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Brief Reports

MANUAL VERSUS MECHANICAL CHEST COMPRESSIONS ON SURFACES OF VARYING SOFTNESS WITH OR WITHOUT BACKBOARDS: A RANDOMIZED, CROSSOVER MANIKIN STUDY

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☐ Abstract—Background: Chest compression quality is decisive for overall outcome after cardiac arrest. Chest compression depth may decrease when cardiopulmonary resuscitation (CPR) is performed on a mattress, and the use of a backboard does not necessarily improve compression depth. Mechanical chest compression devices may overcome this problem. Objectives: We sought to investigate the effectiveness of manual chest compressions both with and without a backboard compared to mechanical CPR performed on surfaces of different softness. Methods: Twenty-four advanced life support (ALS)–certified rescuers were enrolled. LUCAS2 (Physio-Control, Redmond, WA) delivers 52 ± 2 mm deep chest compressions and active decompressions back to the neutral position (frequency 102 min^{-1}; duty cycle, 50%). This simulated CPR scenario was performed on a Resusci-Anne manikin (Laerdal, Stavanger, Norway) that was lying on 3 different surfaces: 1) a concrete floor, 2) a firm standard mattress, and 3) a pressure-relieving mattress. Data were recorded by the Laerdal Skill Reporting System. Results: Manual chest compression with or without a backboard were performed correctly less often than mechanical chest compressions (floor: 33% [interquartile range {IQR}, 27–48%] vs. 90% [IQR, 86–94%], *p* < 0.001; standard mattress: 32% [IQR, 20–45%] vs. 27% [IQR, 14–46%] vs. 91% [IQR, 51–94%], *p* < 0.001; and pressure-relieving mattress 29% [IQR, 17–49%] vs. 30% [IQR, 17–52%] vs. 91% [IQR, 87–95%], *p* < 0.001). The mean compression depth on both mattresses was deeper with mechanical chest compressions (floor: 53 mm [range, 47–57 mm] vs. 56 mm [range, 54–57 mm], *p* = 0.003; standard mattress: 50 mm [range, 44–55 mm] vs. 51 mm [range, 47–55 mm] vs. 55 mm [range, 54–58 mm], *p* < 0.001; and pressure-relieving mattress: 49 mm [range, 44–55 mm] vs. 50 mm [range, 44–53 mm] vs. 55 mm [range, 55–56 mm], *p* < 0.001). In this ∼6-min scenario, the mean hands-off time was ∼15 to 20 s shorter in the manual CPR scenarios. Conclusions: In this experimental study, only ∼30% of manual chest compressions were performed correctly compared to ∼90% of mechanical chest compressions, regardless of the underlying surface. Backboard use did not influence the mean compression depth during manual CPR. Chest compressions were deeper with mechanical CPR. The mean hands-off time was shorter with manual CPR. © 2016 Elsevier Inc.

☐ Keywords—backboard; chest compressions; CPR; LUCAS; manikin; mattress

INTRODUCTION

Chest compression quality is decisive for survival and good neurologic outcome of patients in cardiac arrest

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(1). However, conducting chest compressions is highly complex and may be even more challenging on a soft surface. Compression depth may decrease when cardiopulmonary resuscitation (CPR) is performed on a mattress, and even the use of a backboard does not necessarily improve compression depth (2–5). In-hospital CPR is commonly performed manually on patients lying in a bed and stabilized on a backboard.

When CPR is performed manually on a mattress, several factors (e.g., backboard, bed height, and type of mattress) influence and may reduce the efficacy of chest compressions. Mechanical chest compression devices deliver uninterrupted chest compressions that conform to guidelines and may therefore improve the quality of CPR on a mattress.

The aim of this study was to compare mechanical with manual CPR with and without a backboard performed on different surfaces. The primary outcome was the percentage of correct chest compressions relative to total chest compressions. Secondary outcomes were depth, pressure point, complete pressure release and rate of chest compressions, hands-off time, and time to first defibrillation.

