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Differences Between Handwritten and Automatic Blood Pressure Records

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Comparison of 46 handwritten and electromechanically generated blood pressure records revealed substantial differences between the recordings. The highest automated record pressures exceeded the highest pressures found in corresponding handwritten records. Similarly, the lowest pressures from automated records were lower than those from handwritten records. Seventeen records (37%) had at least three automatic blood pressure determinations with values substantially in excess of the most extreme values recorded by hand. No handwritten record contained a diastolic pressure above 110 mmHg.

Discrepancies between handwritten and automatic records may arise from one or more causes. Among these are readings captured automatically but not observed by the anesthesiologist, faulty reconstruction of handwritten records from memory, and bias in favor of less controversial values. (Key words: Blood pressure: monitoring; physiologic. Medical records: automation.)

THE ANESTHETIC RECORD is by far the most detailed general physiologic and pharmacologic account made in routine clinical practice. Attempts to automate part or all of record keeping have met with only very limited acceptance: the vast majority of records are still made by hand. Recently, Newbower[1] identified cost, "immediate positive payback to the. . . anesthetist," "interface" between man and machine, and "transition" to a new system as obstacles to automated record keeping. If records kept by machine are identical to those kept by hand, the transition may simply require adapting to a new method of production. If the two record types differ in content, however, transition to the mechanical record will change a fundamental medical document.

Detecting differences between handwritten and automatic records requires comparison of actual record entries. The analysis of blood pressure may be particularly fruitful because blood pressure cannot be assessed accurately by observation but must be measured mechanically; is often monitored by a single device; and is uniformly regarded as a basic element of the anesthetic record. The widespread use of automatic noninvasive blood pressure (NIBP) monitors makes such a study relatively easy.

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Materials and Methods

Fifty patients gave informed consent to participate in an institutionally approved study of the efficacy of monitoring methods. Their anesthesiologists were told that a monitoring study was being performed. The study population included 35 gynecologic, six oral, four otorhinolaryngologic, and five general surgery patients, all of whom received general anesthesia with endotracheal intubation. The mean age of patients was 32 yr (±10 yr, standard deviation). One patient was ASA PS III while the rest were PS I or II. Anesthetic technique and general care of the patient during the procedure were determined by the staff anesthesiologist.

A Critikon Dinamap® 845XT automated blood pressure monitor was used for each case. A custom-designed interface circuit consisting of a counter, digital-to-analog converter, and internal calibrator was connected to the monitor's accessory port and used to generate an analog signal proportional to the blood pressure measurement. The interface unit received the same electrical signals that generated the monitor's display. Pressure measurements and several other monitored variables were recorded continuously using Gould 2400 strip chart recorders running at 3 mm/min. The recording assembly was calibrated before each case and the recorder pen tracing visually checked against the blood pressure monitor display.

Anesthesiologists and operating room personnel were informed that the study was taking place but were not told that the automatic and handwritten records would be compared. No effort was made to blind the anesthesiologist to the recording process, although the chart recordings were not easily observed by the physicians. Handwritten records were kept in the usual fashion. During data reduction, automatic and handwritten records were photocopied and blinded to prevent identification of either patient or anesthesiologist.

The first hour of the case (or the entire case, if its duration was less than 1 h) was analyzed. The systolic and diastolic blood pressures were coded, entered into a computer, and analyzed using a statistical program.§ Pressures from handwritten anesthetic records were read to the nearest 5 mmHg (one-half chart division). The caret (diastolic) or inverted caret (systolic) vertex was used as the indication of pressure. The automatic record values were read to the nearest 2.5 mmHg (one-half chart division).

§ Statistical Analysis System, SAS Institute, Cary, North Carolina.

