The first description of modern cardiopulmonary resuscitation (CPR) included the instruction to compress the chest “about 60 times per minute”\(^1\); however, the optimal compression rate was unknown. Franz Koenig is credited with describing the original technique for external cardiac massage, which included a compression rate of 30 to 40 per minute.\(^2\) But in the first published description of external cardiac massage in 1892, Friedrich Maass documented a better clinical response with a rate of 120 per minute.\(^3\) To this day, the optimal compression rate is the subject of controversy. Animal data indicate that cardiac output increases with compression rates up to as high as 150 per minute.\(^3\) In a canine model of prolonged cardiac arrest, compression rates of 120 per minute compared with 60 per minute increased mean aortic (systolic and diastolic) and coronary perfusion pressures, and 24-hour survival (61% versus 15%, \(P=0.03\)).\(^4\) In a study of 9 patients undergoing CPR, a compression rate of 120 per minute generated higher aortic peak pressures and coronary perfusion pressures compared with a compression rate of 60 per minute (the rate recommended by the 1980 American Heart Association [AHA] guidelines). This evidence is supported by another study of 23 patients in cardiac arrest in which compressions at 120 per minute resulted in significantly higher end-tidal carbon dioxide values compared with compressions at 80 per minute.\(^5\)

After a systematic review of the available evidence, the 2010 International Liaison Committee on Resuscitation consensus on CPR science with treatment recommendations stated that chest compression rates for adults in cardiac arrest should be at least 100 per minute, and that there was insufficient evidence to recommend a specific upper limit for compression rate.\(^7\) There was also a recommendation for deeper (≥50 mm) chest compressions. Based on the International Liaison Committee on Resuscitation statement, the current guidelines from the AHA recommend using a chest compression rate of at least 100 per minute and a compression depth of at least 50 mm.\(^8\) The 2010 European Resuscitation Council guidelines differ slightly in that an upper compression rate limit of 120 per minute and depth of 60 mm are recommended.\(^9\)

In this issue of Circulation, Idris and fellow Resuscitation Outcomes Consortium investigators\(^10\) report on the relationship between chest compression rates and outcomes after out-of-hospital cardiac arrest in adults at 9 North American sites. The authors are to be congratulated on this large observational study, which adds valuable new data to the debate on the optimal compression rate. Compression rates were recorded by monitor-defibrillators from changes in thoracic impedance measured by defibrillation pads or from an accelerometer placed on the patient’s sternum. The authors have importantly provided a precise definition for chest compression rate—the actual rate used during each continuous period of chest compressions within a 1-minute interval independent of pauses (lasting either ≥2 or ≥3 seconds depending on which model of defibrillator-monitor was being used). The delivered chest compressions were defined as the actual number of chest compressions delivered during a 1-minute interval, thus taking into account any interruptions in chest compressions. The mean chest compression rates and mean number of delivered chest compressions were determined from data collected during the first 5 minutes of CPR after the monitor-defibrillator was attached.

Of 15,876 patients receiving CPR, 3098 (19.5%) had analyzable CPR process data. During the 5 minutes of CPR analyzed, the mean compression rate was 112±19 per minute and the mean number of delivered chest compressions was 74±23. The authors did a post hoc exploratory analysis and plotted the relationship between chest compression rate and survival, and chest compression rate and ROSC on an adjusted natural cubic spline curve. With this analysis, the authors determined that compression rate was associated with ROSC (\(P=0.012\)) but not survival to discharge (\(P=0.63\)). The curve for ROSC peaks at a compression rate of 125 per minute. When interruptions to compression...
were taken into account, the number of delivered compressions each minute was also associated with ROSC ($P = 0.01$) but not with survival ($P = 0.25$). Compared with a reference range of 75 to 100 delivered compressions per minute, those receiving <75 delivered compressions per minute had a reduced ROSC rate (adjusted odds ratio 0.81; 95% confidence interval 0.68, 0.98; $P = 0.03$).

