AUTOMATED CHARTING OF PHYSIOLOGICAL VARIABLES IN ANESTHESIA: A QUANTITATIVE COMPARISON OF AUTOMATED VERSUS HANDWRITTEN ANESTHESIA RECORDS

Jos G. C. Lerou, MD, PhD,
Ris Dirksen, MD, PhD, Marc van Daele, MD,
Gerard M. M. Nijhuis, MD,
and Jan F. Crul, MD, PhD

Lerou JGC, Dirksen R, van Daele M, Nijhuis GMM, Crul JF. Automated charting of physiological variables in anesthesia: a quantitative comparison of automated versus handwritten anesthesia records.

J Clin Monit 1988;4:37–47

ABSTRACT. Eight physiological variables—tidal volume, breathing rate, end-tidal carbon dioxide fraction, oxygen fraction in the anesthetic circuit, oxygen saturation by pulse oximetry, systolic and diastolic blood pressure, and heart rate—recorded on-line by a commercially available automated system were compared with the same variables recorded on handwritten anesthesia records. We quantified the differences between the automated and handwritten records generated from the same 30 patients (2,412 minutes of general anesthesia for elective eye surgical procedures). Considering the design of the study, we claim that the differences between both records were caused by the incompleteness or inaccuracy of the handwritten records, except in two instances. The amounts of missing or erroneous data for these eight physiological variables were expressed as fraction ("error fractions") of the time being recorded, designated EF_m and EF_e, respectively. For the first five variables the EF_m on the handwritten records ranged between 0.23 and 0.31, and the EF_e ranged between 0.01 and 0.06. For the last three variables the EF_m range was 0.08 to 0.13, and the EF_e range was 0.05 to 0.11. Most of these missing or erroneous data occurred during the period of induction (first 15 minutes) and at the end of the case (last 10 minutes). The EF_m and EF_e during induction had increased to 0.62 and 0.26, respectively, and to 0.76 and 0.06, respectively, at the end of the case. Erroneous data were observed on the automated records for the tidal volume during induction (EF_e = 0.0044) and for the oxygen fraction during maintenance (EF_e = 0.0024). The effect of averaging by the recordkeeper is discussed. The results of this study indicate the clinical relevance of automated record keeping.

KEY WORDS. Records: anesthesia. Equipment: computers. Monitoring: physiologic.

While performing a complex array of tasks, the anesthesiologist is also responsible for maintaining an anesthetic record. This record provides valuable reference data for assessing considered intervening actions and is also a medical and legal requirement. Especially during busy anesthetic periods, record keeping has received a low priority compared with direct patient care. Thus, a problem area may exist because the anesthesiologist has to take care of the patient and at the same time has to add important information to a chart.

Advances in technology have made new instruments available to free the hands of the anesthesiologist. Mechanical control of ventilation has replaced manual bag squeezing during long procedures, and the noninvasive automatic blood pressure (NIBP) monitor has already found widespread acceptance in replacing intermittent manual sphygmomanometry. Further automation of the tasks of the anesthesiologist seems to be a line of development for the future.

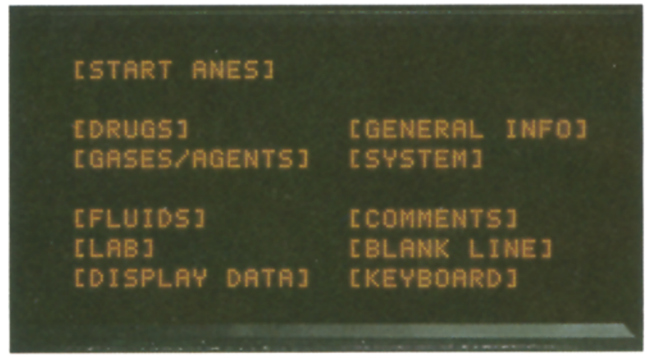
From the Institute for Anesthesiology, University Hospital Nijmegen, Geert Grooteplein zuid 10, 6500 HB Nijmegen, The Netherlands.

Received Feb 2, 1987, and in revised form Aug 3. Accepted for publication Aug 20, 1987.

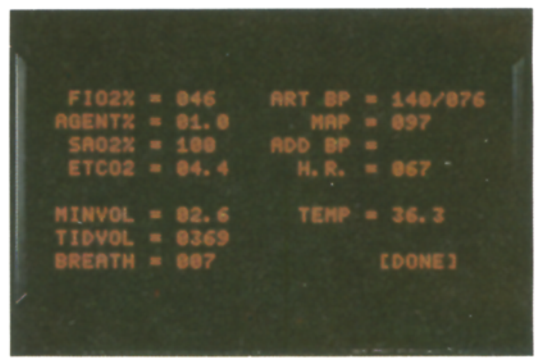
Address correspondence to Dr. Lerou.

Record keeping has been done by hand for almost a century [1]. Obvious benefits of automated record keeping have been claimed, and those recently outlined by Smith [2], include: (1) more accurate data recording, (2) a decreased need for manual charting during crises or other busy periods of anesthetic care, (3) a centralized display on which all data, current and trended, are available on one common screen or other display, and (4) a legible printed record at the end of the case. However, the proposed benefits have to be balanced against possible disadvantages of automated record keeping [3]. These include: (1) less awareness of the time course and detail of anesthetic events, and (2) removal of the physician from the closed loop control of the anesthetic.

Although some of the proposed benefits have been substantiated [4], factual data are scarce and apply only to prototype systems developed in individual institutions. A commercially available automated record keeper, the Ohmeda automated anesthesia record keeper (AARK) integrated into the Modulus II anesthesia system, was used for the present study. This study was designed to compare handwritten records produced at our hospital during clinical practice with computerized records of the same cases. The investigation was limited to the values of those physiological variables that are automatically acquired, displayed, and charted by the AARK.



