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# The quality of chest compressions by trained personnel: The effect of feedback, via the CPREzy, in a randomized controlled trial using a manikin model<sup>☆</sup>

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Chest compliance;  
CPREzy

**Summary** Even after training, the ability to perform effective cardiac compressions has been found to be poor and to decrease rapidly. We assessed this ability with and without a non-invasive feedback device, the CPREzy™, during a 270 s CPR session in an unannounced, single-blinded manikin study using 224 hospital employees and staff chosen at random and using a non-cross over design.

The two groups self-assessed their knowledge and skills as adequate. However, the control group ( $N=111$ ) had significantly more difficulty in delivering chest compressions deeper than 4 cm (25 versus 1 candidate in the CPREzy group),  $P=0.0001$ . The control group compressed ineffectively in 36% ( $\pm 41\%$ ) of all compressions as opposed to  $6 \pm 13\%$  in the CPREzy™ group ( $N=112$ ,  $P=0.0001$ ). If compressions were effective initially, the time until >50% of compressions were less than 4 cm deep was  $75 \pm 81$  s in the control group versus  $194 \pm 87$  s in the CPREzy™ group ( $P=0.0001$  [ $-180$  to  $-57.5$ ]). After a few seconds of training in its use, our candidates used the CPREzy™ effectively.

<sup>☆</sup> A Spanish translated version of the summary and keywords of this article appears as Appendix in the online version at [10.1016/j.resuscitation.2005.08.008](http://10.1016/j.resuscitation.2005.08.008).

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Against the background knowledge that estimation of compression depth by the rescuer or other team members is difficult, and that performing effective compressions is the cornerstone of any resuscitation attempt, our data suggests that a feedback device such as the CPREzy™ should be used consistently during resuscitation.  
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## Introduction

Hospitals are settings to which the 'chain of survival' applies. Interest has recently shifted from improvements in advanced cardiac life support towards improvements in basic life support (BLS). As in any other emergency medical system, in our hospital first responders provide basic life support until the rapid response team (RRT) arrives. The first responders continue to assist as needed, for example in performing the chest compressions. The importance of consistent and adequate chest compressions has been stressed,<sup>1,2</sup> with extrapolation suggesting that chest compressions may be the crucial factor in improving outcome.<sup>3,4</sup>

All personnel in our hospital, not only nursing staff, participate in structured, intensive training and certification, but the frequency of training may be too low to guarantee continuing adequate skills. Loss of skills has been observed as early as a few days after training.<sup>5,6</sup> A further complicating factor is the poor ability of rescuers to assess their own resuscitation skills,<sup>7,8</sup> and those of others, especially in actual cases of resuscitation.<sup>9</sup> Feedback has now been introduced<sup>10</sup> to reduce subjective evaluation of rescuers during external chest compressions. Initial tests have been encouraging.<sup>11,12</sup>

For the purpose of expanding these tests and to gain further understanding of the mechanical engineering involved, we performed two types of evaluation with the CPREzy™ (Health Affairs, London, UK). These were: (1) assessment of compression skills of hospital personnel with and without the use of the non-invasive feedback device, and (2) description of the indicators on the CPREzy™ as a mechanical model on a stiff surface with and without an underlying manikin or human chest.

## Materials and methods

All medical, nursing and support staff members in our hospital were eligible for participation in the study. Over a period of 10 days, during which no training was being given, and using a roster to insure representation of different departments, the investigators toured the hospital, recruiting staff as they

were seen. By referring to management support if needed, staff could not 'bow out' using work load, other tasking, or even coffee breaks as excuses.

Candidates were 'asked' individually to come to a quiet, private, location where the assessment was to be performed. The first questionnaire (Appendix A) was filled out, followed by randomization to the 'control' or 'Ezy' group, and a standardized briefing given. Assessment followed using one of four SkillReporter Resusci Annes (Laerdal, Stavanger, Norway). The practical session, with ventilation being performed by an investigator who offered neither suggestions nor comments, continued for at least 240 s, but no longer than 270 s. This period reflects the maximal time a caregiver might be expected to perform chest compressions over one uninterrupted period in our hospital, as set out in the hospital resuscitation standing orders. It was deemed to be long enough to allow for fatigue, as suggested by Baubin.<sup>13</sup> After the practical session, a second questionnaire (Appendix B) was filled out. The candidate was also asked to sign a form giving permission to use the data, and to access their training database. The two questionnaires and the print out from the SkillReporter were labelled with a unique randomization number. Two investigators experienced in the use of the standardized scoring system, blinded for the randomization, scored the results based on a fixed list of variables (Table 1), and entered directly into the SPSS database. The candidate was not told how he/she had performed.