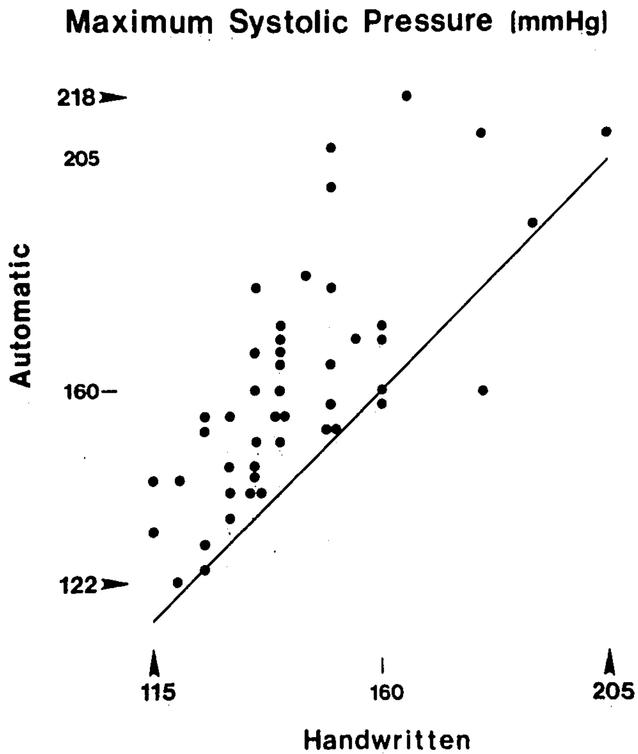

FIG. 1. Highest systolic pressure recorded during the first hour of each case. One data point is plotted for each case. Points lying along the diagonal line represent cases with equal maximum automatic and handwritten values. Points above the line represent cases where the highest automatic value is greater than the corresponding highest handwritten value. For points below the line the automatic value is less than the handwritten one.

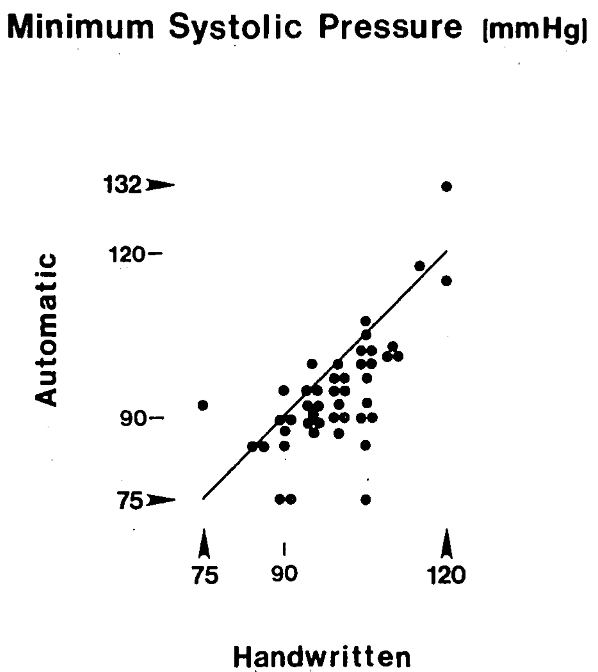

FIG. 2. Lowest systolic pressure recorded during the first hour of each case.

Readings of zero over zero, indicating a self-detected automatic noninvasive blood pressure monitor fault, were coded as missing data and excluded from the analysis. The groups of measurements were compared using the F-test for equivalence of variances. Maxima and minima from collected data were compared using Student's t test, linear regression, and the binomial probability distribution.

Results

Forty-six cases were selected from the original set of 50 recordings. Four cases were excluded because an arterial pressure transducer was present (two cases) or because recording equipment failed (two cases). Thirty-two individuals were associated with the handwritten records; 20 were physicians, 12 were nurse anesthetists. It was impossible to determine the individual responsible for marking the blood pressures because at least two different practitioners participated in each case.

A total of 528 handwritten and 1687 automatically recorded pressures were identified. The mean interval between automatic measurements was 90 s (±53, standard deviation). Handwritten entries were uniformly marked at 5-min intervals, although a few intervals were 10 min and occasionally a systolic or diastolic entry was absent.

The highest and lowest pressures recorded automatically during the first hour of each case are shown plotted against the highest and lowest handwritten pressures recorded during the same period (figs. 1–4).

The highest automatically recorded systolic pressure was at least 20 mmHg greater than the highest handwritten pressure in 19 cases, and at least 40 mmHg greater in four of these. Systolic pressures above 170 mmHg appeared in 11 automatic records but only four handwritten records. Only one handwritten record contained a 200 mmHg or greater systolic pressure entry, in spite of the fact that five cases had pressures of at least 200 mmHg recorded automatically. In all, 158 (9.4%) of all the automatic systolic pressure entries were greater than the highest systolic pressure recorded anywhere in the corresponding 1-h section of the handwritten record, an average of 3.4 entries per case.

