EMERGING TECHNOLOGIES
A Primer to Real CPR Help® Technology

Barbara Malanga, BSEE and Frederick J. Geheb, Ph.D.

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After more than a decade of focusing on AEDs and the early delivery of shocks, attention is shifting back to the maintenance of adequate blood flow during cardiac arrest. The move has prompted various groups, including the American Heart Association, Australian Resuscitation Council, European Resuscitation Council, Heart and Stroke Foundation of Canada, and others to focus on and update their recommendations related to delivery of chest compressions.

To some the turning point stems from the Weisfeld/Becker[1] three-phase model of resuscitation. This model tells us the optimal period for shock delivery is the 4 minutes immediately following cardiac arrest (the Electrical Phase). During the Circulatory Phase (approximately 4 to 10 minutes after the arrest), the optimal intervention is circulatory support. Evidence from human trials suggests reestablishing blood flow before attempting defibrillation improves both shock efficacy[2] and survival.[3]

Key Words: Cardiac Arrest • Cardiopulmonary Resuscitation • Chest Compressions • CPR • CPR Feedback • CPR Prompting • Pulseless Electrical Activity • ROSC • Ventricular Fibrillation

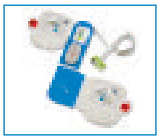
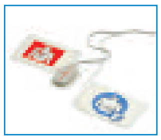
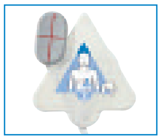
Effective CPR is crucial for victims of sudden cardiac arrest, and "good quality" chest compressions are crucial for effective CPR. The latest guidelines recommend compressions be delivered at a rate of 100 per minute, at a depth of 1.5 to 2 inches, with minimal interruptions. The latest guidelines[4] attempt to simplify the recommendation by describing it as "Push hard, push fast, and don't stop."

When objectively evaluated, chest compression delivery by trained professionals repeatedly falls short of recommended thresholds. In-hospital studies find compression rates fail to meet recognized guidelines. A landmark study reported 37 percent of the 30-second segments analyzed from hospital codes had compressions delivered at less than 80 per minute.[5] A second paper reported compression depth as variable and too shallow.[6] A groundbreaking out-of-hospital trial reported most compressions are less than the recommended depth, with only 28 percent of them falling within the target range of 1.5 to 2 inches.[7]

These studies[5-7] raised further concern about the frequency with which compressions are interrupted. Even brief compression pauses substantially compromise circulatory support, as it takes up to seven compressions to restore pre-interruption blood flow levels.[8-9] After accounting for necessary pauses (rhythm analysis, shock delivery, ventilation, etc.), one study reported chest compressions were still absent 38 percent of the time when they should have been done.[7]

The importance of chest compressions, and mounting evidence that they are not effectively performed resulted in the *American Heart Association Guidelines 2005* suggesting the use of technology to improve chest compressions.[4] Previous studies had shown promise that compression delivery can be improved with feedback systems. An early study showed that an audible pacing tone for compressions resulted in a marked increase in expired end-tidal carbon dioxide levels suggesting better CPR performance.[10] Other work has shown improvements in both rate and depth when CPR feedback technology is used.[11-15]

Table 1: Real CPR Help Compatible Electrodes

Electrode		Description
CPR-D • padz®		A one-piece electrode designed for use with ZOLL AEDs expected to be used by lay responders. The CPR sensor located in the center provides a convenient landmark for hand placement and makes it easy to place it on the victim.
CPR stat • padz® II		Designed for use with manual defibrillators, the two piece construction ensures all therapy options are available for ALS providers.
OneStep CPR OneStep™ Complete		Designed for use with Code-Ready defibrillators, this electrode also eliminates the need for separate ECG cables for pacing and is automatically checked daily for state of readiness, expiration date, and gel condition.

CPR Aids: Prompting vs. Feedback

The number of CPR technologies coming to market in the wake of the *Guidelines 2005* publication creates a challenge for those evaluating their options.