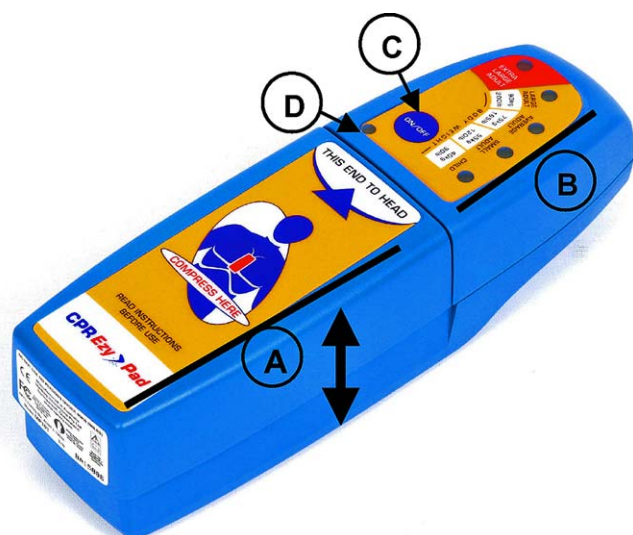
The candidates randomized to the 'Ezy' group used the CPREzy™ (Health Affairs, London, UK). This device was not in use in our hospital and was unknown to all the candidates. It is a small, light (260 g) device, with a resting height of 5 cm, a base of 5.5 cm × 18 cm, and is powered by a 9 V battery (Figure 1). The device is placed on the sternum, and features an illustration to assist with the correct location. It has a non-slip pad on the surface applied to the sternum. When turned on (green) indicator lights show compression force correlated to the weight of the patient. The indications start with one light for a 'child' (40 kg/90 lbs); two lights for a 'small adult' (55 kg/120 lbs), three for an 'average adult' (75 kg/165 lbs), four lights for a 'large adult' (90 kg/200 lbs) and a fifth (red) light

**Table 1** Listing of points scored for each candidate

Overall	Per compression set (15:2)
Randomization (blinded)	Block number
Manikin code	Time block started (s)
Total # compressions	Number leaning
Total time (s)	Actual depth/leaning compression
Total number 15:2	Direction leaning
Mean compression frequency	Actual depth/compression
Mean compression depth	Mean depth/15 compressions
Compression depth lost (mm)	Depth loss/15 compressions
Total # compressions	Number 'out of range' / 15 compressions
Total time (s)	Compression frequency
	Compression:relaxation ratio

Scoring was done by one of two investigators blinded for the randomization and entered into a database directly.

for 'extra large adult'. The force needed to activate the indicator lights for the different sizes is 23, 32, 41, 50, and 54 kg, respectively.<sup>11,12</sup> A metronome flashes an orange light and emits a 60 dB beep at  $100 \text{ min}^{-1}$  in accordance with International Liaison Committee on Resuscitation (ILCOR) guidelines.<sup>14</sup> Candidates randomized to the 'control' group performed standard chest compressions. Candidates were requested to maintain secrecy if asked the



**Figure 1** The CPREzy as used in the trial. The large surface for compression (A) is labelled, as is the LED indication for pressure applied (B). The on/off button (C) is next to the metronome light (D). The arrows indicate the moving planes.

reason for their temporary absence. Approval for the study was given by the Medical Ethics Committee.

For the registration of skills the Resusci Anne<sup>TM</sup> was connected to its external monitor, the "SkillReporter", which uses lights to give feedback and which also produces a written record although not in 'real time'. During the assessment period, the lights on the SkillReporter were not used and the device turned so that the record and print out were not visible to the candidate. On the written record, the chest compression is recoded as a stroke and movement of the chest, and ventilation volumes are recorded as curves. Compression:relaxation ratios must be calculated. The SkillReporter also has an internal data log system which can be printed at the end of a compression stroke. The usefulness of this data in our experimental setup was limited as we analyzed 270 s and worked on a compression to compression basis.

Each compression stroke was inspected carefully, using a standard technique first developed by Berden et al. as a standardizing evaluation tool.<sup>15</sup> This system is in regular use for the courses given in our hospital, and has been adapted to current ILCOR guidelines. A measuring 'ruler' is used by us to improve accuracy further and limit inter-observer scoring variations.

The SkillReporter Resusci Annes were tested beforehand by the hospital medical instrumentation service to validate the methods. In the first series, a standardized force was applied to the manikin and correlated with the SkillReporter written record for compression depth. No relevant ( $<5\%$ ,  $\leq 2 \text{ mm}$  inter-manikin variation) differences could be found in the range expected to be relevant during the study of 20, 30, 40, 50 and 60 kg. A second test evaluated these forces applied to the CPREzy<sup>TM</sup> in relation to the indicator lights and the actual depth in the manikin while on a firm surface. The force to activate the CPREzy indicator lights confirmed the manufacturer's specifications,<sup>12</sup> but also demonstrated a larger spread during dynamic testing, as the interpretation of the indicator light scale is approximate with steps between lights of 4–9 kg. This reflected itself in a maximum 5 mm spread, both within and between manikins. The difficulty lay in applying the exact force needed to just light the indicator light during dynamic testing. During static testing, we confirmed the data from Boyle and Perkins,<sup>12,13</sup> in that at least three lights, and optimally, four lights should (just) be illuminated to achieve adequate depths in our model (Appendix B). The results of these tests were also used to check for inter-observer variability, which was negligible. This pilot used a tech-

nique described elsewhere.<sup>16</sup> The validation tests were performed using the DPM3 Universal Biometer (DPM3, BIO-Tek Instruments Inc. Winooski, VT USA), which can measure pressure applied to 1% of accuracy.