The highest automatically recorded diastolic pressure was at least 20 mmHg greater than the highest handwritten value in 22 of the 46 cases, and at least 40 mmHg greater in six cases. As with systolic pressure, the maximum diastolic pressures recorded by hand were virtually always below the automatic maxima. In only four cases was the maximum handwritten diastolic pressure higher than that recorded automatically, and in these the difference was small and the recorded values noncontroversial. Automated diastolic pressure readings over 110 mmHg appeared 33 times (including eight measurements

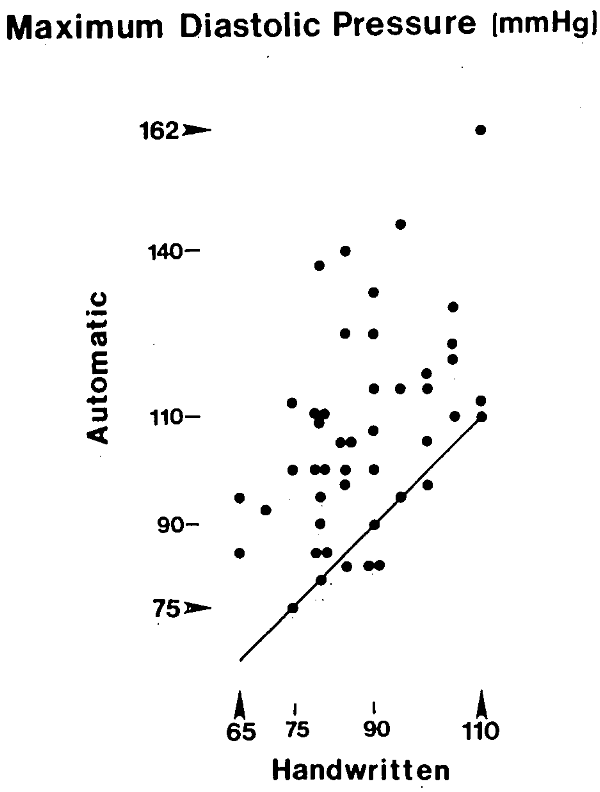

FIG. 3. Highest diastolic pressure recorded during the first hour of each case.

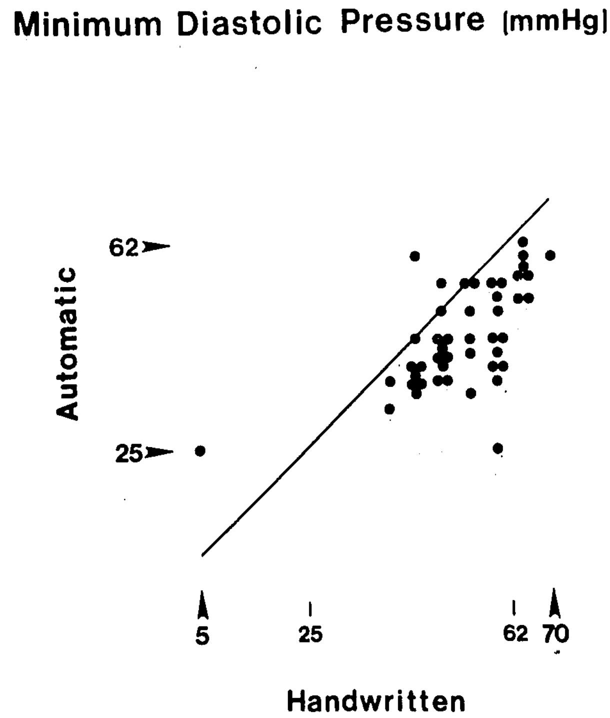

FIG. 4. Lowest diastolic pressure recorded during the first hour of each case.

greater than 125 mmHg) in 15 different cases, but no handwritten record contained an entry over 110 mmHg. The binomial distribution probability of such absence occurring by chance is less than 0.0001.[2]

In contrast to the highest pressures, the lowest systolic pressures recorded automatically and by hand were more tightly clustered. Nineteen cases had systolic pressures of 90 mmHg or lower recorded automatically while only 10 handwritten records contained such entries. These discrepancies were, however, small when compared with those for highest systolic pressure. The lowest recorded diastolic pressure distribution was similar. One handwritten entry listed a diastolic pressure of 5 mmHg, although this was exceptional and the remainder of the handwritten record was smooth.