A



B

Fig 1. The soft key touchpanel of the automated anesthesia record keeper serves both as a computer-human interface and centralized display unit (CDU). (A) The basic touchpanel selections. Selecting the "[DISPLAY DATA]" notation changes the panel into a CDU. (B) The CDU displays the values of the variables automatically recorded by the record keeper.

METHODS AND MATERIALS

Thirty patients admitted to our hospital for elective eye surgical procedures were included in the study. General anesthesia was administered by three staff members or six senior residents under supervision. For each patient, two anesthetic records were made. One was the standard handwritten record as used in our hospital; the other was the record prepared by the AARK.

Equipment

The AARK has three components: (1) a soft key touchpanel combining the functions of computer-human interface and central display, (2) a central processing unit (CPU), and (3) a printer producing the automated record. All three components are integrated into the structure of the anesthesia system (Ohmeda Modulus II).

The AARK is accessed by touching notated areas on the touchpanel mounted on the absorber post. Touching a specific notation is recognized by the microprocessor, and the function specified by the notation is performed. The user receives confirmation of entry from an audible click and display of the requested data. Selecting the "display data" notation on the main menu changes the panel into a centralized display unit (CDU) on which the values of the automatically recorded variables are shown (Fig 1). The user can also enter data manually through the touchpanel by calling up various screen menus and making appropriate selections from lists presented on screen.

Mounted on the back of the Modulus II system, the CPU processes the signals provided by the monitoring devices used in this study: an Ohmeda 2110 NIBP monitor, an Ohmeda 5400 volume monitor, an Ohmeda 5100 oxygen analyzer, an Ohmeda Biox 3700 pulse oximeter, a Datex Normocap carbon dioxide analyzer, and a Hewlett-Packard 78353B electrocardiogram (ECG) monitor. Data from the first two monitors are acquired through serial communication lines. The signals from the other monitors are fed into the AARK through a multiplexed analog-to-digital converter. The heart rate is provided by the ECG monitor. Figure 2 shows how the signals from the monitors are processed by the CPU. The processed data are then sent to the two

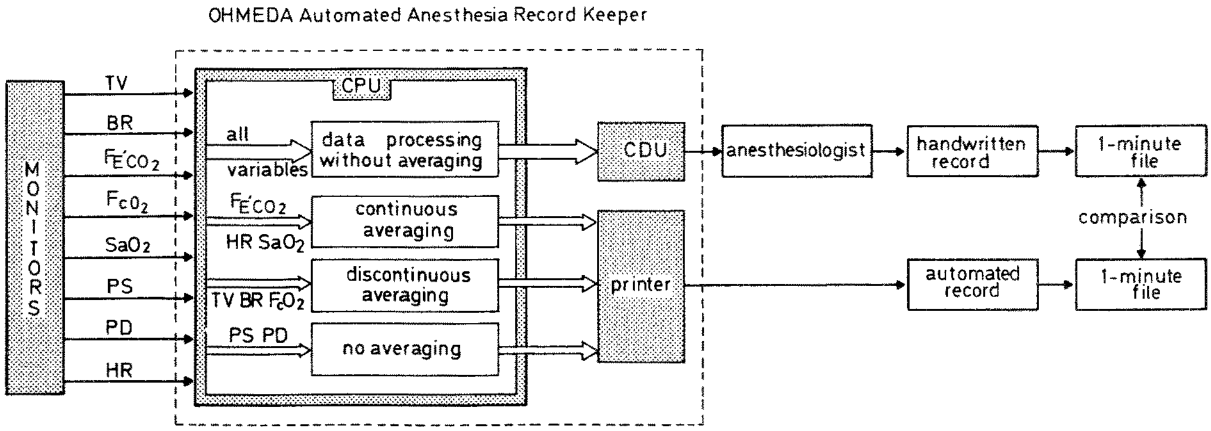


Fig 2. Block diagram of the data flow. Continuous averaging: *the values of these variables are stored over a one-minute period. The central processing unit* (CPU) *then calculates their one-minute average values, which are used to update the computerized record once per minute.* Discontinuous averaging: *the values of these variables are stored for each last minute in a five-minute period, and the average values calculated by the CPU are updated at five minute intervals.* No averaging: *systolic and diastolic blood pressure are updated on the computerized record after each measurement. Note that the anesthesiologist used the values shown on the centralized display unit* (CDU) *to complete the handwritten record, and not those shown on the various monitors.* (TV = *tidal volume;* BR = *breathing rate;* $F_{E'CO_2}$ = *end-tidal CO_2 fraction;* F_{cO_2} = *oxygen fraction in the anesthetic circuit;* SaO_2 = *oxygen saturation by pulse oximetry;* PS = *systolic blood pressure;* PD = *diastolic blood pressure;* HR = *heart rate.)*

output devices of the AARK, i.e., the CDU and the printer.