The principal endpoint was the number of correct compressions a rescuer could perform during the test session. Numeric assessment of compression depth, incomplete relaxation, compression to relaxation ratio and compression frequency were scored as defined by the 2000 ILCOR guidelines. As each candidate had been trained, these scores were related to their skills during the course exit test. More specifically, hand position was scored as incorrect if a lateral force was registered by the manikin, and incomplete relaxation if the chest did not return to the 'resting' position ( $\geq 1$  mm) between compressions. Each variable was scored independently of the other. Secondary endpoints were: the ability of the candidates to assess their compressions and the work required, loss of compression depth during the course of the session, frequency with which the cardiac compressions were performed, and whether individual characteristics, such as age, weight, body-mass-index (BMI) influenced their capabilities.

For each candidate, the results were entered into an SPSS (v12) database for statistical analysis.  $P < 0.05$  was taken to be significant, with data being presented as mean ( $\pm$  standard deviation), with 95% confidence intervals presented in brackets. After testing for normality using the Kurtosis test and the

Levene's test for equality in variance, the (two-tailed) independent samples T test was used for parametric data, with correlations sought using the (two-tailed) Pearson's coefficient, with missing cases excluded pair wise, for parametric values. Using the general linear model, repeated measures analysis as performed with time and depth as variables. The Huynh-Feldt epsilon was used if sphericity conditions were not demonstrated. The Mann-Whitney  $U$  and Chi-squared tests were used for independent sample analysis of non-parametric data. The (two-tailed) Spearman's rho, was then also used, with missing cases excluded pair wise.

## Results

Two-hundred and twenty-four candidates, including physicians, nursing and non-nursing staff, were included (Table 2). One candidate was not randomized due to recent neck complaints and was not replaced. The 223 remaining were randomized to the 'control' and the 'Ezy' groups ( $N = 111$  and  $112$  candidates, respectively). All candidates were able to produce usable records that were entered into the database for analysis. Two were unable to complete the nominal 240 s of chest compressions (protocol deviation) due to technical difficulties with the manikin. In four cases, the candidate stopped early due to shortness of breath ( $n = 1$ ), or other physical discomfort ( $n = 3$ ). Their data remained in

**Table 2** Descriptive statistics for the candidates

	Control mean ( $\pm$ S.D.)	CPREzy mean ( $\pm$ S.D.)	$P$ [95% CI]
$N$	111	112	
Gender	Female: 72 Male: 39	Female: 82 Male: 30	N.S. (0.521)
Age (years)	36.6 ( $\pm 10.5$ )	35.4 ( $\pm 10.2$ )	N.S. (0.401)
Weight (kg)	72.8 ( $\pm 14.4$ )	71.6 ( $\pm 11.9$ )	N.S. (0.518)
Height (cm)	173.2 ( $\pm 9.5$ )	172.2 ( $\pm 8.8$ )	N.S. (0.414)
BMI ( $\text{kg}/\text{m}^2$ ) range	23.8 (23.5–24.8)	23.9 (23.5–24.9)	N.S. (0.822)
Ability at end of training (number and % of ineffective compressions)	155 ( $\pm 50$ )  4.5 ( $\pm 9$ )	159 ( $\pm 48$ )  4.8 ( $\pm 10$ )	N.S. (0.626)  N.S. (0.880)
Function	Nurse: 62 Non-nurse: 31 Physician: 18	Nurse: 71 Non-nurse: 31 Physician: 10	N.S. (0.159) Between groups
Time since training (months)	16.4 $\pm$ 15	14.5 $\pm$ 14	N.S. (0.09)
Actual (recent) BLS experience ( $n$ )	26	23	N.S. (0.603)

Data is presented as mean  $\pm$  standard deviation and the 95% confidence interval in square brackets, except when non-parametric (median + 95% confidence interval).  $n$  = number of cases. This is reported as the actual number for that individual variable if data was missing. No significant differences were found between the two groups, for any category even though there was a tendency to more physicians in the control group. The candidate's abilities are reported on the basis of the post-test skill measurements.

**Table 3** Pre- and post-assessment questionnaire

	Control mean ( $\pm$ S.D.)	CPREzy mean ( $\pm$ S.D.)	<i>P</i> [95% CI]
VAS score	<i>N</i> = 111	<i>N</i> = 112	
Pre-assessment			
Knowledge: at the end of last training course?	7.0 ( $\pm$ 1.4) ( <i>N</i> = 109)	7.0 ( $\pm$ 1.3) ( <i>N</i> = 109)	N.S. (0.891)
Knowledge: this minute?	( $\pm$ 1.7)	5.8 ( $\pm$ 1.8)	N.S. (0.538)
Post-assessment			
Opinion: (0–10) how good were compression?	5.9 ( $\pm$ 1.6)	5.9 ( $\pm$ 1.8) ( <i>N</i> = 110)	N.S. (0.591)
Opinion: depth (5 = correct)	5.2 ( $\pm$ 1.8)	4.7 ( $\pm$ 1.8)	0.039 [0.025–0.98]
Opinion: effective compressions (%)	53 ( $\pm$ 21)	53 ( $\pm$ 20)	N.S. (0.911)
Opinion: how tiring was CPR?	4.8 ( $\pm$ 2.2) ( <i>N</i> = 110)	4.7 ( $\pm$ 2.2)	N.S. (0.714)
Correct depth is? (knowledge)	32	39	N.S. (0.338)
Opinion (0–10) how good was frequency?	( $\pm$ 1.6) ( <i>N</i> = 109)	6.2 ( $\pm$ 1.7)	N.S. (0.407)
Correct frequency is? (knowledge)	46	40	N.S. (0.381)
Opinion of own confidence	5.9 ( $\pm$ 1.8)	6.0 ( $\pm$ 1.9)	N.S. (0.688)