The differences between automatic and handwritten maximum recorded pressures were statistically significant as were those between the automatic and handwritten minimum pressures ($P < 0.001$, paired Student's t test with correction for multiple tests by the Bonferroni method).[3] Linear regression of handwritten values using automatic values as independent variables demonstrated only limited reduction in variance (table 1), although the regression slopes were statistically significantly different from the line of identity.[4]

The frequency with which various pressures appear in the record are shown in figure 5. The histograms are weighted by the interval of the measurement: a single measurement contributes to the histogram in proportion to the actual time it was presented as the current blood pressure. For the handwritten record, this weight is relatively constant. For automatic records the weight varies. The handwritten and automatic record percentages were comparable, except as indicated. The two sets of records had different variances. For both systolic and diastolic pressures, the variance was significantly greater in automatic than in handwritten records (F-test, $P < 0.0042$ and $P < 0.0001$, respectively),[5] considering the groups of data as a whole. Individually, 14 cases had significantly different variances. In only one case was the variance in the handwritten record significantly greater than in the corresponding automatic record.

TABLE 1. Linear Regression of Automatic *Versus* Handwritten Maximum and Minimum Pressures

Variable	a	b	r2	*P*
Maximum systolic pressure	0.61	46	0.51	<0.0005
Minimum systolic pressure	0.60	43	0.47	<0.0005
Maximum diastolic pressure	0.30	56	0.21	<0.0005
Minimum diastolic pressure	0.70	22	0.36	<0.025

(Handwritten) = a (automatic) + b. *P* is the likelihood that the slope is equal to the line of identity, that is, that a = 1.

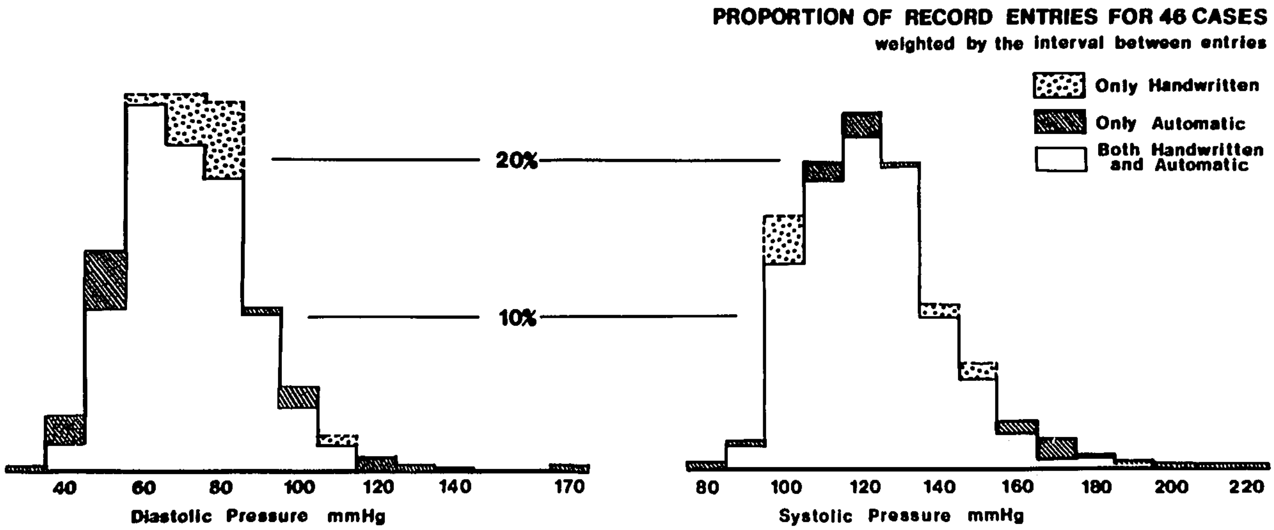

FIG. 5. Frequency with which various systolic and diastolic pressure entries appear in records. Entries are weighted by interval of measurement; a value displayed in the record for 30 s contributes half as much to the histogram height as a similar one lasting 1 min. Note that no handwritten record contained a diastolic pressure entry over 110 mmHg and that handwritten entries cluster towards the center of the distributions. (A single handwritten diastolic value of 5 mmHg is not included.)

Discussion

Improving anesthetic record accuracy is often given as a reason for recommending automatic record keepers. Virtually every published quantitative study of anesthetic record accuracy has been accomplished during evaluation of some new recording device. These investigations largely support automated recording as a means to perform a menial chore, especially during the induction and emergence periods. They implicitly assume that an anesthesiologist's workload limits recording fidelity.