The printer generates the computerized record in a format familiar to anesthesiologists (210 mm by 280 mm). Figure 3 illustrates the first page of a case record; additional pages are automatically generated by the AARK. Tidal volume, breathing rate, and oxygen fraction are presented numerically; the other variables are plotted in graph form. The operational components of the thermal printer are located under the tabletop of the anesthesia system. The paper therefore scrolls backward to be updated and subsequently scrolls forward to be presented on the top of the anesthesia system. The record itself is clearly visible through a protective Plexiglas cover. Access for manual entry is obtained by lifting this cover. Plotting accuracy is ±0.5% of the distance between the "reference line," i.e., the top line on the graph portion of the record, and the plotted value (personal communication, Ohmeda, July 1987). A small mark at the reference line of the chart, printed at each update, allows the anesthesiologist to verify the correct positioning of the printer paper throughout the anesthetic: one mark per one-minute period from the start of

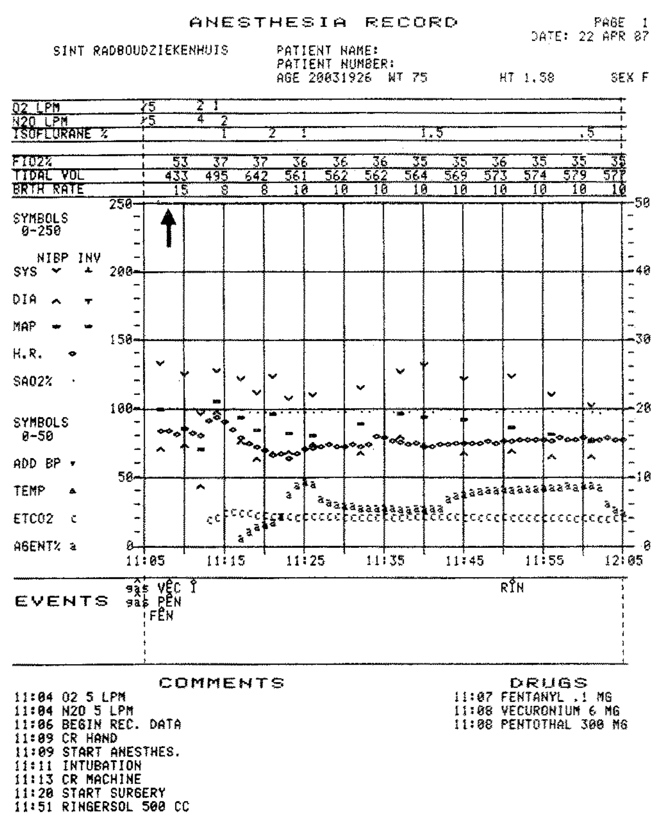


Fig 3. Sample of a computer-generated record (patient name and number removed), showing the first hour of the procedure. The arrow points to one of the small marks that allows verification of the correct positioning of the printer paper. One mark is printed at each update. The marks must coincide with the reference line, i.e., the top line of the graph portion joining 250 *and* 50. *The arrow points to the mark that was printed on the second update of the record. (Isoflurane was measured by mass spectrometry, and the record was scaled from 0 to 5%.)*

data recording can be seen on the sample record shown in Figure 3.

The AARK has a built-in electrical filtration system to remove most electrical disturbances that can distort readings. The AARK also detects and rejects certain types of artifacts that occur during serial communication with monitors and analog waveform processing. The serial communication software is designed to accept data streams from a variety of manufacturers' monitors. If the monitor outputs a known signal or pattern in the presence of artifact, the AARK will reject the signal. Similarly, if the incoming data do not match specified patterns, they are rejected. Analog monitor signals, which are rapidly varying waveforms, require the use of processing algorithms to detect peaks and valleys, for example, in end-tidal carbon dioxide. The end-tidal carbon dioxide algorithm rejects any signal containing frequencies higher than 1 Hz (personal communication, Ohmeda, July 1987).

Methods

We studied 30 patients. One hour after preanesthetic medication, patients were brought into the operating theater. An intravenous route was obtained, and the patient was connected to the ECG and NIBP monitors. The pulse oximeter was applied to a finger of the arm opposite the arm on which the blood pressure cuff was applied. General anesthesia was induced when the initial values of blood pressure, heart rate, and oxygen saturation had been measured. The anesthetic method was determined individually by the anesthesiologist. The patients were artificially ventilated during the anesthetic procedure and monitored by the equipment outlined above.

Eight variables were included in the study: tidal volume, breathing rate, end-tidal carbon dioxide fraction, oxygen fraction in the anesthetic circuit, oxygen saturation by pulse oximetry, systolic and diastolic blood pressures, and heart rate. The recording of these eight variables is fully automated in the AARK. Relatively little effort by the anesthesiologist is required to record these data. Blood pressure was measured at one-minute intervals between measurement cycles for the first 15 minutes of the anesthetic. Thereafter the interval was set to four minutes to avoid long periods of pressure on the ulnar nerve [5]. At the one-minute and four-minute intervals the AARK plots the blood pressure at two-minute and five-minute intervals, respectively, because the measurement cycle itself takes 30 to 60 seconds. If needed, more frequent cycles of the NIBP were manually activated.

The values of the eight variables are presented on the CDU (see Fig 1), and were used by the anesthesiologist to update the handwritten record (see Fig 2). Thus, the anesthesiologist did not use the values displayed on the various monitors to complete the handwritten record. The computerized record was covered to prevent the anesthesiologist from viewing and using those data. The anesthesiologist used the clock in the NIBP monitor, which had been synchronized to the clock of the AARK, for time notations and entries on the handwritten record. The clock also displayed the elapsed time since the last measurement of the blood pressure.

All anesthesiologists were made aware of the purpose of the study. They knew that their records would be compared with the computerized records. However, they were unaware of the details of the methodology used to compare both records. They were not informed about the variable (by variable, and by time) recording intervals of the AARK. Values were recorded on the handwritten chart at intervals chosen by the anesthesiologist assigned to the case. Thus, they completed their handwritten records according to their own habits. Relevant intraoperative events necessitating manual data entry on the touchpanel were recorded by a research assistant to avoid diverting the attention of the anesthesiologist.

Statistics

In our attempt to make a quantitative comparison between a computer-generated chart and a chart produced by a human under the conditions of routine clinical practice, we were confronted with the following circumstances. Basically, the machine updates its record at regular intervals. Extra blood pressure measurements are occasionally added to the preprogrammed measurements after manual activation of the NIBP monitor. The anesthesiologist, however, was allowed to complete the handwritten record at arbitrary moments and therefore irregular intervals. Hence we had to solve two basic problems.