CPR Prompting

CPR aids of this type focus on prompting the start and stop of compression delivery cycles. Blind to the characteristics of the compressions themselves (i.e., rate and depth), these technologies cannot claim to improve delivery.

First and second generation AEDs designed for the Public Access user offer this most rudimentary CPR aid. They tell providers when to start (i.e., “START CPR” or “IF NO PULSE DO CPR”) and stop chest compressions (i.e., “STOP CPR”).

CPR Feedback

This type of CPR aid helps providers to deliver better compressions. They are markedly different from simple prompting devices, in that they give caregivers feedback on their performance.

These tools actually “see” the compressions and guide the caregiver toward effective performance. CPR Feedback aids offer help in the form of prompts (tonal, voice and visual) that urge one to “PUSH HARDER” if the depth is too shallow, and report “GOOD COMPRESSIONS” when they are within guidelines. Some include a metronome to set the proper pace for compressions.

The CPR Feedback Pioneer

The first commercial AEDs/defibrillators to incorporate CPR Feedback were brought to market by ZOLL Medical Corporation. *Real CPR Help®* is real-time feedback that is a standard feature on all defibrillators and AEDs introduced by ZOLL since 2002. The technology utilizes a pioneering CPR sensor that tracks the up and down movements of the chest during compressions.

Designed with simplicity in mind, the CPR sensor is embedded into a family of defibrillation electrodes (see Table 1). This innovative approach adds CPR Feedback without requiring caregivers to take the additional, time-consuming steps related to handling a separate measurement device and its related cables.

The CPR sensor incorporates an accelerometer that measures displacement of the chest as it moves up and down. Its prominent mid-sternum location serves as a convenient landmark for hand placement.

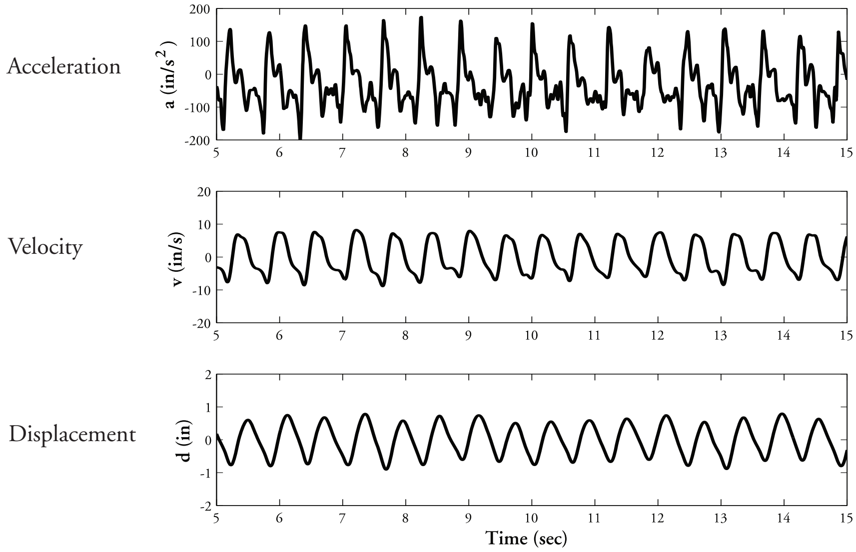
Reliable CPR Detection

The environments in which some defibrillators and AEDs are used include movement on gurneys and in ambulances. This movement creates the challenge of separating real compressions from extraneous motion.

CPR is protocol driven when used with AEDs. The voice prompts to start and stop CPR define the boundaries of a CPR cycle. The unit activates the *Real CPR Help* functions this paper describes between these boundaries.

Detecting chest compressions is more challenging with manual defibrillators because the user dictates the beginning and end of CPR cycles. *Real CPR Help* technology uses a CPR-cycle detection algorithm in

Figure 1: Acceleration, velocity and displacement waveforms recorded by the CPR Sensor.



manual defibrillators to differentiate between real compressions and motion-related artifact. This insures feedback is only given when valid chest compressions are being performed.

The algorithm works by analyzing the incoming acceleration signal for characteristics representing true compressions. The characteristics are examined within a 3-second sliding window.