Most published studies focus on timing the discrepancies rather than on their magnitude or direction. Indeed, the definition of accurate for Lerou, *et al.*[6] and Apple, *et al.*[7] was simply ±20% of the automatic reading. The former computed fractional duration of error while the latter computed the frequency of erroneous entries, but neither characterized the direction or magnitude of the discrepancies. For both studies, the times of induction and emergence were the locus of most blood pressure recording errors. Whether these periods were also the locus of greatest extremes in blood pressure or whether the errors were systematically biased towards normal values is unknown. Logas *et al.*[8] reported that 16% of handwritten entries understated pressure by more than 10 mmHg compared with hand-matched automatic values. Again, whether this represents underreporting of especially high or low readings is unclear.

What is quite clear is that assessing anesthetic record accuracy is no simple task. At least two characteristics of handwritten records make evaluation difficult. First, there are usually multiple readings from a noninvasive blood pressure cuff during the nominal 5 min interval between handwritten entries; record keepers must somehow choose what numbers to write down. Second, keeping the record is a secondary task and the record is frequently completed sometime after the events it describes.

Before automatic noninvasive monitors, a sphygmomanometric pressure reading might well be taken only once every 5 min. The ratio of recorded to measured pressures approached one-to-one. In such a setting, the accuracy issue devolved to the precision with which one might make marks on paper. With the advent of automatic monitors, the frequency of measurement has risen. Since handwritten entries are less frequent than automatic measurements (in the present study, the ratio is about 1 to 3) the record keeper must somehow select a single value. Especially if the measurement interval is uneven (for example, if the monitor is triggered automatically and then manually to produce an extra reading), the weighting of a given measurement becomes an issue.

While the distributions shown in figure 5 have significantly different variances, they are not, in aggregate, remarkably at odds with the automatic records. Considering the collection of entries as a whole, the handwritten records quite fairly reflect the automatically obtained blood pressures. Nevertheless, there are extreme automatic readings which do not appear in handwritten records. This is especially true for hypertensive readings. No handwritten record contains a diastolic pressure over 110 mmHg. The highest automatic systolic pressures exceed the highest handwritten entries, often by significant amounts (fig. 1). While by no means true for every case (a single very high systolic measurement was matched with a handwritten entry), it is clearly the rule. Although handwritten records may also fail to capture low pressures,