METHODS

The local ethics committee waived the requirement for approval. This prospective, randomized, cross-over manikin study was conducted at the Innsbruck University Hospital, Austria. Twenty-four advanced life support (ALS)–certified rescuers were enrolled. All had been trained by European Resuscitation Council (ERC) ALS-certified instructors on manual and mechanical CPR according to the 2010 guidelines (6). The rescuers formed teams of 2 and each rescuer performed the same CPR scenario on different surfaces in a randomized order with manual and mechanical chest compressions. The manual scenarios were conducted once with and once without a backboard (Figure 1). At the end of each scenario the rescuer was asked to assess the efficacy of chest compressions and the level of fatigue using a 100-mm visual analog scale.

The Lund University Cardiac Assist System (LUCAS2; Physio-Control, Redmond, WA) is an electrically powered piston device that provides 52 $\pm$ 2 mm deep chest compressions and active decompressions back to the neutral position with a frequency of 102 min^{-1} and a duty cycle of 50%. A back plate is positioned under the patient and is locked with the upper part of LUCAS2 and acts as a counter-support for chest compressions.

CPR was performed on a Resusci-Anne manikin (Laerdal, Stavanger, Norway) on different surfaces (e.g., on a concrete floor, a firm standard mattress [MoltoMed; Moltoplast, Innsbruck, Austria], and a pressure-relieving mattress [Thera Rest Classic; KCI, San

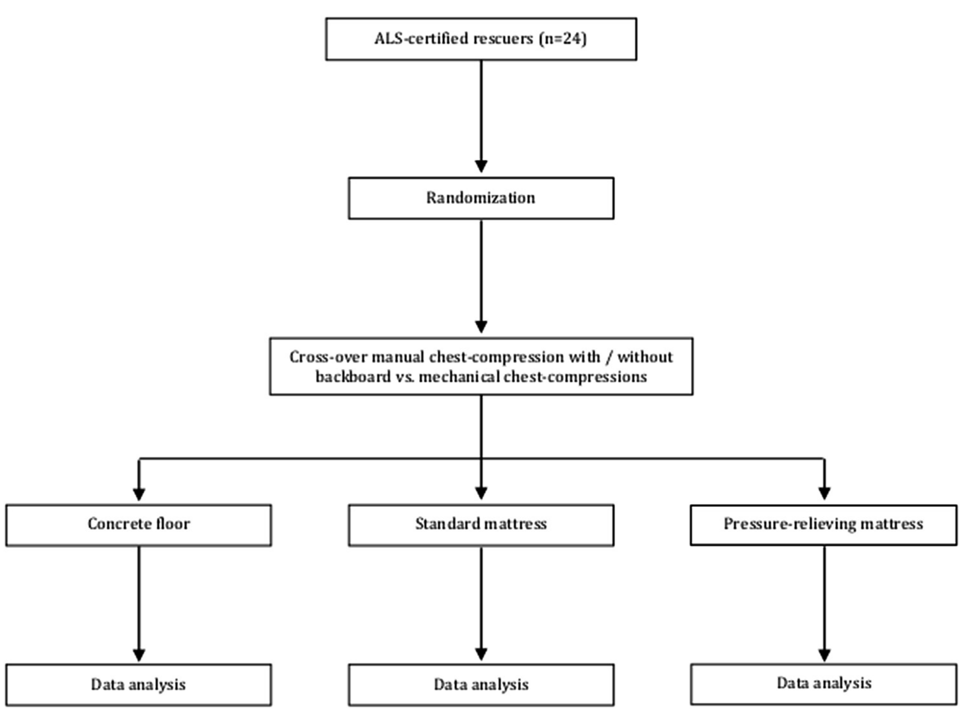

Figure 1. The rescuers performed the same CPR scenario on different surfaces in a randomized order with manual and mechanical chest-compressions. The manual scenarios were conducted once with and once without a backboard. ALS = Advanced life support.

Antonio, TX] in a standard hospital bed). The position of the mattresses was adjusted to mid-thigh height of each rescuer (7). A 15-kg sandbag was added to the weight of the manikin to correct for the torso weight of an adult patient (4). Data were recorded by the Laerdal Skill Reporting System.

