Prompt administration of high-quality cardiopulmonary resuscitation (CPR) is a key determinant of survival from cardiac arrest. Strategies to improve CPR quality at point of care could improve resuscitation outcomes. We tested whether a low cost and scalable mobile phone– or smart watch–based solution could provide accurate measures of compression depth and rate during simulated CPR. Fifty health care providers (58% intensive care unit nurses) performed simulated CPR on a calibrated training manikin (Resusci Anne, Laerdal) while wearing both devices. Subjects received real-time audiovisual feedback from each device sequentially. Primary outcome was accuracy of compression depth and rate compared with the calibrated training manikin. Secondary outcome was improvement in CPR quality as defined by both guideline-recommended compression depth (5 to 6 cm) and rate (100 to 120/minute). Compared with the training manikin, typical error for compression depth was <5 mm (smart phone 4.6 mm; 95% CI 4.1 to 5.3 mm; smart watch 4.3 mm; 95% CI 3.8 to 5.0 mm). Compression rates were similarly accurate (smart phone Pearson’s R = 0.93; smart watch R = 0.97). There was no difference in improved CPR quality defined as the number of sessions meeting both guideline-recommended compression depth (50 to 60 mm) and rate (100 to 120 compressions/minute) with mobile device feedback (60% vs 50%; p = 0.3). Sessions that did not meet guideline recommendations failed primarily because of inadequate compression depth (46 ± 2 mm). In conclusion, a mobile device application–guided CPR can accurately track compression depth and rate during simulation in a practice environment in accordance with resuscitation guidelines. © 2017 Elsevier Inc. All rights reserved. (Am J Cardiol 2017;120:196–200)
application monitored depth and compression rates after which measured parameters from both the mobile application and video were compared. Motion analysis software was used to track the motion of the hands during the CPR sessions from which compression data (depth, rate, and recoil) were calculated. The results were compared with results from video motion capture analysis to calibrate parameters in the mobile application. Calibration was also validated against a commercially available manikin CPR system (Resusci Anne, Laerdal, Norway) which uses a pressure sensor embedded in a manikin’s chest to determine the depth and frequency of compressions.

The study focused on evaluating 2 goals: the performance of the mobile smart watch and smart phone CPR assist application and the effectiveness of the real-time device feedback on CPR performance. The performance of the application was defined as the accuracy of compression depth and rate measurement compared with both a motion tracking software and to the Resusci Anne manikin. The timeliness and relevance of prompts generated during CPR and the perceived user reaction were used to judge the effectiveness of the real-time feedback. Each compression during a CPR session was analyzed beat by beat for rate and depth. A prompt was deemed relevant if it was detected at time when rate, depth, or recoil was inappropriate with resultant in improvement in CPR quality within the proceeding 2 or 3 compressions.

Participants (n = 50) consisted of intensive care nurses (58%) and other health care professionals (MDs, physical therapists, and clinical assistants). Most subjects were up to date on CPR qualifications with 78% reporting CPR retraining at least once every 2 years, and 58% who refreshed their CPR skills at least quarterly over the past year. Participants were asked to perform 3 CPR sessions on a Resusci Anne manikin while wearing both the smart watch and smart phone in the following manner: (1) participants performed CPR on the manikin blinded without any feedback (baseline); (2) real-time feedback using the smart watch—derived data only; and (3) CPR feedback was given from the smart phone—derived data only. Each session was 30 seconds in duration to avoid sequential fatigue. During each session, voice prompts from the manikin system were silenced and video displays hidden from the participants such that for sessions 2 (smart watch) and 3 (smart phone), subjects were guided solely by real-time visual session progress displayed on a computer tablet placed in front of the participant along with audio feedback prompts generated from either mobile device. Data were analyzed from each device (manikin, smart watch, and smart phone) for all 3 sessions, and participants were given an exit survey. The Texas Health Presbyterian Hospital Institutional Review Board approved the study.

Compression rate and depth measurements from the Resusci Anne manikin were considered to be gold standard for device application testing. Between devices, comparison is presented visually as Bland-Altman plots and statistically using Pearson’s correlation and typical error calculation comparing device performance to the Resuscitation Quality Initiative manikin reported compression depth and rate.

Results

Both smart watch and smart phone devices were validated using video motion capture software to measure depth. Both devices were highly accurate (Pearson’s R = 0.91) and had average typical error of 2.9 mm (95% CI 2.1 to 4.7 mm) for compression depth. Fifty subjects then underwent 3 simulated CPR sessions of 30 seconds each on a manikin (1, blinded with manikin system feedback prompts off; 2, smart watch—only feedback; 3, smart phone only feedback) as described in the methods. The average compression depth measured across 150 unique sessions by the Resusci Anne manikin (51 mm ± 5 mm), smart watch (52 mm ± 8 mm), and smart phone (52 mm ± 7 mm) were similar. There was a moderately strong relation between measurements from the CPR assist application from either mobile device (smart phone R = 0.6; watch R = 0.5) and manikin. Both devices were accurate compared with the manikin system over a range of compression depths (Figure 2). The average typical error between the manikin and smart phone was 0.6 mm.
and either smart phone (4.6 mm; 95% CI 4.1 to 5.3 mm) or smart watch (4.3 mm; 3.8 to 5.0 mm) was <5 mm of compression depth. Approximately 5% of sessions using the smart watch and 7% of smart phone resulted in “shallower” compression error of >10 mm compared with the manikin (ie, mobile device reported compression depths that were 10 mm higher than “true” depth). Conversely, 6% of smart watch and 4% of smart phone sessions reported compression depth error “deeper” than 10 mm compared with the manikin system. Of all sessions, 2% were below the lower target compression depth of 50 mm and 2% were above the upper depth target of 60 mm. Compression rates measured by both mobile devices were highly accurate compared with the manikin system (Figure 3). Compression rates correlated well across a range of compression frequencies.