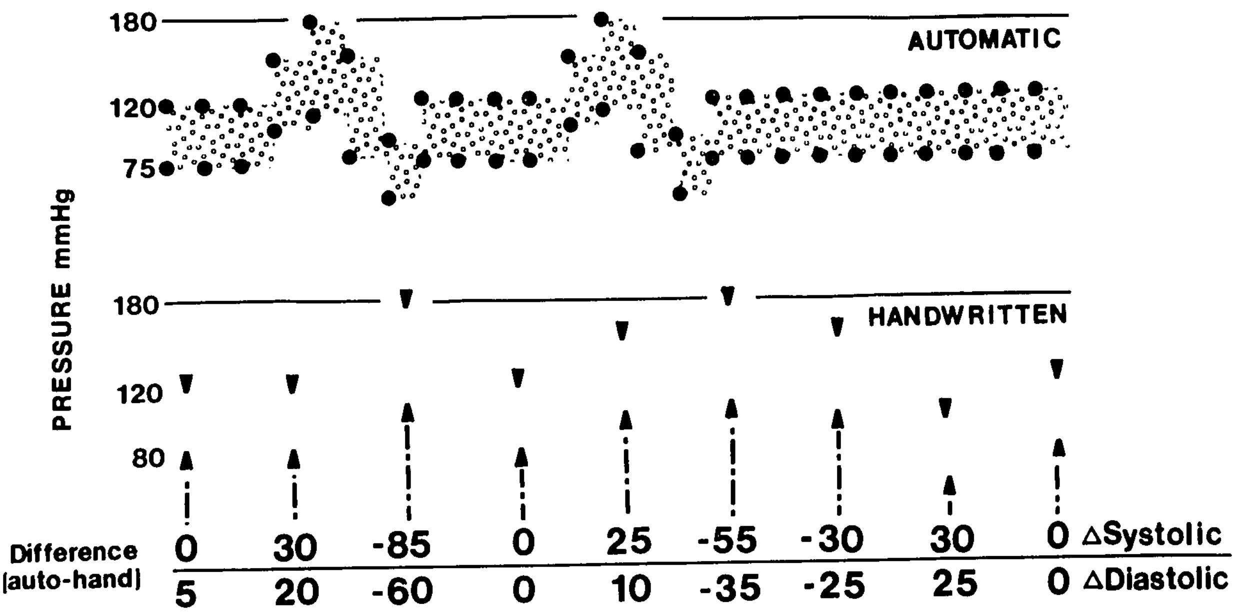

FIG. 6. Demonstration of time uncertainty effects on pairwise comparison of handwritten and automatic anesthesia records. The upper trace represents an automatic record showing two brief pressure changes. The handwritten record below demonstrates the effect of recording with a slight offset in time (left half) and a dilation of time (right half). The 'errors' as computed by pairwise comparison of the two records are shown at the bottom. While the handwritten record captures the magnitude of blood pressure variation in the automatic recording it fails to locate precisely the variation within time. Pairwise comparisons fail to distinguish between timing accuracy and magnitude accuracy.

the present automatic data contain few hypotensive readings.

Extreme values of blood pressure account for only a small portion of automatic measurements; the tails of that distribution are small. The tails of the handwritten distribution, however, are even smaller. If the handwritten record represented an unbiased sample of the automatic readings, figure 5 would contain no shaded areas. There are more middle-range entries, especially for diastolic pressure (60–100 mmHg) than extreme ones: the tails of the distribution are occupied almost entirely by automatically recorded values.

It is unlikely that the extreme readings absent from handwritten records were simply missed by the record keepers. Although a single reading might well be missed (for example, during intubation) most automatic records contained multiple instances of readings above the highest handwritten entry. Manual record keepers had, on average, more than three opportunities to capture and record a systolic pressure greater than the highest one they did record.

Anesthetic records are often constructed some minutes after the events they describe,[9] frequently during the middle of the case.[10] Memory for events more than 30 s in the past is largely symbolic long-term memory; timing such past events presents an opportunity for misplacing the moments at which events occurred and misjudging their duration. James identified this well-known feature of long-term memory in the 1890s,[11] and Loftus[12] and others have added considerable detail. If one remembers a period of hypertension, for example, it is more likely to be recalled as "hypertension following intubation" than as "systolic hypertension above 200 mmHg 60 s after laryngoscopy" which is in turn more likely than recalling "a reading of 228 mmHg from 2:28 P.M. until 2:30 P.M." The exact timing of blood pressure entries is likely to be the least precise portion of the handwritten record. Pairwise comparison of entries from automatic and handwritten records may therefore seem to demonstrate large and frequent magnitude errors that actually derive from imperfections in recalling the initial moment and duration of pressure variations (fig. 6). This problem worsens as the duration of pressure changes shortens and will thus be particularly severe for brief transients. The present analysis avoids making such comparisons, attempting to treat the collection of record entries as a whole and characterizing the magnitude limits of the records.

Although the handwritten record clearly does not represent a simple unbiased sampling of the automatically generated blood pressure displays, it seems unlikely that the few high or low pressures missing from handwritten records cause clinically significant morbidity. One may even argue that almost every case contains a few moments of hypertension and that these are of no particular significance and should not be recorded since they are transient. According to this argument, the handwritten record presents a clinically relevant filtering of physiologic artifact from written records. Perhaps so, but why is there a 110 mmHg ceiling on diastolic pressure? Is there some special significance to that value?[13] Why 110 mmHg and not 120 mmHg? Why not 100 mmHg?

There may be extra-clinical reasons to keep certain magnitudes from appearing in the anesthetic record. Zollinger *et al.*[14] observed that "physicians like smooth charts inasmuch as they imply a better management of the case." The record reflects on its maker and the anesthesiologist is a physician in a society increasingly critical of physicians. The record is a potent legal document and is prepared before the outcome of the anesthetic and surgical procedure is known. The paucity of extreme values in the handwritten record may be an unconscious defensive strategy.

The data presented here demonstrate that automatic and handwritten records differ, especially in their reporting of extreme values of blood pressure. These differences might arise in any of a number of ways, but whatever their source, they suggest that automated records are likely to be qualitatively different from handwritten ones. Transition to a new system of recording may entail changing the contents of a fundamental medical document.

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