The first problem was to answer the question: how often should an anesthesiologist be expected to record data on a handwritten record? No internationally accepted standards exist to answer that question. Anesthesiologists are familiar with a particular layout of their manually kept charts and have their own habits of recording the values of various physiological variables at certain intervals. We did not want to change either the layout of our standard records or the recording habits of our group of anesthesiologists. For example, we could not expect the anesthesiologist to record, every minute, a stable end-tidal carbon dioxide fraction (as the AARK does). However, it is fair to expect that the anesthesiologist would record marked changes in the values of the variables. To allow a quantitative comparison we therefore assumed that the value of a variable remained unchanged until the anesthesiologist entered another value on the handwritten chart. This convention, as well as the use of the standard handwritten record, properly values the normal pratice of our group of anesthesiologists. However, the convention was applied only between the first and last entry on the manually kept chart. Assuming that a variable remained constant, even after the last entry on the chart, would have prevented us from evaluating the actual manual data entry at the end of the cases.

For the actual comparison, we entered by hand the values of the eight variables found on both the manual and the automated record into spreadsheet files, recording one value for each one-minute period. Only end-tidal carbon dioxide, oxygen saturation, and heart rate are updated at one-minute intervals on the automated chart. Tidal volume, breathing rate, and oxygen fraction are updated at five-minute intervals, whereas blood pressure data may occur at irregular intervals because of the possible manual activation of the NIBP monitor (see Fig 2). When entering the values from both records into the spreadsheet files we therefore applied our convention to both the handwritten and the automated record. Thus for both charts the first convention was: if no value was present for a certain one-minute period, the previous value was reentered, but only between the first and last entries found on the records. Figure 4 illustrates the result of applying this first convention on the blood pressure data.

The second problem arose when we observed that some manually kept records showed blood pressure and heart rate data at times when automated data acquisition had not begun or had already been terminated. The AARK inevitably marks the start of automated data acquisition with the message "BEGIN REC. DATA" and the real time (see Fig 3). The end of automated data acquisition is marked on the record with the message "END RECORD" and the real time, and the values of the variables are no longer displayed on the CDU. Thereafter, the anesthesiologist no longer has any information from the CDU with which to update the handwritten chart. Thus, at certain times, such as during induction, when anesthesiologists are often too busy to record data, they most likely committed the data to memory and entered it after the fact in the period after the induction and after the end of the case, reconstructing the course of events on a wrong time scale. We did not want to totally ignore these data because, according to our first convention, data were only interpolated between the first and last entry on the handwritten chart.

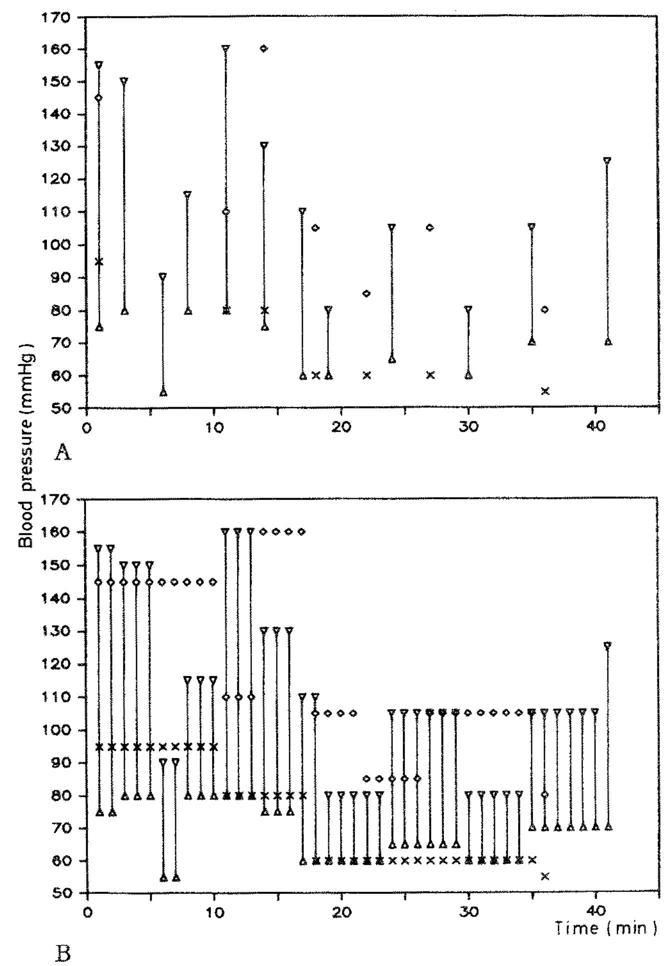


Fig 4. Comparison of blood pressure data before and after applying the first convention described in the text. (A) The superposition of the raw data from the handwritten and the automated record of the same patient. Diamonds and crosses represent the systolic and diastolic pressure, respectively, on the handwritten record. Triangles joined by a vertical line represent the systolic (▽) and diastolic (△) blood pressure, respectively, on the automated record. (B) The data after applying the convention. These latter data were used to compare both records and to calculate the error fractions as described in the text.

Totally disregarding these data would have been unfair to the anesthesiologist who tried to reconstruct data. However, it was improper to regard these data as being missed by the AARK. We therefore included these data in determining the range of interpolation on the handwritten chart, but we supplemented our first convention with a second convention: for each variable, we started and ended the comparison between both records at the first and at the last update on the automated chart.

To evaluate the habits of the anesthesiologists participating in the study, the handwritten records were tested for the number of entries per hour. Therefore, the total number of entries for each variable on the 30 handwritten records was divided by the total number of hours of anesthesia.