At the beginning of the CPR scenario (~6 min duration), an anesthesiologist (i.e., P.B., A.F., or E.F.) checked for airway, breathing, and circulation, and the rescuers started manual chest compressions immediately thereafter. Placement of defibrillation pads, endotracheal intubation, and initiation of mechanical ventilation (Oxylog; Dräger, Lübeck, Germany) were performed by the anesthesiologist simultaneously with the chest compressions. LUCAS2 was mounted before the first rhythm analysis. Defibrillations were given every 2 min. In the manual scenarios, the rescuers alternated performing chest compressions every 2 min, whereas mechanical chest compressions started after the first shock and continued until scenario termination. Chest compressions were only interrupted for rhythm analysis.

The primary outcome was the percentage of correct chest compressions relative to the total number of chest compressions. Chest compressions were regarded as correct when depth, pressure point, and pressure release corresponded the present CPR guidelines (i.e., 50–59 mm for adequate chest compression depth and 100–120 compressions min^{-1} for adequate rate) (6). Secondary outcomes were depth, pressure point, complete pressure release and rate of chest compressions, hands-off time, and time to first defibrillation.

To extrapolate our experimental findings to the clinical practice of in-hospital CPR, we conducted an inquiry among hospitals in Austria (n = 110), northern Italy (n = 144), and southern Germany (n = 172).

Statistical Analysis

Normal distribution of the data was assessed using the Kolmogorov–Smirnov test. The Student's *t*-test was used for paired samples with normal distribution, and Wilcoxon test for samples with non-normal distribution. The Friedman test was used for group comparisons of >2 groups. Two-sided statistical testing was conducted. According to the Bonferroni correction for multiple group comparisons, the corrected significance level was set at 0.016. A post hoc power calculation for the percentage of correct chest compressions (manual vs. mechanical) resulted in a power of 1.00. All statistical analyses were performed with SPSS software (version 20.0; IBM, Armonk, NY). Data are presented as median (interquartile range).

RESULTS

The 24 rescuers (8 women) had a mean age of 27 ± 8 years, a mean height of 175 ± 9 cm, and a mean weight of 75 ± 16 kg.

Manual vs. mechanical chest compressions were less often performed correctly regardless of the surface (Figure 2). The mean compression depth was deeper in the mechanical scenarios. A backboard did not improve compression depth with manual CPR regardless of the mattress used. Pressure points, pressure release, and compression rates were comparable in both manual and mechanical CPR scenarios. The hands-off time was ~15 to 20 s shorter during manual CPR. Time to first defibrillation was comparable with manual and mechanical CPR (Tables 1–3).

DISCUSSION

In this study of simulated CPR, manual vs. mechanical chest compressions were less often performed correctly regardless of the underlying surface. The mean compression depth was deeper with mechanical CPR, but the hands-off time was shorter with manual CPR.

Approximately 30% of manual chest compressions were performed correctly compared to ~90% of mechanical chest compressions, primarily because of a higher rate of shallow chest compressions with manual CPR (Figure 2). To increase compression depth during manual

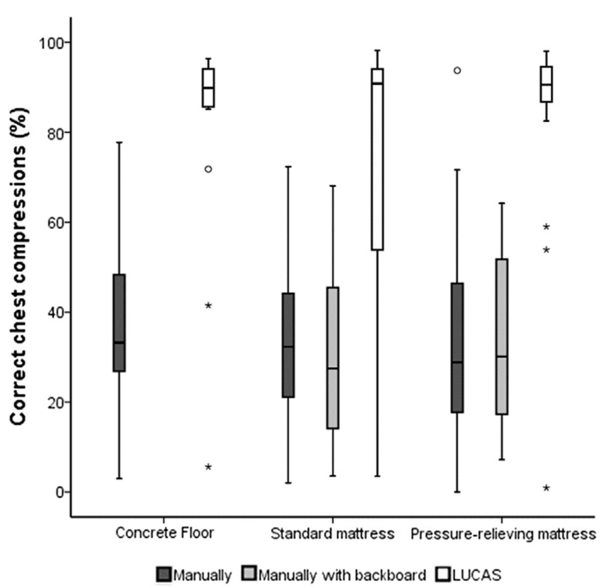

Figure 2. Correct chest compressions (%) are shown according to the surface. Data are given for manual chest compressions with and without backboard and LUCAS2 chest compressions. Asterisks and open circles (○) indicate outliers.