To evaluate the relevance of device feedback prompts, beat-by-beat compression data from all sessions were analyzed. A feedback prompt was defined as relevant if it identified rate or depth metrics outside the defined parameter range (100 to 120 compressions/minute for rate; 50 to 60 mm for depth). If a subject corrected the deficiency within the subsequent 2 to 3 compressions, it was categorized as a successful prompt (Figure 4). Per session, prompts were found to be successful in 98% of the time if compression rate was incorrect, 97% if recoil was not adequate, and 99% if compression depth was incorrect. On average, subjects received 2 prompts during each 30-second CPR session in 50% of sessions and more than 5 prompts in approximately 30% of testing sessions.

Sessions were graded in binary terms if they met or did not meet both recommended compression depth and rate as measured by the Resuscitation Quality Initiative manikin. Without feedback, 50% of sessions met both criteria for depth and rate. With feedback from either mobile device, the number of sessions meeting compliance increased to 60% (p = 0.3) with the majority of suboptimal sessions occurring because of inadequate depth (46 ± 2 mm). All subjects reported feeling feedback from either mobile device was appropriate with regard to prompt relevance and frequency of prompts (Table 1). The majority felt ergonomically comfortable with the smart watch, but fewer felt comfortable wearing the smart phone, particularly those with no formal CPR training (30%).

Discussion
In this study, we describe the effectiveness of wearable mobile device technology in facilitating high-quality CPR. Both smart watch and smart phone derived metrics were highly accurate in measuring compression rate, and both devices had similar degrees of accuracy when
measuring compression depth (<5 mm). Audio and visual feedback prompts from both devices were timely and appropriate.

Delivering high-quality CPR at the point of care remains a persistent public health challenge. With nearly 325,000 arrests in the United States alone and 90% mortality rates, sudden cardiac death is a leading cause of the death globally. Prompt administration of high-quality CPR has been shown to improve outcomes and a number of feedback devices have been developed to address this gap in performance. Devices that monitor CPR compression quality range from simple metronomes to more complex instruments measuring compression depth using either accelerometers or pressure/resistance springs. To date, 2 such devices have been tested clinically. The Cardio First Angel is a hand-sized nonelectronic, compression spring-based system that is applied to the center of the chest. In a study of 80 intensive care unit patients, those randomized to the Cardio First Angel had a nearly twofold greater increase in return of spontaneous circulation nor survival to discharge. Of note, audio prompts were muted by paramedics in 14% of events and average compression depths were below current (post 2010) recommended guidelines of at least 50 mm potentially explaining the null result with regards to patient outcomes. Similar studies using sensors placed in defibrillator pads have had similar null results but have also been confounded by adherence to older 2005 AHA guidelines for compression depth (38 to 50 mm).

In our study, the mean depth of compression was approximately 51 mm across all devices and with only 4% of sessions above or below the guideline recommendation of 50 to 60 mm. With mobile device feedback active, 60% of sessions fulfilled both depth and rate criteria for high-quality CPR assessed by pressure and rate sensors embedded in the manikin. Most “failures” were due to inadequate depth which on average was 4 mm below the lower recommended limit of 50 mm. Previous studies have suggested minimal differences in return of spontaneous circulation or survival to discharge between compression depths of 46 to 50 mm.

The baseline skill of the tested group was high with 50% of blinded (nonfeedback) sessions meeting guideline depth and rate. Previous reports suggest CPR quality even among health care professionals is quite poor with adequate compressions achieved in only 10% to 18% of resuscitations. Almost 80% of the present study group reported receiving regular and formal CPR refresher training which may have confounded the ability to detect significant improvement in CPR quality. Regardless, all participants reported finding the visual depiction of each compression on a large computer tablet with clearly defined and highlighted depth targets helpful in maintaining a narrow compression range of 1 cm. From an ergonomic standpoint, users reported feeling comfortable with the smart watch with fewer reporting comfort using the smart phone placed in an arm-band around the bicep. In a small study testing depth recordings of a similar mobile-based application, a smart phone gripped within the hands while performing CPR was felt not to be accurate due to slippage.

As mobile devices become ubiquitous, the scalability of medical technology and cost-effectiveness of mobile applications improves. Efforts to empower bystanders and health care workers in developed and developing countries could lead to the development of a wide network of well-equipped first responders. The ability to review and debrief after a CPR event can further enhance training, either instructor led or self-directed (Supplementary Figure 1). Resuscitation data may even be aggregated across an institution by storing event data in a secure network server allowing for institutional review and assessment of CPR quality. Furthermore, parameters in the software application can be quickly modified in the event of future changes in CPR recommendations, effectively ensuring rapid, cost-effective dissemination, and implementation of evidence derived guidelines, with the ultimate goal of facilitating improvement in resuscitation outcomes.

Disclosures

The authors have no conflicts of interest to disclose.
Supplementary Data

Supplementary data related with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.amjcard.2017.04.007.