To quantify the comparison, all data on the handwritten record were considered to be erroneous if they were more than 20% at variance with the automated chart (15% and 5% in case of end-tidal carbon dioxide fraction and oxygen saturation, respectively). Data present on the automated chart but absent on the handwritten chart were designated "missing." As a consequence of the conventions outlined above, missing data could only be found before the first and after the last notation on the handwritten chart. We actually interpolated data between the first and last notation because of the solution we accepted for the first problem described above (see Fig 4).

The result for each single variable is expressed as an "error fraction" for the missing data (EF_m) and for the erroneous data (EF_e). Because one value for each variable was entered into the spreadsheet files for each one-minute period, the error fractions are calculated as follows:

EF_m = minutes of missing data from all patients/minutes of anesthesia;

EF_e = minutes of erroneous data from all patients/minutes of anesthesia.

The error fractions were calculated for the total record time (2,412 minutes). For example: $EF_e = 0.07$ means that 169 minutes of erroneous data are present for a certain variable. The results were also analyzed separately for the first 15 minutes of the anesthetic procedures (induction period), the last 10 minutes (end of the case), and the period in between (maintenance). For example, the study of 30 patients allowed us to evaluate 450 minutes of induction period; $EF_m = 0.2$ means that 90 minutes of missing data are found in this 450-minute time frame.

Our method of comparison and its possible weaknesses are addressed in the Discussion section. A special point of concern was the fact that the AARK updates the tidal volume, breathing rate, and oxygen fraction in the anesthetic circuit only once per 5 minutes. Thus it was possible that the anesthesiologist did record a change during the first 4 minutes of a five-minute period, whereas the AARK recorded this change only at the end of such a five-minute period. In that case, the AARK would be given an error, and not the anesthesiologist. We therefore critically evaluated all data for these three variables, paying special attention to the instances where our method might have caused incorrect results.

Simulations

Apart from the clinical studies, we simulated the impact of averaging by the AARK in the following ways. First, a simulation program was used to predict the output of the AARK after a sudden, brief bradycardic episode. A change in heart rate from 103 to 57 beats per minute followed by a return to 103 beats per minute was used to simulate a bradycardic episode lasting one minute. This simulation assumed that the ECG monitor in use does not influence the result on the computerized record. Second, an ECG simulator fed a sinus rhythm to the Hewlett-Packard 78353B ECG monitor used in our study. The ECG monitor was connected to the AARK in the usual way. The output of the AARK was studied during production of a decrease in heart rate identical to the one described in the first test.

RESULTS

The average duration of the anesthetic procedure was 80.4 minutes (range 44 to 120 minutes, SD = 25.34 minutes). The results for the total record time (2,412 minutes) are presented in Figure 5, which shows that for seven of the eight variables studied (diastolic blood pressure being the only exception), there are more missing data than erroneous data.

Figure 5 also shows that the totals of EF_m and EF_e for blood pressure and heart rate, the classically recorded circulatory variables, are smaller than those for the other recorded variables. This result is due to the much smaller incidence of missing data for these "circulatory" variables than for the other variables. Erroneous data, however, are more frequently observed for the recorded blood pressures than for any other variables. Figure 5 shows that 57% more erroneous data are observed for the diastolic blood pressure ($EF_e = 0.11$) than for the systolic blood pressure ($EF_e = 0.07$).

In Figure 6 the results are subdivided into the periods of induction (450 minutes), maintenance (1,662 minutes), and end of case (300 minutes). This figure demonstrates the differences in the error fractions between the busy periods (induction and end of case) and the maintenance period. During maintenance, all error fractions are smaller than 0.15, whereas during induction and at the end of the procedure, error fractions can range up to 0.62 (EF_m for the oxygen saturation) and 0.76 (EF_m for the end-tidal carbon dioxide fraction). The largest error fractions during busy periods are due mainly to missing data, except for the induction period, in which there are more erroneous data for the diastolic ($EF_e = 0.26$) and the systolic ($EF_e = 0.16$) blood pressures.

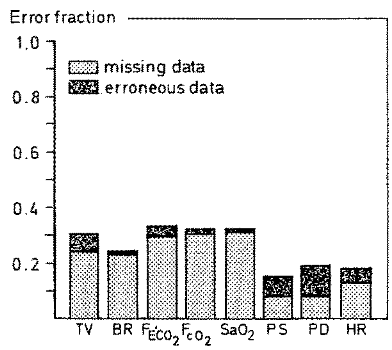


*Fig 5. Missing and erroneous data, expressed as fractions of the total record time, on handwritten records. (*TV = *tidal volume;* BR = *breathing rate;* $F_{E'CO_2}$ = *end-tidal* CO_2 *fraction;* F_{CO_2} = *oxygen fraction in the anesthetic circuit;* SaO_2 = *oxygen saturation by pulse oximetry;* PS = *systolic blood presure;* PD = *diastolic blood pressure;* HR = *heart rate.)*

After critical evaluation of all data for tidal volume, breathing rate, and oxygen fraction in the anesthetic circuit, we found two instances where the anesthesiologist recorded a change before the AARK did. For 1 patient the anesthesiologist recorded an increase in tidal volume during the induction period before the machine did; for a second patient the anesthesiologist recorded an increase in the oxygen fraction earlier during the maintenance period. We took these findings into account for the calculation of the error fractions shown in Figures 5 and 6. In addition, we expressed these findings as error fractions for the AARK using the algorithms described above: the EF_e for the tidal volume was 0.0008 and 0.0044 (total record time and induction period, respectively), and the EF_e for the oxygen fraction was 0.0017 and 0.0024 (total record time and maintenance, respectively).