The VAS score is used with a non-calibrated 10 cm line on which the candidate marked their answer. In the two questions labelled 'knowledge', the candidate was asked to answer with the ILCOR guidelines. This was scored as correct or as not correct. N.S.: not significant. Data is presented as mean ( $\pm$ standard deviation), except when non-parametric. If significant the 95% confidence interval [95% CI] is reported. *N*: number of cases. This is reported in the individual variable if data was missing. No significant differences were found between the two groups, except for in the difference between estimation of compression depth ( $P=0.039$ ). This difference does not seem clinically relevant.

the database for analysis. Failures of the CPREzy™ did not occur.

The two groups were well balanced in their physical characteristics and potential skills. In particular, similarity in the 'time since last training' (16.4 versus 14.5 months) and the 'compressions skills at the end of training' (95 versus 95% effective compressions) in the control and the CPREzy™ groups, respectively, suggest that randomization was adequate (Table 2). In the pre-assessment questionnaire, all the candidates reported that they were capable of performing BLS-CPR {6.9 ( $\pm$ 1.4) versus 7 ( $\pm$ 1.3);  $P=0.536$ } at the end of their last course (Table 3). They estimated that their current skills were 5.7 ( $\pm$ 1.7) out of 10, versus 5.8 ( $\pm$ 1.8), (control and CPREzy groups, respectively;  $P=0.538$ ), with their knowledge estimations essentially the same. In the post-assessment questionnaire, these estimations became 5.9 ( $\pm$ 1.6) and 5.9 ( $\pm$ 1.8),  $P=0.591$ . Both groups reported that they felt that they had performed about 53% of the compressions correctly, while the CPREzy group was less confident in actually having achieved and maintained adequate depth {4.7 ( $\pm$ 1.8) versus 5.2 ( $\pm$ 1.8) for the control group, respectively, with  $P=0.039$  [95% CI = 0.025–0.98]}. Similar results were reported for the physical work needed to perform chest compressions. These were 4.8 ( $\pm$ 2.2) versus 4.7 ( $\pm$ 2.2), respectively ( $P=0.714$ ), on a 10-point scale with 0 being 'extremely tiring' and 10 being 'no effort at all' (Table 3).

Practical skills differed markedly between the two groups (Table 4). The control group had significantly more difficulty with achieving and maintaining effective compressions over time even though this was not reflected in their opinion during the post-assessment questionnaire ( $P=0.591$ ). This lack of performance could be expressed in the number of candidates unable to perform compression depth of more than 4 cm (25 in the control group versus 1 in the CPREzy group:  $P=0.0001$ ). Of the remaining candidates, 48 members of the control group started with adequate compressions but lost compression depth progressively, reaching < 4 cm by 75 ( $\pm$ 81) s, without recognizing or correcting this inadequacy for the remainder of the trial period. In the CPREzy group, the minimum effective depth threshold was maintained by all but 11 members up to 194 ( $\pm$ 87) s ( $P=0.0001$  between groups for time as well as number of candidates reaching threshold, see also Figure 2 {CI –180 to –57.5}). The number of ineffective compressions for the control group, within each block of 15 compressions, ranged from a mean of 4 ( $\pm$ 6) initially to 7 ( $\pm$ 7) at 240 s, as opposed to 1 ( $\pm$ 4) consistently throughout the trial for the CPREzy group (see also Figure 3,  $P=0.0001$  CI = 59–100). The overall percentage of candidates not reaching a mean 4 cm compression depth during each block of 15 compressions ranged from 21% at 15 s to 38% at 270 s. The incidence of incomplete relaxation was limited in both groups (13 and 14 cases, respectively), while 50 candidates

**Table 4** Practical skills assessment (compression and frequency aspects)

	Control mean (±S.D.)	CPREzy mean (±S.D.)	P [95% CI]
N	111	112	
Actual time (s)	260 (±26)	258 (±23)	N.S. (0.589)
Actual number of 15:2 cycles	21 (±4)	21 (±3)	N.S. (0.784)
Mean depth (mm)	40 (±9)	45 (±4)	0.0001 [−0.32 to −2.15]
Depth loss (mm)	4 (±5) (N= 106)	3 (±4) (N= 109)	N.S. (0.143)
Incidence of ineffective chest compressions (N)	25 (never correct)	1 (never correct)	0.0001
No. of candidates compressing <4 cm consistently (after an adequate start)	48	11	0.001
Time until compressions become and remained <4 cm (s)	75 (±81)	194 (±87)	0.0001 [−180 to −57.5]
Total ineffective compression (% of all compressions)	36 (±41)	6 (±13)	0.0001 [22.7–38.7]
Ineffective compressions (n)	94 (±104)	15 (±33)	0.0001 [59–100]
Leaning (incidence)	13	14	N.S.
Incorrect hand position (incidence 15:2 <sup>-1</sup> )	136	88	0.001
Actual compression frequency (cpm)	106 (±21)	102 (±10)	N.S. (0.056)

This table summarizes the practical skills. mm: millimetres of impression; s: seconds after initiation of CPR; N: number of cases; cpm: compressions/min. Ineffective compressions are those outside the ILCOR range. If a subgroup is reported, the actual number of cases is listed. Leaning was scored as present if the registration showed >1 mm non-return to resting position. Hand position was scored if an ‘incorrect hand position’ exclamation mark was listed on the written record (not specific for the four potential sites of the error: see text for explanation).