These values, as well as the presence or absence of detected compressions in the previous 3- to 5-second window, are used to determine if CPR compressions are present. The algorithm recognizes the presence of compressions within 3 to 8 seconds after the start of a CPR cycle. There is a 10-second delay in recognizing the termination of compressions. This is done to accommodate the short pauses required for giving breaths or delivering a shock.

The CPR-cycle detection algorithm was tested against a database of CPR records from out-of-hospital field cases. It demonstrated 100 percent sensitivity for detecting chest compressions. When tested against a database of waveforms collected from the use of ZOLL AEDs in the back of an ambulance, the algorithm demonstrated 100 percent specificity; it rejected all 220 instances of motion-caused artifact.

Real CPR Help Feedback

Real CPR Help uses rate, depth and duty cycle to guide caregivers toward delivering compressions that meet recognized guidelines. Further, on manual defibrillators it integrates them into a unique visual indicator that lets one instantly see the quality of their effort.

Compression Depth Feedback

Defibrillators equipped with *Real CPR Help* employ visual and verbal cues to give feedback on chest compression depth. Depth is measured by filtering and converting the acceleration signal obtained from the CPR Sensor into displacement (i.e., up and down) and reported in inches or millimeters (see Figure 1).

The peak-to-peak amplitude of the displacement waveform represents the depth of compression. A sliding window of 5 compressions is analyzed. If the recorded depth fails to achieve 1.5 inches in 3 of the 5 compressions, the unit periodically generates a voice prompt that says, "PUSH HARDER." When the 1.5 inch threshold is achieved in 2 of 3 compressions in a sliding window, the "GOOD COMPRESSION" voice prompt is heard.

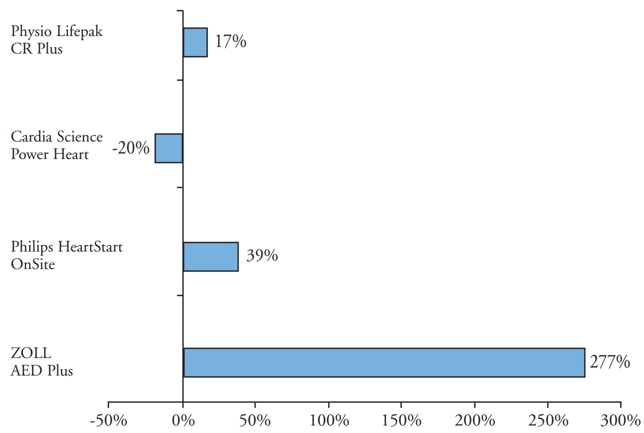
Accuracy of the depth feedback mechanism was validated by comparing the compression depth measured by the CPR sensor to measurements independently recorded by an instrumented manikin capable of measuring the compression rate and depth. Measurements were recorded while 20 minimally trained rescuers performed compressions for 45 to 60 seconds on a manikin in the absence of any feedback.

The CPR sensor and test fixture were within 0.05 inches on average (Table 2). This finding establishes the compression depth measurement to be ±0.25 inches 95 percent of the time (95 percent confidence limit). The value of compression depth feedback is supported in a

Table 2: Displacement (Depth) Feedback Validation

	Mean Displacement (Inches)	Standard Deviation (±Inches)
Test Fixture	1.830	0.514
Defibrillator	1.878	0.496
Average Difference	0.048	0.130

Figure 2: Improvement in Depth of Compression with Real CPR Help



study of untrained lay rescuers that demonstrated a 270 percent improvement in chest compression depth when compared to unaided CPR[15] (see Figure 2).

Rate Feedback

Defibrillators and AEDs equipped with *Real CPR Help* have a metronome that paces rescuers at the recommended rate of 100 compressions per minute.

On AEDs, the metronome is enabled during all CPR cycles. It begins to beep following detection of the first few compressions, and continues to beep until the CPR period has ended or until compressions have stopped for more than a few seconds. On manual defibrillators, the metronome operates on a "by exception" basis. The beeps come on when compressions fall below recommended thresholds. It is silent when the rate is above threshold.