As a consequence of our conventions, the missing data for a particular variable during the maintenance period result from the fact that some anesthesiologists started their handwritten records more than 15 minutes after the first notation on the computerized chart, or terminated their handmade chart more than 10 minutes before the last notation.

The number of entries per hour for the physiological variables on the 30 handwritten records is listed in the Table. During the study our group of anesthesiologists updated their records with blood pressure and heart rate data at a mean interval of six minutes. Other variables were less frequently updated.

Figure 7 shows the results of the simulations. The results relate, among other factors, to the position of the sampling window of the AARK. However, the greatest impact of averaging occurs if a stepwise change in the value of a physiological variable occurs between 30 seconds before and 30 seconds after the end of the one-minute averaging period. This "worst case" was used for our simulations. The simulation program predicts that straightforward averaging would smooth the 45% decrease in heart rate (103 to 57 beats per minute) to a 21% decrease (103 to 81 beats per minute). However, a slightly different effect in the printed output of the AARK is seen if the ECG simulator and the ECG monitor are used. This is because the heart rate is calculated in the Hewlett-Packard 78353B ECG monitor. In the range of 52 to 104 beats per minute, this monitor calculates

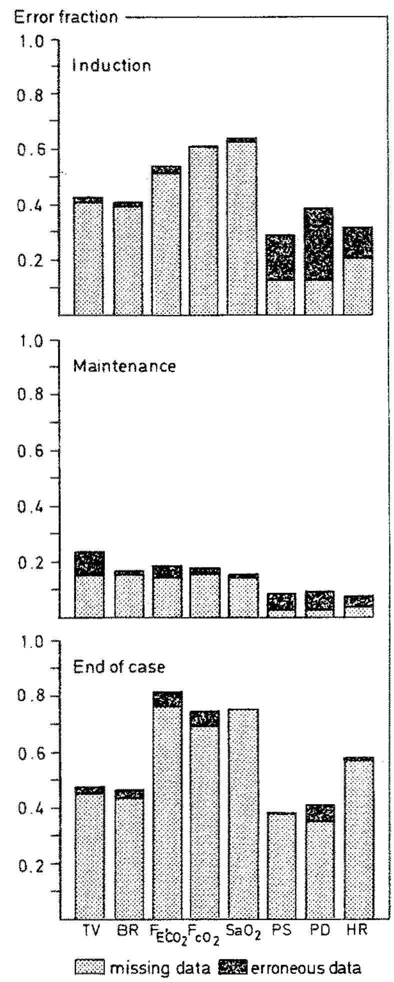


*Fig 6. Results from each of the three periods of anesthesia. The amount of missing and erroneous data on handwritten records is expressed as fractions of the three major periods of anesthesia: induction (first 15 minutes), end of case (last 10 minutes), and maintenance (period in between). (*TV = *tidal volume;* BR = *breathing rate;* $F_{E'CO_2}$ = *end-tidal* CO_2 *fraction;* F_{CO_2} = *oxygen fraction in the anesthetic circuit;* SaO_2 = *oxygen saturation by pulse oximetry;* PS = *systolic blood pressure;* PD = *diastolic blood pressure;* HR = *heart rate.)*

Average Number of Handwritten Entries per Hour on 30 Records

	Entries/hr	
Variable	This Study	Zollinger et al[a]
Oxygen fraction	2.7	
Tidal volume	2.7	
Breathing rate	2.6	
End-tidal CO_2 fraction	2.7	
Oxygen saturation	2.7	
Systolic blood pressure	10.2	11.4
Diastolic blood pressure	10.2	11.4
Heart rate	9.7	10.8

[a]Results for blood pressure and heart rate reported by Zollinger et al [4] are given for comparison.

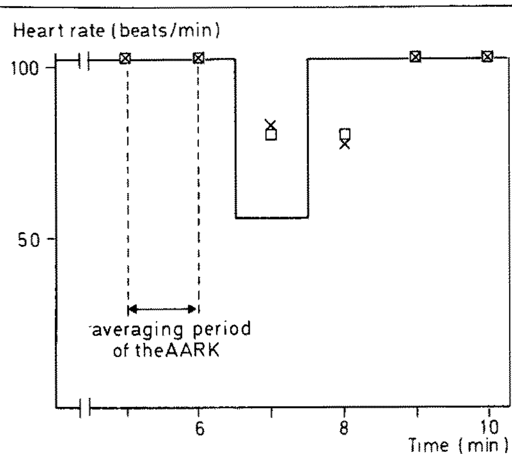


Fig 7. Two simulations of the effect of averaging by the Ohmeda automated anesthesia record keeper (AARK) *on a brief decrease in heart rate (from 103 to 57 beats per minute). The continuous line represents the heart rate. The open squares represent the result of straightforward averaging; i.e., no effect of the electrocardiogram (ECG) monitor is assumed. A slightly different effect is seen in the printed output of the AARK if an ECG simulator feeds the same decrease in heart rate to a Hewlett-Packard 78353B ECG monitor connected to the AARK. The output of the AARK in the latter case is represented by the crosses.*

the heart rate from the time elapsed during four heartbeats (personal communication, Hewlett-Packard, The Netherlands, July 1987). Thus the monitor produces a signal that does not exactly reflect the stepwise change in heart rate. The signal from the ECG monitor is then processed by the CPU of the AARK, i.e., a one-minute average is calculated and sent to the printer.

DISCUSSION

The handwritten records used for comparison in the present study were representative of the records produced at our hospital. The Table shows that the recording habits of our anesthesiologists for blood pressure and heart rate data are not very different from the habits of the group studied by Zollinger et al [4]. The average number of entries per hour in the present study is approximately similar to the number these authors reported. The handwritten records in our study were possibly more accurately completed than in everyday practice, because the anesthesiologists were aware that a comparison with the computerized charts would be made. In addition, the anesthesiologists did not have to scan all the monitors to obtain the actual values of the physiological variables. These values were grouped in the central display. Thus, to complete a handwritten chart required the observation of a single screen. It is assumed this would render the handwritten chart more complete and accurate than otherwise.