Table 1. Manual vs. LUCAS2 Chest Compressions on a Concrete Floor*

Concrete Floor	Manual CCs	LUCAS2 CCs	*p* Value
Correct CC (%)	33 (27–48)	90 (86–94)	<0.001
Correct CC depth (%)	37 (29–55)	92 (86–96)	<0.001
CC too deep (%)	15 (3–43)	5 (1–8)	0.018
CC too shallow (%)	29 (4–65)	3 (1–5)	<0.001
Mean CC depth (mm)	53 (47–57)	56 (54–57)	0.003
Correct pressure point (%)	100 (97–100)	100 (99–100)	0.041
Correct pressure release (%)	99 (95–100)	100 (99–100)	0.013
Mean CC rate (min^{-1})	118 (110–123)	103 (102–103)	<0.001
Total hands-off time (seconds)	26 (23–28)	41 (37–47)	<0.001
Time to first defibrillation (seconds)	33 (27–37)	30 (28–36)	0.798
Fatigue (%; self-assessment)	58 (44–74)	0 (0–0)	<0.001
Efficacy (%; self-assessment)	65 (51–77)	95 (88–99)	<0.001

CCs = Chest compressions.
* Data are presented as median (interquartile range).

CPR on a mattress, current guidelines recommend the use of a backboard. However, studies investigating the efficacy of a backboard during CPR on a mattress reported equivocal results (5,8–10). Interestingly, backboard use did not influence the mean compression depth in this study, suggesting that on the softer surface these young and fit rescuers increased the effort during the 6 min of chest compression, which is in line with another manikin study comparing compression depth on the floor and in the bed (11). The level of exhaustion was higher in the scenarios without backboard (Tables 2 and 3).

In this study, the mean depth of mechanical chest compressions was ∼5 mm deeper both on the standard and on the pressure-relieving mattresses (Tables 2 and 3). Compression depth linearly correlates with cardiac output, mean arterial pressure and successful resuscitation. For instance, a 1-cm reduction in compression depth resulted in a 50% decrease in cardiac output and a 30% decrease in mean arterial pressure in an animal study (12). Human observational studies associated deeper chest compressions with a higher probability of defibrillation success and return of spontaneous circulation, and reported a 30% survival benefit for each 5-mm increase in mean compression depth (13,14). However, a recent prehospital multicenter trial comparing LUCAS2 vs. manual chest compressions did not find any significant difference in survival or neurologic outcome (15). However, in that study, manual chest compression quality may have been good because of well-trained rescuers and because prehospital chest compressions are often performed on firm surfaces (e.g., on a floor). Unfortunately, mean compression depth and chest compression quality was not reported in that study (15).

In our experience, in-hospital CPR is commonly performed on mattresses. This hypothesis was also confirmed by an international inquiry where 67% of respondents confirmed that in-hospital CPR is performed manually on a mattress (supplementary data related to

Table 2. Manual Chest Compressions With or Without a Backboard vs. LUCAS2 Chest Compressions on a Standard Mattress*

Standard Mattress	Manual CCs Without a Backboard	Manual CCs With a Backboard	LUCAS2 CCs	*p* Value
Correct CC (%)	32 (20–45)	27 (14–46)	91 (51–94)	<0.001†
Correct CC depth (%)	40 (26–59)	36 (27–53)	91 (52–94)	0.001
CC too deep (%)	2 (0–30)	11 (1–34)	3 (0–44)	0.092
CC too shallow (%)	41 (12–66)	34 (27–65)	5 (1–9)	0.001
Mean CC depth (mm)	50 (44–55)	51 (47–55)	55 (54–58)	<0.001
Correct pressure point (%)	99 (94–100)	98 (72–100)	100 (99–100)	0.035
Correct pressure release (%)	99 (90–100)	99 (90–100)	100 (99–100)	0.009
Mean CC rate (min^{-1})	106 (102–114)	115 (107–118)	102 (101–102)	<0.001
Total hands-off time (seconds)	27 (24–31)	30 (28–35)	43 (36–46)	<0.001
Time to first defibrillation (seconds)	31 (27–35)	30 (27–34)	30 (27–33)	0.417
Fatigue (%; self-assessment)	70 (60–79)	60 (46–79)	0 (0–0)	<0.001
Efficacy (%; self-assessment)	62 (51–72)	70 (60–77)	95 (90–99)	<0.001

CCs = Chest compressions.
* Data are presented as median (interquartile range).
† A post hoc test using Wilcoxon tests showed significant differences between manual CC without a backboard and LUCAS2 CC ($p < 0.001$) and between manual CC with a backboard and LUCAS2 CC ($p < 0.001$).

