saturation is considered reliable [6,9]. This is the primary criterion for reliability. Secondary (minimal) criteria for validity, for

Table 1. Study Population

Number	10
Gestational age (weeks)	34.3 ± 4.5 (median 33.5)
Age (days)	3.4 ± 3.2 (median 2)
Birth weight (gm)	2496 ± 726
Sex (M : F)	5 : 5
Assisted ventilation (n)	5
Oxygen therapy (n)	7

both the conventional and proposed algorithms, include: (1) mean pulse saturation must be ≥60; and (2) mean heart rate ≥60 and ≤250 beats/min. The conventional algorithm includes an additional secondary criterion: At least 5 pulses must be detected in the 10-sec interval. (The primary criterion is the primary test for data quality. The secondary criteria exclude data that are obvious artifacts that occasionally pass the primary criterion.)

The new system will allow validation of oximeter data without requiring a separate ECG signal. However, to determine if it is as reliable as the "compared to the ECG" method, we used heart rate data from a bedside neonatal monitor (cardiotachometer) (78801, Hewlett-Packard, Palo Alto, CA). Its analog signal was digitized using an analog/digital (A/D) converter (DAS-100, Digital Air Systems), which was also attached to the microcomputer (see Fig 1).

Data acquisition and storage

Each line of the text file written by the microcomputer represented 10 sec of the recorded data and contained: the median heart rate and median pulse saturation from the pulse oximeter, the Q_i, and the heart rate from the cardiotachometer. All comparisons of conventional and new algorithm results used data thus recorded.

Software controlling the data acquisition was written by one of the authors (DS) in the C computer language (Microsoft Corporation, Redmond, WA), using an asynchronous communications library (Blaise Computing, Inc.). In addition, this software also controlled the DAS-100 as it digitized the cardiotachometer heart rate. All data were recorded in a computer disk file every 10 sec. (See Fig 2, Box 4.)

Newborn infants studied

Ten acutely ill, but stable, infants (Table 1) with respiratory distress were studied if they met the following criteria: birth weight, >750 g; age, 1 to 14 days; hospitalized in a tertiary neonatal intensive care unit; and monitored by a Nellcor N-200 pulse oximeter. Infants were excluded if they received muscle relaxants or deep sedation, as these would lessen movement and spuriously reduce our ability to determine if the system can deal with movement artifact. Infants with cyanotic congenital heart disease or other major congenital anomalies were also excluded. No infant was hypotensive during the study. Pulse oximetry probes were generally placed on the infant's foot or were otherwise distal to the ductus arteriosus.

All infants were studied for a minimum of 16 hr. No alterations in patient care were made for the purposes of data collection. Also, since the system did not affect the oximeter's display, no alterations in care were made because of the data collection.

The first 16 hr of data available from each subject were used in subsequent analyses. For 6 infants, this was the first 16 hr of data recorded. For 4 infants, data from the 17th hour of recording were substituted for episodes where the monitor was disconnected (two episodes) or where full clinical observations were not recorded (two episodes).

Study of variability in infants: further guidelines for data selection and presentation

As we were interested in the spontaneous fluctuations of oxygen saturation in the hospitalized infant, we did not evaluate 30 min of data collected during and immediately after each F_iO_2 and/or ventilator adjustment, resulting in rejection of a median of 2.5% of each infant's recording (25th and 75th percentiles: 0.0 to 4.7%). After culling data obtained shortly after changes in ventilatory support, the data set was divided into 15-min periods. Excluded from analysis were fragments resulting from division of odd lengths of data into 15-min periods, and periods with less than 25% validated data, as determined by the new algorithm using the optimal Q_{min} (60, see below). The total percent time excluded for both of these reasons was small (median per patient, 1.7%; 25th and 75th percentiles, 0.4 to 10.8% of each infant's time). The mean SpO_2 the 5th percentile of all validated SpO_2 readings, along with the 95th percentile, were calculated for each of the remaining 15-min periods (i.e., for each of 551 periods).