A major concern about automated record keeping is the possible appearance of erroneous results on the automated chart. Automated systems faithfully record data, even if these data are in error. Three basic processes of data handling can be recognized in an automated system: data acquisition, data processing, and data display (usually requiring a hard copy in the case of anesthetic record keeping). Errors can arise from various sources during these processes. Detection of the physiological signals is the first of several steps in the production of the automated chart. Examples of sources of possible error during the measurement process are improper placement of sensors, calibration errors, and artifacts that are due to interference with the sensors or the electrical circuitry of the monitors. Well-known examples are the artifacts on the ECG produced by the use of an electrosurgical unit and the aberrant blood pressure results caused by surgeons bumping the blood pressure cuff. Well-designed artifact detection and rejection systems may reduce the impact of artifact on the measurement. The averaging by the AARK not only aids in data reduction, but also aids in rejecting some possibly aberrant results. For instance, the one-minute averaging algorithm reduces the impact of possible artifacts on heart rate readings. In contrast, an automated system recording the actual value of the heart rate every 60 seconds may faithfully record an erroneous value caused by an artifact. Other possible errors arise from the analog-to-digital or digital-to-analog conversions in the automated system, faults in data processing, and printer or plotter weaknesses. An automated record keeping system should therefore not be relied on solely in clinical practice until it has been proven to behave as expected. Hand-charting anesthesiologists can filter out aberrant results because they can interpret intelligently the results shown on the monitors before recording them. Anesthesiologists using an automated record keeper can use manual data entry to note an event for later clarification, or they can make a notation directly on the automated chart regarding data integrity.

Artifacts caused by electrosurgical units or members of the surgical team were not a problem during this study. In fact, one year of clinical use of the equipment described above in the operating theaters for eye surgical procedures revealed none of the described problems that may occur with an automated system. Some of the habits of our group of anesthesiologists and surgeons may account for this finding. Eye surgeons in our hospital use various devices for cauterization: they frequently use a battery-operated ophthalmic cautery (Optemp, Alcon Laboratories Inc, Fort Worth, TX). Battery operation ensures noninterference with monitoring or computer equipment. However, another device operates from main current and generates heat by means of radio frequency (13.56 MHz) power delivered to the electrode (MIRA radio frequency diathermy instrument, Medical Instrument Research Associates, Inc, Boston, MA). This device always induces "noise" on a two-channel paper recorder (Hewlett-Packard 7402A) placed on the upper shelf of the Modulus II anesthesia system, but the device does not interfere with the AARK or the other equipment used in the present study. It is common practice in all operating rooms of our hospital to use a firm mechanical shield to protect the blood pressure cuff if there is any chance that the surgeon or another member of the operating team may bump it. Schneider [6] reported that it is important to shield the blood pressure cuff when using automated systems. Moreover, the surgical team tends to make only gentle movements during eye surgical procedures. We have therefore never mistrusted the values of the physiological variables detected by the equipment used in the present study, and we are convinced that our results were not influenced by aberrant readings.

This study might give the impression that we assumed that the AARK as a whole was a perfect system. This false impression can be removed by carefully considering the circumstances of the study. The values for the eight variables acquired from the various monitors are first processed by the CPU and are then sent both to the CDU and to the printer generating the automated chart (see Fig 2). Some variables are averaged before printing. The anesthesiologists used the values shown on this CDU to update their handwritten records, and not the values on the various monitors. Thus, possible errors at the front end of the AARK did not influence the results of this study. For example, suppose an error exists during data acquisition from the oxygen monitor. The monitor reading is 40% but, because of the supposed error, 31% is displayed on the CDU and printed on the automated record. In our example the anesthesiologist would also enter 31% on a handwritten chart. This fictitious and exaggerated example clearly illustrates that, by using the data at the back end of the CPU, we were assured that identical data were available for both the handwritten and the automated record. Therefore, any difference between the handwritten and the computerized chart was due to missing or erroneous entry on the handwritten chart, provided that printing errors and differences caused by averaging or the five-minute update period of the AARK (tidal volume, breathing rate, oxygen fraction) could be excluded. These possible sources of differences between the two types of records will be discussed below.

Plotting errors owing to shifting of the printer paper during the case could be excluded because of the mark made by the printer at each update. Averaging may induce differences between both records, e.g., during brief variations in the heart rate that may be caused by traction on the extraocular eye muscles. It is possible that the anesthesiologist, who was spot checking the centralized display, entered a value on the handwritten chart different from the value plotted by the AARK due to averaging. When considered important enough by the anesthesiologist, such necessarily short-lasting variations are annotated on the handwritten chart. These annotations, each of which noted a bradycardic episode lasting less than one minute, were found in only three instances. They were discovered by the dip in the automated record and by the remark of the anesthesiologist on the handmade record, e.g., "bradycardia 40 bpm during 15 s." This is our normal practice for serious bradycardia caused by traction on extraocular eye muscles. During such an event the AARK allows for manual entry of a comment through the touchpanel or by writing directly on the record. The problem would better be solved by having the AARK begin updating more frequently whenever preset alarm limits are exceeded. This method would, however, result in recording of more data, thereby increasing the number of pages required.