Table 3. Manual Chest Compressions With or Without a Backboard vs. LUCAS2 Chest Compressions on a Pressure-relieving Mattress*

Pressure-relieving Mattress	Manual CCs Without a Backboard	Manual CCs With a Backboard	LUCAS2 CCs	p Value
Correct CC (%)	29 (17–49)	30 (17–52)	91 (87–95)	<0.001†
Correct CC depth (%)	38 (22–54)	35 (21–60)	91 (87–96)	<0.001
CC too deep (%)	2 (0–28)	7 (0–28)	1 (0–7)	0.504
CC too shallow (%)	47 (14–71)	43 (26–70)	6 (2–10)	<0.001
Mean CC depth (mm)	49 (44–55)	50 (44–53)	55 (55–56)	<0.001
Correct pressure point (%)	97 (86–100)	98 (73–100)	100 (98–100)	0.001
Correct pressure release (%)	98 (90–100)	98 (93–100)	100 (99–100)	0.003
Mean CC rate (min^{-1})	106 (102–117)	109 (103–114)	102 (101–103)	<0.001
Total hands-off time (seconds)	26 (22–29)	31 (28–36)	44 (33–49)	<0.001
Time to first defibrillation (seconds)	29 (25–32)	30 (29–37)	31 (28–33)	0.453
Fatigue (%; self-assessment)	70 (56–80)	70 (53–80)	0 (0–0)	<0.001
Efficacy (%; self-assessment)	61 (40–72)	60 (45–70)	93 (86–95)	<0.001

CCs = Chest compressions.
* Data are presented as median (interquartile range).
† A post hoc test using Wilcoxon tests showed significant differences between manual CC without a backboard and LUCAS2 CC ($p < 0.001$) and between manual CC with a backboard and LUCAS2 CC ($p < 0.001$).

this article can be found at: www.journals.elsevierhealth.com/periodicals/jem), and in this setting chest compression quality is likely suboptimal (Tables 2 and 3). We therefore hypothesize that mechanical chest compression devices—aside from other tools, such as feedback devices—may improve the quality of CPR and potentially patient outcome compared to manual chest compressions after in-hospital cardiac arrest, but clinical studies are required to confirm our experimental findings (16).

The application of LUCAS2 may be time-consuming, and in this study it increased the hands-off time by ∼15 to 20 s compared to manual CPR. Interruptions in chest compressions are detrimental because they decrease coronary and cerebral perfusion pressures (17). However, the application of AutoPulse (Zoll Medical, Chelmsford, MA), another mechanical CPR device, was associated with longer hands-off times after 5 min of CPR but decreased hands-off times in CPR lasting ≥10 min compared to manual chest compressions (18). It is likely that LUCAS2 will reduce hands-off times likewise in prolonged CPR scenarios (e.g., ≥10 min) (19–21).

Manual CPR quality was rated consistently too optimistically in this study. This has been described in other studies as well (3,22). Mechanical CPR was rated properly when performed correctly, but mechanical chest compressions that were deeper than recommended were not recognized (Tables 1–3)—for example, 7 rescuers malpositioned LUCAS2 on the standard mattress without detecting this misplacement (Figure 2). Misjudging compression depth may not only reduce efficacy but also increase the incidence of adverse events (23–25). Therefore, regular training of rescuers to avoid mechanical CPR device misplacement is of utmost importance.

Limitations

There are some limitations to this study. First, CPR was performed on a manikin and may not reflect real CPR. However, this study shows that chest compression characteristics can be improved by means of a mechanical device and that it is difficult to provide manual chest compressions on a soft mattress regardless of the use of a backboard. Second, the scenario was limited to 6 min. It is likely that a longer scenario may have led to different results (i.e., a shorter hands-off time in the mechanical group and poorer chest compression quality in the manual group related to exhaustion of the rescuers, especially in the scenarios with the pressure-relieving mattress). Third, it was not possible to blind the rescuers to the intent of the study, but they were blinded to the adequacy of chest compressions. Finally, there is still no high-quality evidence showing improved survival with mechanical CPR in humans (15). It is therefore unknown whether improved compression quality such as in this study will translate into better clinical outcomes.