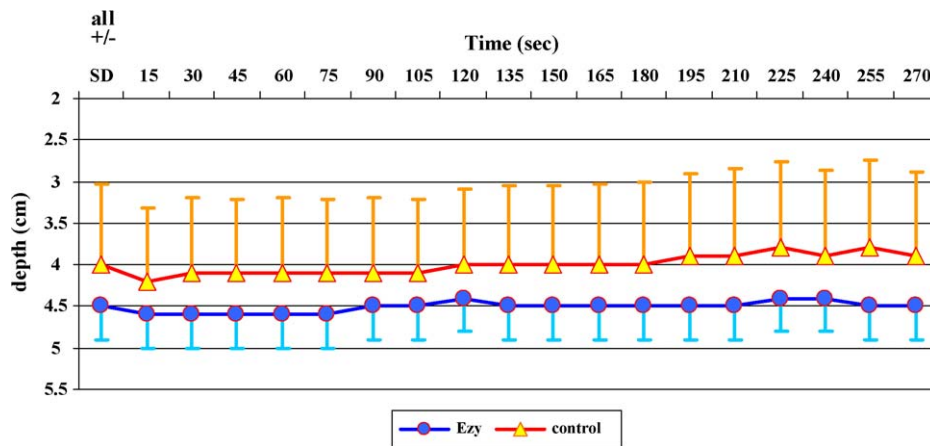
in the control group and 98 in the CPREzy group demonstrated consistently correct hand positions ( $P=0.001$ ). Compression frequency did not differ significantly between groups (Table 4).

Correlations between the use of the CPREzy, the adequacy of their compressions and potential confounders such as caregiver physiognomy, time since last training, weight, and the self-opinion of their abilities, could not be demonstrated. Notably, a rescuers opinion could not be correlated to their

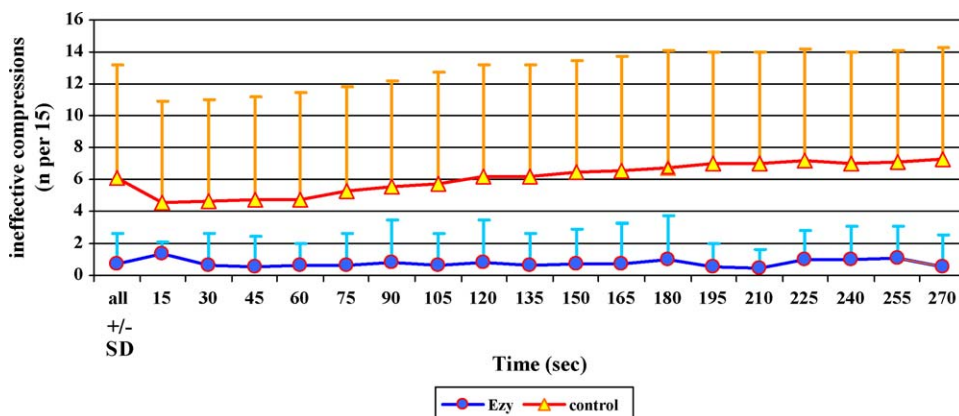
actual ability when the skill was expressed as adequate compressions ( $P=0.38$ ,  $r = -0.084$ ).

### Discussion

This unannounced study assessed the compression skills of 224 trained rescuers with and without the use of an unfamiliar non-invasive feedback device, the CPREzy<sup>TM</sup>, in a manikin setting. Two investi-



**Figure 2** Compression depth over time (data presented as mean ± S.D. for each time segment). Compression depth measured from 0 (resting). Measurements of a compression to compression basis, with the series of compressions being scored closest to the time interval.



**Figure 3** Number of ineffective compressions by group over time (data presented as mean  $\pm$  S.D.). Measured on a compression to compression basis. Ineffective defined as compressions (measurably) less than 4 cm depth.

gators, blinded for the randomization, and using a standardized scoring system, evaluated the effectiveness on a compression-to-compression basis and scored pre and post assessment questionnaires. The use of a feedback device in a large, non cross-over, manikin study with rescuers at known levels of training and time since training, and a questionnaire, had not been performed.

We found, as expected, a generally moderate ability to perform adequate chest compressions at an average of 15 months after the most recent training, with a mean of 6 of each 15 compression series being inadequate over time. While the assessment lasted up to 270s, it demonstrates (Figure 3) that the period during which one rescuer may compress the chest effectively, may need to be limited further to about 120s. When the CPREzy™ is used, the overall percentage of adequate compression during the assessment period was increased significantly, from an average of 9 ( $\pm 8$ ) compressions of sufficient depth in the control group to at least 14 ( $\pm 2$ ) per 15 compression series in the Ezy group. This improvement in effectiveness is both for consistency of depth as well as for adequacy of depth. Use of the CPREzy™ was not correlated with improvements in frequency, nor did it increase incomplete relaxation between compressions. However, the low incidence of these errors may have contributed to this outcome.