To describe how the pulse saturation variability may be related to the average saturation (Fig 6), the periods were grouped by their associated mean saturation values (integers, for example, 88, 89, 90, ..., 99). For each group, the difference from means of the 5th and 95th percentiles was calculated. Linear regression (MINITAB) was used

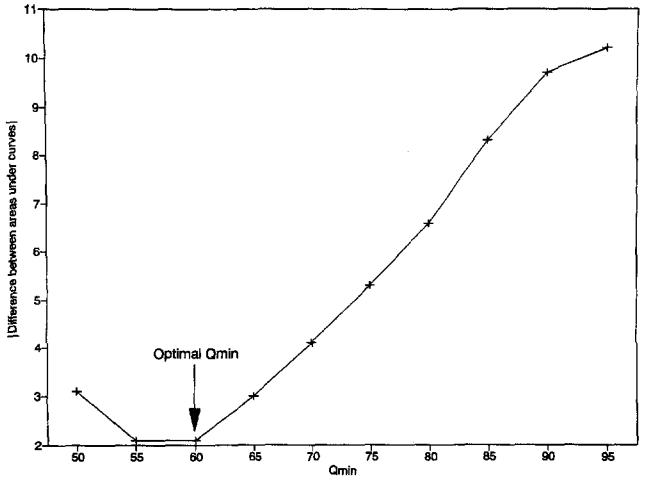

Fig. 4. Difference between the conventional algorithm and the proposed algorithm (using different Q_{min} values). The area between the conventional and proposed algorithm curves in Figure 3 is plotted against the trial Q_{min} values used. The curves most closely approximate at the optimal Q_{min} value of 60.

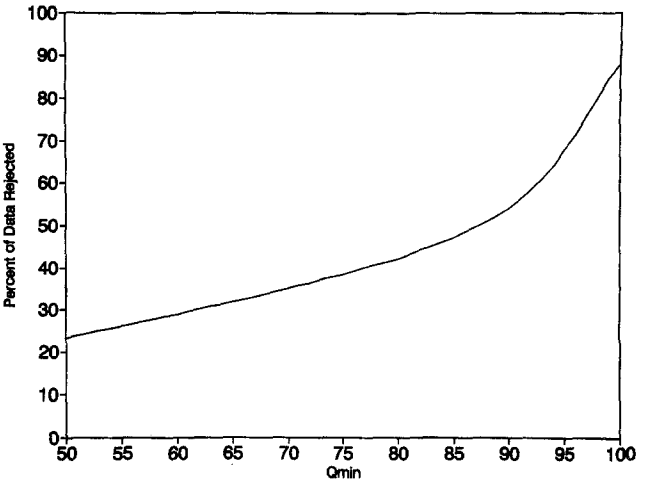

Fig. 5. Data rejection rate of proposed algorithm using different Q_{min} values. As Q_{min} increases, so does the rate of data rejection. Note that if Q_{min} = 100, 87% of the oximetry data is rejected. However, at the optimal Q_{min} value of 60, only 28.9% of data is rejected.

to determine if the range of saturation over these 15-min periods increased as the mean saturation decreased.

RESULTS

We used pulse oximetry and cardiotachometer data from a total of 160 hr recording time, comprising 57,600 10-sec intervals, in the 10 infants studied.

Comparison of oximetry data sets using the conventional and new validation algorithms

The distributions of the validated readings for both the conventional algorithm and the new algorithm are shown in Figure 3. Of all 10-sec intervals considered using the conventional algorithm, 37.3% were rejected as artifact by the "compared to the ECG" method. For the new method, after empiric trials of Q_{min} values, a threshold of 60 was found to produce a distribution curve of validated readings that nearly superimposed over the conventional algorithm plot as seen in Figure 3. The results of these empiric trials are depicted in Figure 4, which shows the area between the conventional and proposed algorithm curves (see Fig 3). The area between the conventional and proposed algorithm curves reaches a minimum at Q_{min} = 60. Using the proposed algorithm and Q_{min} = 60, 28.9% of readings were rejected as artifact with the new technique (Fig 5). No improvement in the match between the two curves was added by higher Q_{min} values that would justify rejecting a higher percentage of the data.