We found only two instances of erroneous data for the tidal volume and oxygen fraction that were caused by the AARK and not by the hand charting anesthesiologist. The reason may be obvious. The anesthesiologist most likely evaluated the changes in the settings of the ventilator or the rotameters by looking at the patient and the changing values of the variables on the CDU before completing the handwritten record. Again, more frequent updating by the AARK might be desirable, although the updating of the end-tidal carbon dioxide and the oxygen saturation at one-minute intervals proves that adequate ventilation is present.

The results presented in Figure 6 quantify the observations made during the study. These observations are illustrative for everyday clinical practice: all anesthesiologists made all necessary manipulations for induction and subsequently started to complete their handwritten records. In most cases, the anesthesiologists filled in data for blood pressure and heart rate from memory. This after-the-fact data entry was usually omitted for the other variables. Thus, there are many missing data for these variables during the time of induction and the subsequent several minutes. The EF_e values for the systolic and diastolic blood pressure during the induction period prove that the memory of the anesthesiologist is limited. The EF_e for the diastolic blood pressure indicates that our group of anesthesiologists memorized preferentially the systolic blood pressure, and entered a preconceived matching diastolic pressure. The diastolic pressure, however, is an important physiological variable, e.g., for patients with hypertension or atherosclerotic heart disease.

The results for the maintenance period illustrate that, during eye surgical procedures where no major disturbances in the homeostasis of the patient are provoked by the operation itself, the anesthesiologists keep track of the physiological variables at an acceptable level of accuracy. During procedures with homeostatic perturbations, however, record keeping might receive a lower priority than immediate patient care, and the error fractions might increase. Also, the number of entries per hour might be smaller than that listed in the Table. However, the automated record of the averaged variables may also degrade in the case of rapid variations in the patient's condition.

The amount of missing and erroneous data during the end of the case is similar to that during the induction period. Missing data prevails because most anesthesiologists failed to enter after-the-fact data.

A definite difference in error fractions (see Fig 5) between the classically recorded circulatory variables (blood pressure and heart rate) and the other physiological variables is observed. Our group of anesthesiologists was accustomed to regularly recording the end-tidal carbon dioxide and the oxygen fraction in the anesthetic circuit. They were not accustomed to recording the readings from a pulse oximeter, which was introduced only recently in our hospital. However, the number of entries in the Table indicates that these three variables, together with the tidal volume and breathing rate, were manually charted with the same update frequency. The smaller EF_m and EF_e results for the blood pressure and heart rate suggest that these primarily circulatory variables are better surveyed than the others. However, many "critical incidents" that occur during anesthesia are related to the interface between patient and breathing circuit, e.g., breathing circuit disconnections during mechanical ventilation [7]. The computerized record provides information at one-minute intervals, e.g., the end-tidal carbon dioxide fraction indicates that appropriate ventilation is present. The infrequent hand charting of important physiological variables indicates that even eight physiological variables are too many to record manually with a high update frequency. Therefore, a manually kept record may not be as useful in helping detect trends as is an automated record. Additionally, an automated record allows for correlation and comparison of specific/significant data in real time [8,9]. If the computerized anesthesia record is regularly consulted, the anesthesiologist will be more aware of the time course and detail of anesthetic events and will have better control of the anesthetic [10]. However, averaging, which helps reduce the impact of artifacts, deprives the automated chart of an exact representation of brief changes.

We have merely illustrated the effect of averaging in Figure 7. However, the response of a system to one well-defined, sudden change in its input is of interest in any analysis. It is clear from our simulation results that the AARK will record any value between 57 and 103 beats per minute, depending on the sampling window. We deliberately used a sampling window that produced marked differences between the real time course of events and the averaged values. We also pointed out that the monitor in use influences the recorded response to a step change in heart rate. Substantial conclusions would demand a comprehensive study of all possible interactions between monitor preprocessing, sampling rate and sampling window of the AARK, averaging algorithms, and update frequency on the automated chart.

We have measured the efficiency of a group of anesthesiologists in transcribing the values of eight physiological variables from a display screen to a chart while they also administered an anesthetic during elective eye surgical procedures. The results indicate that the automated record keeper provided our clinicians with a more accurate and complete record than was achieved through hand charting. The differences in accuracy and completeness were most evident during induction and at the end of the case, periods during which the attention of the anesthesiologist is fully concentrated on the patient.

The preliminary results of this study were presented during the industrial session at the congress, Computing in Anesthesia and Intensive Care, September 1986, Rotterdam, The Netherlands.

REFERENCES

1. Griffith HR. Some practical observations on general anesthesia. Classical file. Surv Anesthesiol 1985;29:362
2. Smith NT. Automated anesthetic record keeping. In: Osswald PM, ed. Computers in critical care and pulmonary medicine. Heidelberg: Springer-Verlag, 1985:147–161
3. Noel TA II. Computerized anesthesia records may be dangerous. Anesthesiology 1986;64:300. Letter
4. Zollinger RM, Kreul JF, Schneider AJL. Man-made versus computer-generated anesthesia records. J Surg Res 1977;22:419–424
5. Sy WP. Ulnar nerve palsy possibly related to use of automatically cycled blood pressure cuff. Anesth Analg 1981; 60:687–688.
6. Schneider AJL. Automated systems. In: Gravenstein JS, Newbower RS, Ream AK, et al, eds. Monitoring surgical patients in the operating room. Springfield, IL: Thomas, 1979:159–169
7. Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. Anesthesiology 1984;60:34–42
8. Rosen AS, Rosenzweig W. On computerized anesthesia records. Anesthesiology 1986;65:131. Letter
9. Sarnat AJ. Do not fear computerized anesthesia records. Anesthesiology 1986;65:132. Letter
10. Dirksen R, Lerou J, van Daele M, et al. The clinical use of the Ohmeda automated anesthesia record keeper integrated in the Modulus II anesthesia system: a preliminary report. Int J Clin Monit Comp 1987;4:135–139