CLINICAL PAPER

Basics in advanced life support: A role for download audit and metronomes

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Summary
An intention in 2003 to undertake a multicentre trial in the United Kingdom of compressions before and after defibrillation could not be realized because of concerns at the time in relation to informed consent. Instead, the new protocol was introduced in one ambulance service, ahead of the 2005 Guidelines, with greater emphasis on compressions. The results were monitored by analysis of electronic ECG downloads. Deficiencies in the standard of basic life support were identified but were not unique to our service. The introduction of metronomes and the provision of feedback to crews led to major improvements in performance. Our experience has implications for the emergency pre-hospital care of cardiac arrest.

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Introduction
The quotation comes from the seminal study of external chest compression by Kouwenhoven et al. It heralded the birth of a new era of feasible resuscitation from cardiac arrest, first of all for those in hospital and later for those in the wider community. Since then, countless thousands have survived episodes of aborted sudden cardiac death in every continent; but most have received not only chest compression with ‘two hands’ but also artificial ventilation, defibrillation, and drug therapy that together make up the components of modern cardiopulmonary resuscitation.

Although numerous publications have attested to an increasing success rate in the early years of the new era, recent data have suggested that little progress has been made over the past quarter century; despite many new
technical advances and increasing expenditure of time and money there has been little change in survival rates from attempted resuscitation. The explanation for this paradox in now widely accepted: the increasing availability of ancillary techniques for resuscitation, that should enhance results, has distracted rescuers from the maintenance of standards in essential basic procedures. This concept clearly influenced the International Liaison Committee for Resuscitation (ILCOR) 2005 Consensus on Science, from which present-day guidelines have been drawn. A considerable increase in emphasis was placed on chest compressions, in terms of both their number and quality. We had considered undertaking a trial to investigate whether our preliminary observations revealed a need to improve the performance of basic life support to make such a trial meaningful, and because of concerns over changes that were expected in the law governing consent by incapacitated patients. Paramedics and ambulance technicians were, however, enthusiastic to improve the quality of basic life support once the deficiencies were understood. The experience has led us to believe that monitoring of performance collected during cardiac arrests, either in real time or retrospectively, should become an established procedure in all emergency services. This paper describes the monitoring procedures that we adopted locally with our new protocol, and how increased surveillance led to identification and correction of deficiencies that were reflected in outcome data.

Method

With approval from the Resuscitation Council (UK) and from The Brighton and Mid-Sussex Local Research Ethics Committee to deviate from the 2000 Guidelines, we adopted for routine use a protocol that was to have been tested in the proposed trial. It included continuous compressions for the first 2 min of cardiopulmonary resuscitation (CPR), only interrupted halfway by a brief look at the monitor screen to identify heart rhythm. If a shockable rhythm was identified, the defibrillator was charged during compressions so that a shock could be given after only seconds of hands-off time. Compressions were resumed immediately after the shock. Conventional ventilations were withheld until after the second rhythm check. For non-shockable rhythms, ERC guidelines current at the time were used for compression and ventilation. The policy of transporting patients with on-going CPR after three unsuccessful shocks or early in cardiac arrests with non-shockable rhythms was also discontinued.

Observations took place from May 2004 to December 2006, starting with one ambulance station within the Service, but eventually involving six. The population covered was both urban and rural varying in number through the audit from around 300,000–400,000. In all, approximately 70 paramedics and 80 technicians contributed to the data.

The automated defibrillators (Welch Allyn 20®) were used in manual mode, with data cards that recorded the electrocardiogram (ECG) during the entire resuscitation attempt after the pads had been placed. The records were then accessed using specialized software (Smartview© v2) and printed in hard copy. In order to help compliance with correct compression rates, we introduced musicians’ metronomes progressively over several months from January 2005 (Seiko© DMS50). They were attached to the AEDs to be turned on at the start of any resuscitation attempt.

Analysis was performed by two observers (DF and DAC) generally working together. Most observations were straightforward, but in some tracings compression artefact could not be distinguished readily from fibrillation waveforms. Consensus was then reached as to whether identification of compressions was near-certain or whether the relevant analyses should be discarded.

Our observations centred on the first 5 min of each resuscitation attempt, with particular attention to compression rate, the duration of pauses for ventilation, and the longest pause without compressions where need for them was apparent. For each download in which compressions could be identified reliably, we recorded the fastest and slowest rates. Two values were derived from these to characterize the individual download, their average (mid-range rate) and difference (range). Pauses could generally be measured only during periods of asystole: it was not always possible to be sure during fibrillation that no compressions were being given, and if any QRS complexes were present then pauses may be acceptable. For this reason, pause data were available for fewer subjects than compression rate data.

Few data were collected in 2004; the results are presented as averages for that incomplete year. Subsequent observations in 2005 and 2006 were batched into 3-month periods and subsequently aggregated into whole calendar years.