Variability in saturation ranges as mean saturation changes

The average pulse saturation range for each mean saturation is given in Table 2. We observed that the pulse saturation range (defined here as the difference between the 5th and 95th percentiles) increases as the mean saturation decreases ($p < 0.001$), as illustrated in Figure 6.

DISCUSSION

Maintaining SpO_2 at levels within ranges consistent with adequate tissue oxygenation and reduced oxygen toxicity to the lung and the developing retina is a primary goal of neonatal intensive care. However, prolonged studies of the "adequacy" of oxygenation using pulse oximeters have been hampered because of excessive artifact, particularly when the infant moves [15]. We describe a system that will simplify the recording of SpO_2 in infants by establishing the validity of the recorded measurements without excessive data rejection. This system requires only a single cable between a commercially available personal computer and the oximeter. We thus avoid the complexity of a special interface between the computer and an A/D converter that is receiving cardiotachometer data. The results agree (see Fig 3) with measurements validated using algorithms

Table 2. Pulse Saturation Range Increases as Average Saturation Decreases

Average Saturation	Number of Periods	Percentiles		5th–95th Percentile Range	Range Relative to Mean[a]	
		5th	95th		Below	Above
99	20	96.6	99.7	3.1	−2.4	0.7
98	54	95.7	99.4	3.8	−2.3	1.4
97	71	94.0	98.8	4.8	−3.0	1.8
96	83	93.2	98.0	4.9	−2.8	2.0
95	66	92.5	96.8	4.4	−2.5	1.8
94	82	91.0	96.1	5.1	−3.0	2.1
93	54	88.8	95.3	6.5	−4.2	2.3
92	48	87.3	94.5	7.2	−4.7	2.5
91	33	85.2	94.2	9.0	−5.8	3.2
90	10	80.5	94.2	13.7	−9.5	4.2
89	10	79.9	93.7	13.8	−9.1	4.7
88	8	72.7	95.4	22.6	−15.3	7.4

[a] As seen in Figure 4.

that compare oximeter pulse rate display to electrical heart rate.

Our results show that, in stable infants, over periods as short as 15 min, SpO_2 will be as much as 6 to 10% above or below the mean saturation displayed by the oximeter. Stated another way, a target SpO_2 range of, for example, 90 to 93% will quite predictably include SpO_2 ranging from 81 to 95%. How nurses or respiratory care personnel caring for the infant respond to these perhaps briefly displayed fluctuations has an as yet undefined effect on attempts to adjust or wean ventilatory support. Moreover, our results suggest that the results of clinical epidemiologic studies of the relationship between outcome and the usual manually recorded SpO_2 will be affected both by the duration of SpO_2 recording and the variability about the mean.

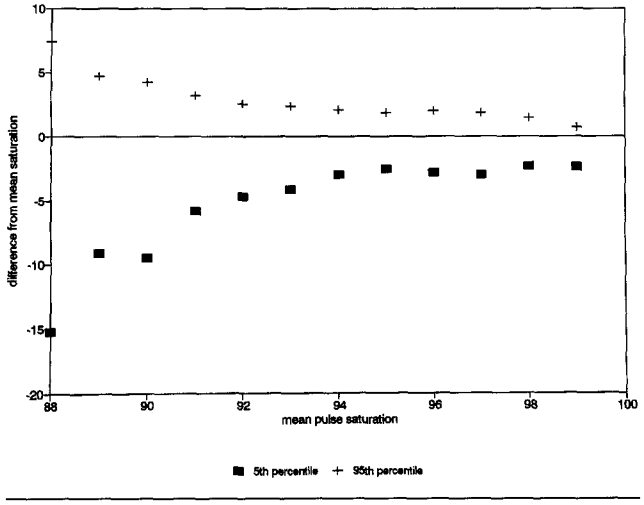

Fig. 6. Changes in width of range of SpO_2 as saturation changes. This figure shows data from all 10 patients. The saturations on the X axis are the mean, in integers, of the SpO_2 for 551 15-min intervals. The Y axis is the absolute percent difference from the mean. The upper curve is the mean of the 95th percentile and the lower curve is the mean of the 5th percentile of differences from the mean saturations within each 15-min interval. The range (95th percentile minus 5th percentile) about the mean widens at lower saturations.