The rate is determined by measuring the interval between compressions on the displacement waveform (see Figure 1). Accuracy of the defibrillator's rate detection mechanism was validated by comparing the compression rate determined using the CPR sensor to the rate independently recorded by a compression-measuring device attached to a training manikin's chest. In all cases, the average rate differences between the defibrillator and the test fixture were less than 2 compressions per minute.

Using the method described above, rate was monitored for 20 minimally trained rescuers during 45 to 60 seconds of chest compressions, with and without feedback. Without feedback, only 30 percent of the rescuers achieved an adequate compression rate. When feedback was turned on, 75 percent achieved recommended rate thresholds.[15] Further, the frequency with which compressions were delivered at adequate rates rose from 58 percent to 94 percent of the time (see Table 3).

Idle Time Display

Manual defibrillators equipped with *Real CPR Help* display an elapsed time indicator when there is an extended gap between compressions. The timer appears 10 seconds after the last detected compression (see Figure 3).

It initially displays "0:10" and starts counting from there. The 10-second period allows short pauses (e.g,. delivery of breaths) to be overlooked, and yet provides an indication of longer interruptions.

The CPR Index

Manual defibrillators used during the confusion of a code or in the back of a moving ambulance are equipped with an innovative feature called the *CPR Index*™. The *CPR Index* is a single indicator that incorporates the three characteristics of compressions (i.e., rate, depth, and interruptions) into an at-a-glance status of chest compression delivery.

The *CPR Index* is based on a variant of the Windkessel physiologic model of the circulatory system. It is designed to indicate the cumulative positive effect of consistent "good quality" compressions. The indicator fills when chest compression delivery is within recommended guidelines. If delivery falls below recommended thresholds, it begins to empty.

Table 3: The Effect of Real CPR Help on the Rate of Delivered Compressions

	Without Feedback	With Feedback
Rescuers that achieved an average compression rate between 95 and 105 per minute.	30%	75%
Percent of time compression rate exceeded 90 per minute.	58%	94%

Figure 3: Idle Time and CPR Index indicators

The *CPR Index* incrementally fills with each detected compression. The filling amount varies with the quality of the compression. If a good compression is delivered, the indicator fills approximately 1/29. The *CPR Index* completely fills after about 20 seconds of good compressions.

If compressions are delivered at depths below 1.75 inches, the filling increment will be too small to achieve full inflation. When compression delivery falls below 90 per minute, they are not frequent enough to overcome the continuous emptying, so the indicator will never completely fill. This continuous emptying also allows the indicator to go from full to empty in 10 seconds after compressions are stopped.

See-Thru CPR™ Filter

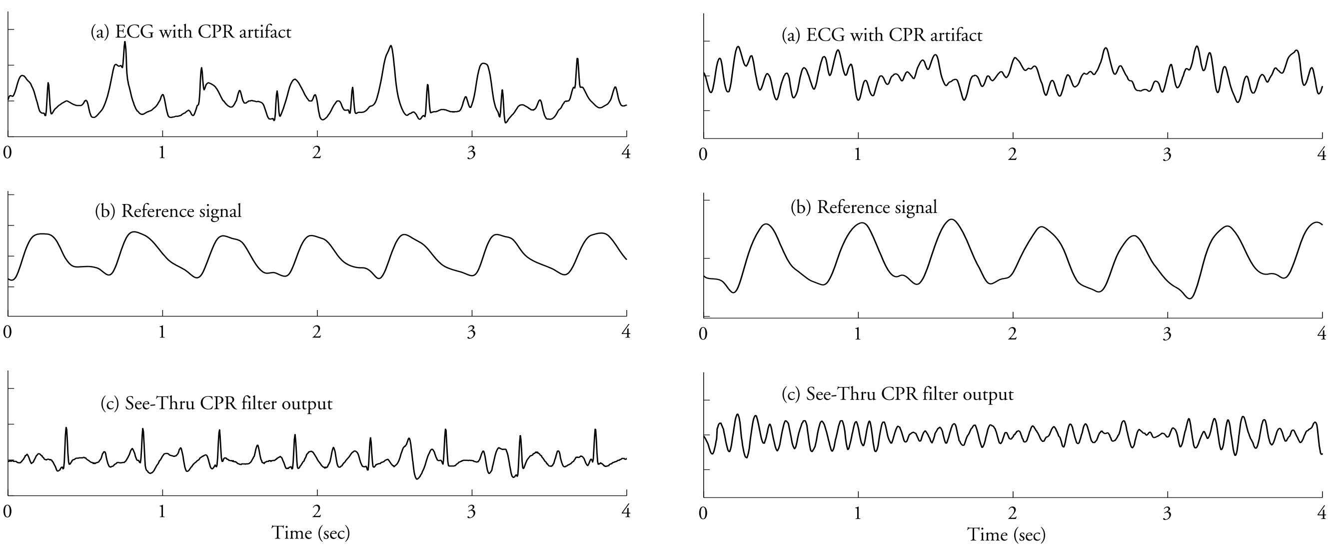
The *See-Thru CPR** filter, proprietary to ZOLL, minimizes interruptions to chest compressions delivery by reducing artifact caused by chest and electrode movement. This gives clinicians the ability to discern the presence of organized electrical activity without interrupting compressions.