Our study demonstrates that better definition and consistency of force during chest compressions is feasible in a population of rescuers not specifically trained in the use of the CPREzy. This is a significant prerequisite for application in patient resuscitation. Compression force and depth assessable during chest compressions has received little attention. This may have been caused by early emphasis on getting the lay public to perform compressions to the exclusion of aspects difficult

to teach. Outcome studies have been careful to score 'early access' while avoiding estimation of adequacy.<sup>14,17</sup>

Early work, performed by Thomas et al., reports on the use of a force indicating gauge to improve depth estimation. They report improvement of compression efficacy from 33 to 96% in a manikin study of trained flight nurses using a cross-over design.<sup>10</sup> However, they drew no general conclusions. Their impressive results could not be reproduced entirely by Elding et al., although this study also demonstrated statistically significant improvement in compression efficacy and general technique.<sup>18</sup>

The CPREzy™, first described by Boyle et al. in 2002 in a limited group assessed without and with the CPREzy™ on consecutive days, found a 3-fold improvement (13–42%) in effective compressions if the CPREzy™ was used.<sup>11</sup> The suggestion that this improvement may not translate to clinical improvement seems justified in their study, as the rate of effective compressions remains low even after instruction and introduction of the feedback device. Perkins et al. validated Boyle's results using a small group of medical students when resuscitating on a bed.<sup>12</sup> In this later study, the students received instructions, practiced, and were told how many indicator lights were optimal, with some of the test candidates having been active in the validation series.

Our data confirms but also expands on this experience. While our improvement, expressed as a percentage is smaller, it brings the percentage of adequate compressions in line with what seem to be realistic clinical demands. In addition, we used an interrupted compression model in order to simulate the discontinuity this brings with it, incorporating a maximum time that one rescuer may need to perform BLS before being relieved. We avoided a

cross-over design to exclude a learning curve as may have occurred in Boyle's and Perkins's studies. A potential individual learning effect of uncertain magnitude cannot be ruled out. We increased the number of participants to limit any bias caused by skills (Table 2). Perhaps most importantly, we did not train our rescuers in the use of the CPREzy™: they were confronted with it as randomized, and were instructed to "use the lights as indicated and begin immediately", so as to standardize unfamiliarity most likely to occur in the clinical setting. We also demonstrate that improvement is independent of time since training, rescuer weight and function within the hospital. The mean time since training in our assessment was 15 months (range 0–37 months with a normal distribution). A sub-group analysis of those with training less than 6 months earlier and those with training between 12 and 18 months demonstrated that the CPREzy maintains skills, as suggested by others. These results demonstrated that the use of the CPREzy might increase the useful interval extensively, giving it both a teaching as well as practical role.

The need for quality in basic life support, both early and during the advanced stages of a resuscitation effort need not be expanded upon.<sup>1,2,12,19</sup> Without a feedback device, such as the CPREzy™, the rescuer as well as the physician have to depend on their 'experience' and 'memory' to evaluate the effectiveness of the compressions, while evidence suggests that this is neither taught in courses nor is it clinically possible for instructors or rescuers.<sup>9</sup> Their experience relates to manikins in the training situation, and negates understanding of the variables such as the loss of rescuer capabilities over time, individual chest wall stiffness and chest diameter.<sup>2,4</sup> The characteristics of a device, such as the CPREzy, with its effect on the force applied to the individual patient (Appendix B) is, perhaps regrettably, unclear to many. The CPREzy™ provides one of these variables and empirically a second, thereby reducing the number of unknowns in a user-friendly manner. The feedback device also gives the rescuer a benchmark for compressions, allowing physician delegation and monitoring of this basic life support task. Its use can be considered an adjuvant to CPR as is ETCO<sub>2</sub> monitoring, and expensive methods such as impedance evaluation built into defibrillators.

In our hospital the CPREzy is brought to the scene by the advanced life support team, and implemented as the first step in their protocol: although the first minutes of chest compressions may be sub-optimal, it allows improved maintenance of chest compressions during advanced life-support procedures, which may continue for up to an hour.

The importance of chest compressions has been rediscovered.<sup>2,4,19</sup> The exact amount of force required to create an optimal artificial circulation in humans is still a matter of discussion. Force needed for compressions labelled as adequate vary from manikin to manikin, and 20–70 kg for human adults.<sup>4</sup> Suggestions that force and depth should be individualized have been expressed,<sup>2</sup> but may need to remain in the realm of advanced skills. Perkins et al. described the force needed when working with the CPREzy as a range from child to extra-large adult as 23–54 kg. Timerman et al, working with a novel chest compression device, reported that they used  $51 \pm 20$  kg of peak force in their population.<sup>12,20</sup> Experimental determination of the force to compression relationship with the CPREzy on a rigid surface demonstrated agreement with the values listed above. Doubts have been expressed in the past about whether such force indicators retain their meaning when the CPREzy is used on a flexible or compressible support,<sup>12,14</sup> such as the human chest. Our experience confirms this accuracy, while recognizing that the amount of physical work on a multiple layer support exceeds that of compression on a rigid surface. Clinically, this allows the rescuer performing chest compressions to recognize that, should the patient be lying in a hospital bed, the total distance their hands move may be more than 4–5 cm, and may initially require extra work to achieve correct depth, even on modern hospital beds, as this position often is not used for training.