Whether the variability we determined is only another type of artifact is a fair question to raise. While there have been some historical concerns for the accuracy of oximeters at lower saturations [16,17], the precision is good in the range of SpO_2 at which we saw considerable variability within subjects. There is no reason to believe that readings at low SpO_2 are less repeatable than at higher values of SpO_2. Therefore, we believe that the variability demonstrated in Figure 6 represents reliable measurements of SpO_2.

The increased variability in saturations we observed begins near saturations where the oxyhemoglobin dissociation curve steepens. This likely explains a good deal of the variability seen. Although the shape and the steepness of the oxyhemoglobin dissociation curve is known by clinicians, the variability in SpO_2 near the transition to a steeper curve is, perhaps, less widely appreciated.

Two other technical explanations may be made for this increased variability at low saturations. First, hypoxemic infants may have increased catecholamines and vasoconstriction. Vasoconstriction leads to a lower amplitude pulse signal, resulting in a poor signal-to-noise ratio. The relative increase in noise may appear as increased variability. Second, the oximeter uses the relative tissue absorption of infrared and red light to calculate SpO_2. At low saturations, there is a greater fraction of reduced hemoglobin, which strongly absorbs red light

(nominal 660 nm), leaving less to scatter in tissue. Infrared light is less well absorbed, leaving more to scatter in tissue. Since penetration is inversely related to scatter, there is an imbalance in the depth of penetration of the two light wavelengths. This may lead to error as the SpO_2 is calculated and, therefore, greater observed variability.

Our study was not designed to analyze all potential causes of SpO_2 fluctuations in stable sick newborns. Nevertheless, we are quite confident that movement artifact cannot fully explain the fluctuations seen when using the new algorithm. We are confident because the data from the new and the conventional algorithms are so similar (see Fig 3), and movement artifact would lead to rejection of data by the conventional algorithm. Therefore, it would be unlikely that the data accepted by the new algorithm would be as comparable (see Fig 3) to the conventional data if the new data were reflective of artifact that had been rejected using the conventional algorithm. Furthermore, acute changes in SpO_2 due to changes in mechanical minute ventilation or FiO_2 do not in and of themselves explain the variability observed, because data obtained for 30 min after ventilator setting changes were not analyzed. We are currently considering studies using continuous video recordings to document patterns of infant behavior and handling that may contribute to changes in SpO_2 without altering the acceptability of the pulse signal. We have also undertaken studies to determine if SpO_2 variability differs between the acute and recovery phases of neonatal respiratory distress syndrome.

We chose the conventional method as our standard because it is used commonly in clinical practice. Other "gold standards," such as the co-oximeter, cannot provide continuous saturation readings for comparison.

We must emphasize that this system was developed as a tool to help interpret prolonged (e.g., >12 hr) unattended recordings of pulse oximetry data. Since it does not detect momentary desaturations (e.g., 5 sec), and since it makes no provision for periods of monitor artifact other than to label it as such, this system cannot replace the current "low saturation" alarm on the oximeter itself.

We must also emphasize that the techniques described are specific to the Nellcor N-200 and its internal software that produces the lines of data in the current format used to calculate Q_i. In particular, how the oximeter determines the rate of acquisition of line-by-line heart rate and saturation are matters of proprietary concern that are unpublished. Provided that the beat-to-beat data continue to be available from new and different oximeters, this problem may be addressed by updating Q_{min} using the techniques described here.

The necessary equipment for future use of this system is similar to that used in this study (see Fig 1), except that the cardiotachometer and the A/D converter are unnecessary and may be omitted.