This technology uses the output of the CPR sensor and employs an adaptive filtering technique. The initial step for removing the compression artifact is converting the acceleration signal into compression velocity. Next, the velocity signal is used to estimate the artifact the chest movement (Reference Signal) produces in the ECG signal. Finally, the estimated artifact is subtracted from the ECG with an adaptive filter (see Figure 4).

The *See-Thru CPR* filter reduces the artifact in the ECG by 70 to 90 percent. The filter is only activated during compression cycles so the ECG signal outside of these cycles remains unaltered.

Prominent course ventricular fibrillation rhythms (>500 µV), as well as those often associated with a return of spontaneous circulation (e.g., bradycardia), can often be visualized in the ECG during chest compression delivery when the *See-Thru CPR* filter is activated.

Figure 4: Effect of the See-Thru CPR Filter on Compression Artifact



When the *See-Thru CPR* filter was tested on 459 ECG episodes of shockable (n=200) and non-shockable (n=259) rhythms, with CPR compressions delivered at a rate of 90 cpm and an average depth of 2 inches, a >98 percent decrease in artifact amplitude was reported.[16]

While the *See-Thru CPR* is a useful tool for minimizing interruptions to chest compressions, as with all filters it has some limits. When the rhythm change is seen through the filter, only then should compressions be paused for the caregiver to confirm the rhythm.

Summary

Effective chest compressions remain a crucial link in the Chain of Survival for victims of cardiac arrest. In light of repeated findings that the quality of compressions delivered by trained professionals fails to achieve recommended levels, technology is increasingly expected to aid CPR delivery.

CPR Feedback, in all its forms, helps providers deliver chest compressions that are in line with recognized guidelines and recommendations.

Real CPR Help and *See-Thru CPR* represent a breakthrough in CPR feedback. They are designed to aid providers to meet the recommended guidelines and optimize the victim's chance for survival. The day when caregivers deliver unaided chest compressions is coming to an end.

About the Authors

Barbara Malanga - holds a B.S. in Electrical Engineering, with a specialization in Biomedical Engineering, from the College of Engineering at Rutgers University. She worked with ECRI for 10 years, where she performed comparative evaluations of non-invasive cardiology equipment, and was their resident defibrillator expert. She has been working as an Independent Consultant to industry since 1998.

Frederick J. Geheb - holds a PhD and MS in Bioengineering, along with a MSE in Computer Engineering from the University of Michigan, Ann Arbor, MI, and a BSE in Electrical Engineering from Oakland University, Rochester, MI. He has over 25 years experience with the design of medical equipment and signal processing with companies such as GE Medical Systems and Siemens Medical. Dr. Geheb is presently the Senior Director of Advanced Development for the ZOLL Medical Corporation.

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