The Resusci Anne uses its SkillReporter lights to specify incorrect hand position. Incorrect position of the hands, and the application of force in a non vertical direction while the hands are correctly placed, will be scored as incorrect. During our study, we used the written record which does not specify the location/direction of the error. Earlier investigation found a propensity for too low a position of the CPREzy<sup>12</sup>; our study design, which relied on the written record, does not allow us to confirm or repudiate this aspect in chest compressions.

Our study has a number of limitations. We did not use a cross-over design as discussed above; by including large groups of candidates at random, we allowed for variables such as motivation, physiognomy, and skills to correct themselves in the sampling. As the candidates were unaware of which task they would perform next, any bias should be limited. Human evaluation of the written record was also used: while the blinded investigators, dedicated resuscitation officers, have extensive skills and practices in evaluating the records, and the benchmarking did not demonstrate relevant differences, more checks during scoring may have

increased security as to the value of the scores. However, a post hoc analysis of the database, using the investigator as a variable, could not demonstrate any systematic differences.

While the device increases the possibility for the rescuer to choose a force and judge the consistency of their compressions, it does not allow insight into the force which might be optimal for that patient. In manikin studies this effect is difficult to simulate and the manikin may not be related to actual clinical conditions.<sup>21</sup> Our study also used manikins, and relied on the written record as an accurate representation of reality.<sup>15</sup> However, even the CPREzy does not allow for more accuracy than increments of 3–9 kg of force. The actual force required, or even the optimal impression depths in humans are still subject to debate<sup>4</sup> and may be greater than currently thought (i.e. 70 kg or more needed).

In order to evaluate compression skills optimally, we de-emphasized ventilation. We used the compression ventilation ratios for one-rescuer CPR, but supplied a non-intervening rescuer to perform these ventilations. While introducing interruptions for the ventilations, our protocol did not require the movement of hands to open the airway and the additional fatigue caused by mouth-to-mouth ventilation was not evaluated. This did allow for a large number of compressions to be evaluated in a brief period of time.

## Conclusions

Our study demonstrates a marked improvement in achieving and maintaining adequate depth during chest compressions when a feedback device, the

CPREzy™, is used. This difference was found even though the rescuers were not specifically trained in its use. Although it requires more work, the variation in depth is significantly smaller than without the device, regardless of physiognomy of the caregiver. It also shows that this device de-emphasises the interval after training without compromising quality. The improvements in efficacy should be an important factor in optimization of the 'Chain of Survival'.

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## Appendix A

### A.1. The pre-assessment questionnaire

This was filled in by the candidates before they had been briefed on the explicit purpose of the assessment. The visual analogue scale (VAS) was measured to be exactly 10 cm. The candidates placed an 'x' at a position of their self evaluation. Time to last course was validated using the hospital's training database. BLS-CPR = basic life support cardiopulmonary resuscitation.

randomization number:

Name; age; weight; height:  
 Department; function  
 Time since last training:

Question	VAS (place an "X" at your choice on the scale)
<i>With regard to your knowledge:</i> How well do you feel that you were equipped to perform BLS-CPR <b>at the end of your last training course?</b>	0 ----- 10 (not at all) (perfectly)
<i>With regard to your practical skills:</i> How well do you feel that you were equipped to perform BLS-CPR <b>at the end of your last training course?</b>	0 ----- 10 (not at all) (perfectly)
<i>With regard to your knowledge:</i> How well do you feel that you are equipped to perform BLS-CPR <b>this minute?</b>	0 ----- 10 (not at all) (perfectly)
<i>With regard to your practical skills:</i> How well do you feel that you were equipped to perform BLS-CPR <b>this minute?</b>	0 ----- 10 (not at all) (perfectly)

## A.2. The post-assessment questionnaire

This was filled in immediately after completion of the practical session.

Randomization number:

I have / have not practiced (on a manikin) since my last course (circle the appropriate answer)

I have / have not performed actual BLS-CPR since my last course (circle)

Question	VAS (place an "X" on the 10 cm scale)
How well do you feel that you just did with regard to <b>compression depth</b> ?	0 ----- 10 (very poorly) (perfectly)
Do you feel your compressions were generally too deep or too shallow?	0 ----- 10 (to shallow) (to deep)
What percentage (%) of compressions do you think were in the correct range?	0 ----- 100 (none) (all)
How tiring did you find performing the chest compressions to be?	0 ----- 10 (extremely) (not at all)
How well do you feel that you just did with regard to <b>compression frequency</b> ?	0 ----- 10 (very poorly) (perfectly)
What is the correct compression frequency, according to the guidelines?	..... compression min <sup>-1</sup> (adults)
What is the correct compression depth (range) for adults?	..... to ..... cm deep (adults)
How <b>confident</b> are you that the above two answers are correct?	0 ----- 10 (none) (complete)

## Appendix B. The effects of combining springs with different properties as applied to CPR

During CPR courses, caregivers are taught to compress the chest and to strive for 4–5 cm compression depth. Little is said about the role of force needed for this. Applying sufficient force to compress the chest deep enough can be a challenge.