In summary, we have described a method for validating SpO_2 data using an oximeter and a personal computer. We have compared the results to those obtained using conventional algorithms, and found them to be virtually the same, when an empirically derived minimum level of quality was used. Our results during 16 hr of recording in each of 10 ill newborns show the considerable variability of SpO_2 over short (15-min) intervals.

GLOSSARY

DIP SWITCH	Set of small electrical switches.
SaO_2	Arterial oxygen saturation of hemoglobin.
SpO_2	Oxygen saturation estimated by pulse oximetry.

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APPENDIX: BASIC COMPUTER LANGUAGE VERSION OF PROGRAM

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10 REM          BASIC Language Version of Neonatal Pulse Oximetry Data Acquisition and Validation Program
20 REM Program runs using BASIC interpreters supplied with MS-DOS (Microsoft Corp.) (e.g. DOS versions 2.11 and 6.2)
30 OPEN "COM1:1200,n,8,1" FOR INPUT AS #1 LEN = 8192: CLS
40 DIM DATAINPUT$(100), HRARRAY%(400), SATARRAY%(100)
50 PRINT "PULSESAT       Neonatal Pulse Oximetry Data Acquisition and Validation Program"
60 PRINT "For research only; no warranties. See article by Sprague/Richardson/Baish/Kemp"
70 PRINT "Connect computer COM1 port to Nellcor N-200 using null modem.  Set N-200's DIP"
80 PRINT "switch: 2,4,7,8 down; 3,5 up. Don't use EKG input to N-200. For neonates only."
90 PRINT "This program may become invalid if N-200 has major changes.          June 1994": REM Used N200 version 2.7
100 INPUT "Enter data file name (will append existing files): ", FILENAME$
110 START = TIMER: LAST = START: DISCARD$ = INPUT$(LOC(1), #1): REM Start timekeeping, flush COM1 buffer
120 OPEN FILENAME$ FOR APPEND AS #2
130 PRINT "*** DATA ACQUISITION STARTED  (press ESC key to quit)  ": DATE$; " "; TIME$; " ***"
140 PRINT "Format:Seconds, HR, SpO2, Data Quality (Qi), (1=validated 0=artifact), comment"
150 WRITE #2, "PulseSat study started " + DATE$ + " " + TIME$ + "  Data file: " + FILENAME$
160 WRITE #2, "Format:Seconds, HR, SpO2, Data Quality (Qi), (1=validated 0=artifact),comment"
170 ON TIMER(1) GOSUB 590: TIMER ON: REM Check for press of ESC key (See subroutine at end of program)
180 REM ======= Beginning of main program loop =======  (Remember: in BASIC, X% means "the integer X", not X percent)
190    LINE INPUT #1, RAWDATA$: REM Read line of data from oximeter.  One line is produced with every pulse detected.
200    IF TIMER < LAST THEN LAST = LAST - 86400!: MIDNIGHT = MIDNIGHT + 1
210    WHILE TIMER > LAST + 10: REM --- Summarize and print results every 10 seconds (except last raw data line) ---
220        LAST = LAST + 10
230        READINGS% = 0
240        FOR I% = 1 TO NUMDATA%: REM Convert oximeter data (format: RxxxSyyy (xxx=HR, yyy=SaO2)) into HR% and SAT%.
250            IF LEN(DATAINPUT$(I%)) <> 9 THEN GOTO 330: REM Ignore garbled line of data (not correct length)
260            HR% = VAL(MID$(DATAINPUT$(I%), 3, 3))
270            SAT% = VAL(MID$(DATAINPUT$(I%), 7, 3))
280            IF HR% <= 0 OR HR% > 400 THEN GOTO 330: REM Ignore impossible data (probably garbled line of data)
290            IF SAT% <= 0 OR SAT% > 100 THEN GOTO 330: REM Ignore impossible data (probably garbled line of data)