The authors have identified the principle weaknesses of their study—it was a retrospective analysis and only 20% of the treated patients had electronic CPR process files, and data relating to other chest compression variables (compression depth, leaning [failure to allow the chest wall to fully recoil at the end of each compression], and duty cycle [percent of time the chest is compressed versus time allowed for chest recoil]) are not reported.¹¹ Despite adjustment for confounders and these being the best data available, one should question the validity of conclusions drawn from only the first 5 minutes of monitored CPR from a potentially much longer period of CPR both before or after the period analyzed. There is some selection bias because there are differences in some characteristics between the analyzed and nonanalyzed cohorts (not least being the higher rate of ROSC in the analyzed cohort). Furthermore, those Resuscitation Outcomes Consortium emergency medical services using recording defibrillator monitors might conceivably provide CPR of higher quality compared with those not using such devices. A small but nevertheless significant proportion (12%) of the sample studied had CPR feedback technology devices enabled. This technology measures and provides real-time feedback, often with prompts to rescuers, on the quality of CPR such as compression rate, depth, and presence of leaning. These devices are known to influence CPR adherence with guideline recommendations but lack robust data for an impact on outcome.¹²,¹³ Although the authors adjusted for known factors that could influence outcome (sex, age, bystander-witnessed arrest, emergency medical services–witnessed arrest, first known emergency medical service rhythm, attempted bystander CPR, public location, and site location) it remains possible that some unmeasured confounding factor (such as the emergency medical services clinician impression of survivability) might have influenced the compression rates. Finally, this study took place when rescuers were following guidelines published in 2005. At the time of data collection, the recommended rate for chest compressions was “about 100” per minute and the recommended depth was 40 to 50 mm.¹⁴

Despite the acknowledged limitations, this study is important because it demonstrates again that those receiving fewer delivered compressions (<75 per minute), because of lower compression rates or more frequent interruptions, are less likely to achieve ROSC. The cubic spline curve for ROSC also suggests that ROSC rates might decline with compression rates >125 per minute.

What are the implications of the study findings on practice guidelines for manual CPR? First, one must remember the importance of education and implementation. Studies consistently show a marked variation in CPR quality in the real world despite the content of the guidelines.¹⁵ Indeed, the chest compression rates in the current study varied widely from the rate of 100 per minute recommended at that time.

We need to close the gap between what the guidelines say and what actually happens in practice. Recommendations have to be easily learnt, easy to remember, and easy to apply in actual cardiac arrests and not just in the classroom.

Next, when making recommendations for the optimal chest compression rate, the inter-relationship between the rate and other chest compression variables must be considered. Human observational studies show deeper chest compressions are associated with improved shock success for terminating ventricular fibrillation and an increase in survival to hospital admission after out-of-hospital cardiac arrest.¹⁶⁻¹⁸ The impact of different chest compression rates on the other compression variables has been investigated in a randomized, controlled crossover trial using an instrumented manikin.¹⁹ Increasing chest compression rate (range 80–160 per minute) during 2 minutes of continuous compressions by trained rescuers increased the number of delivered chest compressions per minute and increased the duty cycle but at a cost of a reduced chest compression depth and an increase in the proportion of compressions with leaning. This study also showed that a chest compression rate of 120 per minute was feasible while maintaining an adequate chest compression depth.

The inverse relationship between compression rate and depth has also been observed during CPR after out-of-hospital cardiac arrest. Another large study from the Resuscitation Outcomes Consortium group showed that when the chest compression rate exceeded 120 per minute, most (70%) chest compressions were too shallow according to 2005 guidelines.²⁰ In a recent study of 133 patients requiring CPR for out-of-hospital cardiac arrest there was a clinically significant decline in chest compression depth once chest compression rates exceeded 120 per minute (personal communication, K. G. Monsieurs, May 14, 2012). In the present study, compression depth data were available for only 362 (11.7%) patients, but these data also showed that compression depth also declined with increasing compression rate. All of these studies concerning the relationship between compression rate and depth followed the 2005 guidelines. Whether these findings hold true when rescuers are asked to compress at a rate of 120 per minute and a depth of at least 50 mm (AHA) or 50 to 60 mm (European Resuscitation Council) according to the current guidelines remains to be seen.

The current study also reinforces previous evidence from the Resuscitation Outcomes Consortium group for minimizing interruptions to chest compressions.²¹ Even with the correct chest compression rate, pauses during CPR will decrease dramatically the number compressions actually delivered.

Friedrich Maass²² published his clinical observations on chest compressions 120 years ago: “I increased the compression rate to 120. Soon a carotid pulse wave corresponding to the increased chest compression rate was palpable.” The current mantra for those teaching, learning, and doing chest compressions is “push hard and push fast,” and the study by Idris et al¹⁰ provides further evidence for how fast. The sweet spot for manual chest compressions is a rate of about 120 per minute or, to put it simply, 2 compressions per second.

Disclosures

Dr Nolan is Editor-in-Chief of the journal Resuscitation (honorarium received), a board member of the European Resuscitation Council.
References


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