The CPREzy technology suggests that a force of 50–54 kg on the CPREzy may be adequate for compressions in an adult. Most adults can produce such a force for limited periods of time and we suggest that this feedback may help in controlling and maintaining this effort. But does the use of the feedback system also influence the work the caregiver must produce?

This appendix approaches that question from a simplified, mathematical, point of view.

In [Figure 4](#), an object such as a manikin or the chest wall of a human being, represented as a weak spring is compressed while lying on a firm surface [22]. The stiffness of the chest wall,  $d$ , and the spring compression  $x_1$  are related to the loading force  $F_1$  via the equation:

$$F_1 = dx_1 \quad (1)$$

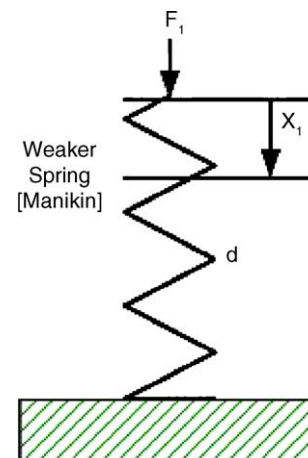
In [Figure 5](#), a spring-loaded device (e.g. the CPREzy) is put on a firm surface. The stiffness of the spring

$D$  and the compression of the spring  $x_2$  are related to a loading force  $F_2$  via the equation:

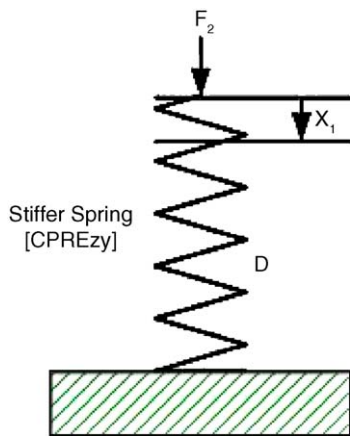
$$F_2 = Dx_2 \quad (2)$$

If the above two springs are placed one on top of the other ([Figure 6](#)), i.e. in series, such as the CPREzy on the sternum of the chest, with the patient lying on a firm surface, continuity of force requires that:

$$F_1 = F_2 \quad (3)$$



**Figure 4** See [Appendix B](#) for explanation of the symbols. Schematic diagram of a weak spring (e.g., the human chest) on a firm surface.



**Figure 5** See Appendix B for explanation of the symbols. Schematic diagram of a stiff spring on a firm surface.

Hence

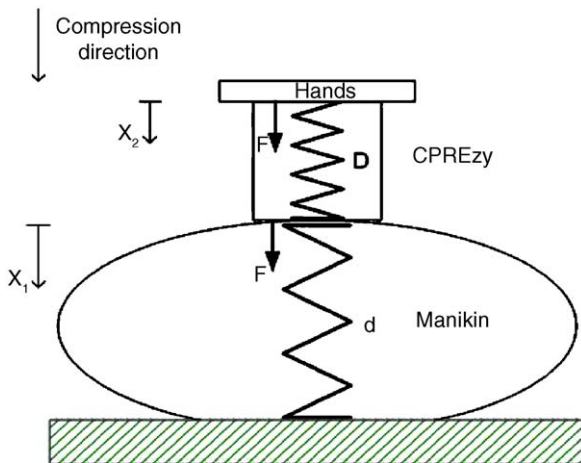
$$x_1 = \left(\frac{d}{D}\right) x_2 \quad (4)$$

The work done on the spring in the first example (Figure 4) equals:

$$W_1 = \frac{Fx_1}{2} \quad (5)$$

The work done on the combined springs (Figure 6) is equal to:

$$\begin{aligned} W_2 &= \frac{Fx_2}{2} + \frac{Fx_1}{2} = \left(\frac{F}{2}\right) (x_1 + x_2) \\ &= \left(\frac{Fx_1}{2}\right) \left(1 + \left(\frac{d}{D}\right)\right) \end{aligned} \quad (6)$$



**Figure 6** See Appendix B for an explanation of symbols. Schematic diagram of the CPREzy on the chest of a manikin lying on a firm surface demonstrating the accumulation of work.

Hence, for the same compression of the lighter spring (i.e. the patient or the manikin,  $x_1$ ) the ratio of the amounts of work equals:

$$\frac{W_2}{W_1} = \left(1 + \left(\frac{d}{D}\right)\right) \quad (7)$$

For the particular combination of the CPREzy with our manikin, measurements show that  $d/D=1.07$ . For example using Eq. (7) compressing the combination of springs will require close to twice as much work as compressing the CPREzy or the manikin alone, without affecting the force needed. The results of the study demonstrate that this should not be a clinical concern.

It does clarify why caregivers may feel that their hands are uncomfortable and why they are tiring: the amount of work being performed has increased. This increase is most likely both in terms of the force being applied (due to the feedback) as well as to the hard, a relatively small surface on which it is applied. In effect, it has also become possible to individualize force and depth both as a teaching as a clinical tool.

### B.1. Conclusions

In these models, force indicators are not significantly disturbed by multiple layers, when their masses can be ignored. However, levels of compression may be entirely different, depending of the stiffnesses of the springs. The physical work performed by the caregiver also depends on spring stiffnesses and is increased in our example.

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