CONCLUSIONS

In this experimental study, ∼30% of manual chest compressions were performed correctly compared to ∼90% of mechanical chest compressions, regardless of the underlying surface. Backboard use did not influence the mean compression depth during manual CPR. Chest compressions were deeper with mechanical CPR. The mean hands-off time was shorter with manual CPR. Clinical outcome studies are required for these scenarios.

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Competing Interests

Physio-Control had no involvement in the study design, statistical analysis, interpretation of results, or writing of the manuscript.

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ARTICLE SUMMARY

1. Why is this topic important?

In cardiac arrest, chest compression quality significantly correlates with survival and neurological outcome. However, chest compressions performed on a mattress are far from optimal, even when a backboard is used.

2. What does this study attempt to show?

In an experimental setting with different mattresses, this study shows substantial differences in the quality of manual and mechanical chest compressions in terms of depth, pressure point, complete pressure release, compression rate, hands-off time, and time to first defibrillation.

3. What are the key findings?

Only ~30% of manual chest compressions compared to ~90% of mechanical chest compressions were performed correctly regardless of the underlying surface. Backboard use did not influence the mean compression depth during manual cardiopulmonary resuscitation (CPR). The mean compression depth on both mattresses was deeper with mechanical chest compressions. In this brief scenario (~6 min duration), the mean hands-off time was shorter with manual CPR.

4. How is patient care impacted?

In-hospital CPR can be improved by means of mechanical chest compression devices. They could be a solution to this under-recognized problem and could help save lives. Clinical studies are required to confirm our experimental findings.

Supplementary Data

Questionnaire

- How many beds are in your hospital?
  ○ <200 ○ 200–500 ○ >500
- How many CPR scenarios were conducted in your hospital during the last 5 years?
  2008 ______________ ○ not known
  2009 ______________ ○ not known
  2010 ______________ ○ not known
  2011 ______________ ○ not known
  2012 ______________ ○ not known
- Who performs in-hospital CPR? (Multiple answers possible.)
  ○ Anesthetist/intensive care specialist
  ○ Ward physician
  ○ Internist
  ○ Emergency team
  ○ Others:___________________
- On which surface is CPR normally conducted? (in %)
  ○ Floor (approx:____%)
  ○ Bed with CPR board (approx:____%)
  ○ Bed without CPR board (approx:____%)
  ○ Others: (approx:____%)
  ○ If CPR is conducted on other surfaces please specify___________________
  ○ Not known (approx:____%)
- Do you use mechanical CPR devices in your hospital?
  ○ Yes (in approx:____%)
  Which device? ○ Autopulse ○ LUCAS
  ○ Others
  ○ No
- How often is the CPR team trained?
  a) Training in manual CPR: b) Training in mechanical CPR:
  ○ Every 0–6 months ○ Every 0–6 months
  ○ Every 7–12 months ○ Every 7–12 months
  ○ Every 13–24 months ○ Every 13–24 months
  ○ >24 months ○ >24 months
  ○ Mechanical CPR is not performed

Results

Sixty-two questionnaires were returned (reply rate, 14.6%). Mainly smaller hospitals replied: 39% with <200 beds, 37% with 200–500 beds, and 24% with >500 beds. CPR was executed in a median of 28 cases [IQR, 12–54] per hospital in 2012, 27 cases [IQR, 10–50] in 2011, 26 cases [IQR, 10–55] in 2010, 33 cases [IQR, 7–57] in 2009, and 15 cases [IQR, 7–55] in 2008. In-hospital CPR was most frequently performed by anesthetists (76%) and internists (47%); multiple nominations were possible. In-hospital CPR was mostly carried out in the bed (67%), and in 69% of these cases a backboard was used. CPR on the floor was accomplished in 12%, on other surfaces 3% (e.g., on a stretcher), and in 18% on unspecified surfaces. In 27% CPR was done mechanically, predominantly (85%) with LUCAS2. Training for manual and mechanical CPR most frequently was undertaken every 7 to 12 months (60%).