Distributions of mid-range compression rate, range of compression rates and longest pause duration were markedly positively skew. Histograms of these variables by year were constructed for illustrative purposes. Analyses of variance, both parametric and non-parametric (Kruskal–Wallis) were performed to compare the 3 years, followed by unpaired t-tests and non-parametric Mann–Whitney (M–W) tests comparing 2005 vs. 2004 and 2006 vs. 2005.

Results

Compression rates

Initially, progress was very slow because of the progressive roll-out of the system, but also because the electronic data cards were not always used. Only 42 downloads were obtained in the 8 months of 2004, of which 27 were suitable for analysis. Several of the remainder had few definite compressions, whilst others were of poor quality or they could not be distinguished reliably in the presence of fibrillation. Identifiable compression rates ranged from 60 to 210 min⁻¹, but most were too fast: 19 of the 27 downloads had compression rates exceeding 140 min⁻¹. Examples of rapid compressions are shown in Figure 1.
The number of downloads increased to 178 in 2005, of which 164 could be analyzed. Fewer were available in 2006 for manual compressions because of the brief introduction of mechanical compression, but 123 of 137 could be analyzed. Figure 2a and b show the considerable improvement in mean compression rates that followed feedback of the results to crews, and the progressive introduction of metronomes: not only did the mid-range rate fall to near ideal, but the variability was greatly reduced. Using the M–W test, the mid-range rate fell significantly from 2004 to 2005 ($p = 0.003$) and from 2005 to 2006 ($p < 0.001$). Intra-subject variation in compression rate, expressed as the range, likewise fell significantly from 2004 to 2005 (M–W $p < 0.001$) and probably also from 2005 to 2006 ($t$-test $p = 0.004$, though M–W $p = 0.25$).

Pauses in compression

We also observed considerable improvement in unexplained, prolonged ‘hands-off time’ without compressions. These were almost certainly related to interruptions for intubation, drug administration, and moving patients during the resuscitation attempts. From each patient’s record, we extracted the duration of the longest individual pause. In the first two quarters of 2005, the typical (median) longest individual pause durations were 34 and 23 s, respectively. The longest pause recorded was a full 7 min. During the subsequent six quarters, the comparable medians were, with one exception, less than 15 s. Histograms for the three calendar years are shown in Figure 3. The duration of the maximum pause was significantly less in 2006 than 2005 (M–W $p = 0.02$). Pause data were available for only 16 downloads in 2004; comparing 2005 with 2004, statistical significance is not attained ($p = 0.26$). The duration of most ventilatory pauses, recognized by recurring sequences of compressions interspersed with pauses of similar duration, was acceptably brief, with a median of 6 s in 90 analyzable downloads.

Those downloads that showed long pauses often also showed excessive compression rates. Figure 4 shows one example of very poor practice that was, fortunately, from a case in which survival was in any case most unlikely. Most recent downloads have not only shown compressions at satisfactory rates with briefer pauses but, importantly, they have generally continued to within a few seconds of a shock being given, with prompt resumption afterwards in accordance with our protocol. The median delay from last compression to shock in 2006, calculated from 28 downloads in which compressions could be clearly seen even during VF, was 2 s; the median delay from shock to resumption of compressions was 3.5 s. An example is shown in Figure 5.

Outcome

In 2003, before any attempt had been made to change practice, 202 patients were admitted from the principal area of our study to the Royal Sussex County Hospital with on-going CPR or a spontaneous pulse, but only two were discharged alive. In 2004 and 2005 as the policy of moving patients during cardiac arrests was discontinued, the admission figures were respectively 196 and 139, but hospital discharges increased to 7 and 17.

In assessing the statistical significance of this striking year-on-year increase in patients discharged alive, we were mindful that a comparison of the proportions surviving would overestimate the improvement in outcome: the falling denominators over the 3 years were influenced by the restricted transport policy. Instead, we base the statistical analysis solely on the numerators, 2, 7 and 17. Even if we make the over-conservative assumption of a 20% year-on-year increase in potential caseload due to population growth and ageing, the resulting improvement in survival remains statistically significant (chi-square = 8.02, d.f. = 2, $p = 0.02$).
Figure 2a  The panels in column A show histograms for the averaged compression rates during each resuscitation attempt recorded in 2004, 2005 and 2006. The figures were derived by averaging maximum and minimum rates recorded during the first 5 min. The vertical line represents the target rate of 100 min$^{-1}$. Column B shows the inconsistency of rate (maximum minus minimum) during the same periods of the resuscitation attempts. Further details in text.
Figure 2b  A graphical representation of the improved adherence to compression rate guidelines during the course of the observational study. The central line represents the median rate in each time period and the outer lines the medians of the fastest and slowest rates in the first 5 min of each download. The separation of the lines is therefore a measure of the variability of compression rates.

Discussion

We believe that our observations have an important bearing on the lack of improvement in outcome from out-of-hospital cardiac arrest in recent decades. Increasingly, emphasis in both initial and refresher training has been away from basic life support with results that have been detrimental or even disastrous. Tracheal intubation has clear potential benefits but difficulties in achieving it in emergency situations may lead to increased morbidity and mortality. Moreover, no drug has been proven to increase survival to discharge from hospital; only basic life support and defibrillation have been shown definitely to improve survival after cardiac arrest.