300           HRARRAY%(HR%) = HRARRAY%(HR%) + 1: REM Store the HR% data this way to facilitate calculation of median
310            SATARRAY%(SAT%) = SATARRAY%(SAT%) + 1: REM Store the SAT% data this way for calculation of median
320            READINGS% = READINGS% + 1
330            NEXT I%
340        SUM% = 0
350        FOR I% = 0 TO 400: REM Calculate median heart rate
360            SUM% = SUM% + HRARRAY%(I%)
370            IF SUM% >= READINGS% / 2 THEN MEDIANHR% = I%: I% = 999
380            NEXT I%
390        SUM% = 0
400        FOR I% = 0 TO 100: REM Calculate median pulse saturation
410            SUM% = SUM% + SATARRAY%(I%)
420            IF SUM% >= READINGS% / 2 THEN MEDIANSAT% = I%: I% = 999
430            NEXT I%
440        FOR I% = 0 TO 100: SATARRAY%(I%) = 0: NEXT I%: REM Reset pulse saturation data array to zeros
450        FOR I% = 0 TO 400: HRARRAY%(I%) = 0: NEXT I%: REM Reset heart rate data array to zeros
460        REM Calculate the % of pulses detected by pulse oximeter. Given the heart rate (MEDIANHR%) and
470        REM  the number of pulses detected (READINGS%) over 10 sec, we can calculate the data quality (Qi).
480        IF MEDIANHR% > 0 THEN QI% = 100 * ((READINGS% * 60) / (MEDIANHR% * 10)) ELSE QI% = 0
490        REM If Qi >=60, and the secondary data checks are passed, then the SpO2 is validated.
500        IF QI% >= 60 AND MEDIANHR% <= 250 AND MEDIANSAT% >= 60 THEN VALIDATE% = 1 ELSE VALIDATE% = 0
510        IF VALIDATE% = 1 THEN COMMENT$ = "VALIDATED" ELSE COMMENT$ = "ARTIFACT"
520        WRITE (LAST + MIDNIGHT * 86400!) - START, MEDIANHR%, MEDIANSAT%, QI%, VALIDATE%, COMMENT$
530        WRITE #2, (LAST + MIDNIGHT * 86400!) - START, MEDIANHR%, MEDIANSAT%, QI%, VALIDATE%, COMMENT$
540        NUMDATA% = 0
550        WEND: REM ------- End of summary & print routine -------
560    REM Add most recent raw data line to DATAINPUT$() storage array (except if data array is unexpectedly full)
570    IF NUMDATA% <= 100 THEN NUMDATA% = NUMDATA% + 1: DATAINPUT$(NUMDATA%) = RAWDATA$
580 GOTO 180: REM ======= End of main program loop =======
590 REM This subroutine is executed every second to test for press of ESC key:  if ESC key was pressed, end program.
600 IF INKEY$ = CHR$(27) THEN PRINT "Data acquisition finished.": SYSTEM:  ELSE WHILE INKEY$ <> "": WEND: RETURN
```

SAMPLE PROGRAM DISPLAY:

```
PULSESAT       Neonatal Pulse Oximetry Data Acquisition and Validation Program
For research only; no warranties. See article by Sprague/Richardson/Baish/Kemp
Connect computer COM1 port to Nellcor N-200 using null modem.  Set N-200's DIP
switch: 2,4,7,8 down; 3,5 up. Don't use EKG input to N-200. For neonates only.
This program may become invalid if N-200 has major changes.          June 1994
Enter data file name (will append existing files): SAMPLE
*** DATA ACQUISITION STARTED  (press ESC key to quit)  06-01-1994 15:00:00 ***
Format:Seconds, HR, SpO2, Data Quality (Qi), (1=validated 0=artifact), comment
10,120,95,100,1,"VALIDATED"
20,120,93,50,0,"ARTIFACT"
Data acquisition finished.
```

SAMPLE DATA FILE:

```
"PulseSat study started 06-01-1994 14:00:00  Data file: SAMPLE"
"Format:Seconds, HR, SpO2, Data Quality (Qi), (1=validated 0=artifact),comment"
10,120,95,100,1,"VALIDATED"
20,120,93,50,0,"ARTIFACT"
```

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