We know that our findings are not confined to one ambulance service. When our results were made known to colleagues in three other services, exactly similar problems were found in limited download surveys, and similar measures were used to correct them. It seems likely that the problem is a general one, and that procedures should be adopted that will permit on-going monitoring and feedback.

Initially, only a minority of compressions were delivered at an appropriate rate; the majority were given too rapidly. Fast compression rates are not widely perceived as a problem. The 2005 Consensus on Science recommends 'at least 100 compressions per minute' and quotes observational studies to emphasise that rates tend to be too slow. Only the last of these was an out-of-hospital study: whilst the number of compressions per minute tended to be inadequate, the rates when compressions were actually given were similar to those in our own experience. It seems that rates for out-of-hospital compression are faster when given by healthcare professionals than when delivered by first responders: one recent, large study of downloads from railway stations and airports found a median rate of 120 min⁻¹. Moreover, the method of observation may have a bearing on compression rates. Subsequent analysis of downloads stored in electronic form has the great advantage that it is not intrusive. Obvious real-time monitoring might artifi-

Figure 3 Histograms for maximum duration of non-ventilatory pauses for 2004, 2005 and 2006.
A download of one unsatisfactory download recorded early in the series. In this instance, the whole resuscitation attempt lasted only 5 min 39 s, during which time 140 compressions were given at an average rate of 167 min$^{-1}$ with 85% of the period showing untreated asystole. Only one sequence was of the correct length. The prognosis in this case was totally unfavourable: this no doubt influenced performance.

Figure 5  An example of a very brief interval between last compression and charging of the defibrillator (less than 2 s) and of the re-starting of compressions very soon after the shock (about 2 s) as recommended in our own current protocol.
leading European ambulance services, reported compression depth in 176 adult cardiac arrests. In 62% of cases the depth was less than the minimum recommended in the guidelines, whereas in none was it too deep. A subsequent publication confirmed the effect of adequate depth on outcome\textsuperscript{12} reflecting the impact on aortic pressure and blood flow shown in experimental data using a mechanical device.\textsuperscript{23} Compression depths that were less than that recommended resulted in successful shocks in less than 60% of cases; at the recommended depth the figure was 88%, and even higher in the small number of cases in which compressions were deeper than the guideline recommendations. Even healthcare professionals share the fear, common in lay rescuers, of causing injury by forceful compressions\textsuperscript{24} without sufficient appreciation that survival may depend on them.

Adequate release of compressions has also been shown to have important effects on the circulatory response, and has been found frequently to be defective when analyzed.\textsuperscript{25} We have no reason to believe that performance in our ambulance service had been any better in terms of depth or release of compressions than has been found elsewhere, and our own limited visual observations suggested that, here too, there was much scope for improvement, now addressed during refresher training.

Professional basic life support has shown a tendency to other errors that impact adversely on success. Ventilations tend to be given too rapidly, too frequently, and often too forcefully. This compromises venous return and, therefore, forward flow during compressions to a degree that can prevent successful resuscitation.\textsuperscript{26} This occurs even if ventilatory pauses are not prolonged. Our novel protocol limits the number of ventilations: none are given for at least 2 min—twice that period in cases with a shockable rhythm. We attempted no systematic observations of ventilation rate in this study.

We recommend, without reservation, the use of audible prompts to achieve and maintain appropriate compression rates, as others have done previously.\textsuperscript{27} Ideally, these should be built into all automated defibrillators, as indeed is increasingly the case. Unobtrusive systematic examination of downloads is excellent for revealing deficiencies in some aspects of basic life support, as shown by ourselves and by others\textsuperscript{13,16} but is very time consuming; it cannot be achieved as a routine without experienced staff committed to the task. Analysis of only a sample of downloads may be more practical for widespread use. Technology may render even this compromise unnecessary: the availability of automated, real-time analysis and instant feedback on resuscitation variables is now feasible\textsuperscript{28} and can improve performance during out of hospital arrests.\textsuperscript{29} Such devices will become more readily available and will help to guide best practice in basic life support. A method for uniform reporting of measurements of the quality of CPR, obtainable from new technology, has recently been published.\textsuperscript{30}

Limitations of the study

Analysis of waveforms from electronic downloads cannot be totally free from occasional subjectivity, but we took care to discard data for which real doubt existed. The audit developed progressively over the time of the data collection so that detailed epidemiological data cannot be provided. Over the time of our observations, three distinct changes occurred. The first was the adoption of a new resuscitation protocol (ahead of the official guideline change) the second was the introduction of retrospective observation and feedback; the third was abandoning the practice of moving patients during CPR. The improvements in outcome that we observed were restricted to data from one hospital. Small numbers gathered over consecutive periods during which three variables changed cannot be added as evidence for the benefit of any one. It is, nevertheless, reasonable to believe that greater emphasis on compressions with retrospective surveillance of performance were responsible for the improvement in survival. The effect on staff morale and increase in expectation of success were additional unquantifiable benefits.

Conflict of interest statement

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References


