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Injuries in manual and mechanical CPR

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Abstract:

Objective: To compare the rate of injuries during cardiopulmonary resuscitation (CPR) using manual versus mechanical chest compressions with the Lund University Cardiopulmonary Assist System (LUCAS™).

Design: Systematic literature review

Methods: We investigated the use of 2 different CPR methods, manual and mechanical, in order to determine if one was more likely to cause injury in individuals during a cardiac arrest. PubMed searches were conducted using the terms "cardiopulmonary resuscitation," "adverse effect," "classification," "method," "mortality," "statistical and numerical data," "trends," "complication," "epidemiology," and "etiology." Studies were excluded if they took place before the year 2000, included individuals under 18 years of age, or included living individuals. One hundred forty six studies were found, and after inclusion and exclusion criteria were evaluated, 136 were removed. Four studies were ultimately chosen that were considered most relevant to our research question.

Results: All studies used post-mortem analysis to determine the rate and type of injuries amongst cardiac arrest patients who received manual or mechanical compressions with the LUCAS™ device. Friberg et al evaluated 414 deceased adults. Amongst the control group, 38% had sternal fractures, 77% had rib fractures, and 1.9% had severe soft tissue injuries. The LUCAS™ group showed higher percentages, with 80% sternal fractures, 96% rib fractures, and 10% severe soft tissue injuries. These trends were consistent with Smekal et al and Lardi et al, who both demonstrated a statistically-significant higher number of rib fractures amongst LUCAS™ patients. Lardi C et al (2015) retrospectively examined CPR performed either with the LUCAS™ device or manually. This study emphasized duration of CPR, which was almost twice as long when providers used the LUCAS™ device, when compared to manual compressions. Ondruschka B et al displayed similar results in terms of sternal fractures and rib fractures; however, the study offers the alternative that rib fractures correlate more with a patient's age and CPR duration, rather than the method of compressions performed. While this study found no statistically-significant correlation, an overall higher number of injuries were demonstrated in the LUCAS™ group.

Conclusion: The risk of injuries in CPR when comparing manual compressions to mechanical compressions using the LUCAS™ device demonstrates evidence of increased rates of post-traumatic injury in individuals who were given mechanical compressions.

Introduction:

Every year in the United States, there are over 550,000 cardiac arrests, which occur both in and out of the hospital.[1] Cardiopulmonary resuscitation (CPR) is a life-saving procedure to restore circulation in victims of cardiac arrest that consists of compressions and rescue breaths given to the patient by healthcare providers. Manual compressions are performed by the provider pressing down on the patient's sternum at a rapid and fixed rate. However, manual CPR is provider-dependent, and the rate and depth may differ according to the provider's training, size, and strength. Manual CPR by skilled and experienced medical providers still leads to a decline in precision and adequate perfusion within 1-2 minutes of uncomplicated cardiac arrests.[2] In addition, provider fatigue, psychological factors, and difficult settings all play a role in the outcome of CPR. The latter are particularly evident in emergency medical services (EMS), where compressions are often performed on a moving vehicle with transitions between many providers.

The Lund University Cardiopulmonary Assist System (LUCAS™) is an automated device that provides mechanical compressions to combat the variability in manual CPR. The device contains a central arm with a suction cup that attaches to the patient's sternum and provides compressions at a consistent rate and depth, which can be adjusted to meet the provider's local protocol. Additionally, the LUCAS™ device rests on a small backboard placed behind the patient, providing a firm surface for compressions, rather than the cushion of an EMS or hospital stretcher.[3] This is advantageous, as more force reaches the patient's heart rather than getting transferred through the stretcher. Compressions performed by a small automatic device also conserves space and frees more providers to perform other aspects of patient care during CPR, such as maintaining the airway. Decline in adequate resuscitation associated with provider fatigue, patient compatibility, and experience become obsolete in conjunction with mechanically sustained management. For these reasons, LUCAS™ provides more efficient compressions, and has been incorporated into many settings throughout the country, including EMS, emergency departments, and catheterization laboratories.[3]

For larger patients, it automatically increases the force needed to achieve a compression depth of 2.1 inches.[3] This constant force is always applied as long as the machine is on, despite any sternal or rib fractures that occur. In addition, since it is used for longer transports and frees providers to perform other tasks, the device is typically left on patients for longer than manual compressions are performed.[4] The constant force and increased time of compressions might predispose the patient to more injuries than manual CPR, including cutaneous chest lesions, sternal and rib fractures, internal organ injuries, and pneumothoraces.

We aim to answer the clinical question: Among adult men and women who have undergone life-saving treatment using LUCAS™ or manual CPR in or out of the hospital setting, do compressions with the LUCAS™ device as compared to manual chest compressions lead to an increase in chest injuries? The aim of this study is to conduct a literature review of multiple retrospective cohort studies examining the nature and incidence of injuries sustained in manual and mechanical CPR through post-mortem autopsy analysis of cardiac arrest patients.

Methods:

A literature search was conducted under PubMed using the terms "cardiopulmonary resuscitation," "adverse effect," "classification," "method," "mortality," "statistical and numerical data," "trends," "complication," "epidemiology," and "etiology." The initial screening of records contained 146 reports with no duplicates. Inclusion and exclusion criteria eliminated studies before the year 2000, individuals under 18 years of age, and living individuals, removing 136 articles for eligibility. The remaining 10 studies that fit the inclusion and exclusion criteria were further evaluated based on their relevance in the comparison of manual and mechanical chest compression injuries. Methods used yielded 4 studies for our data analysis.

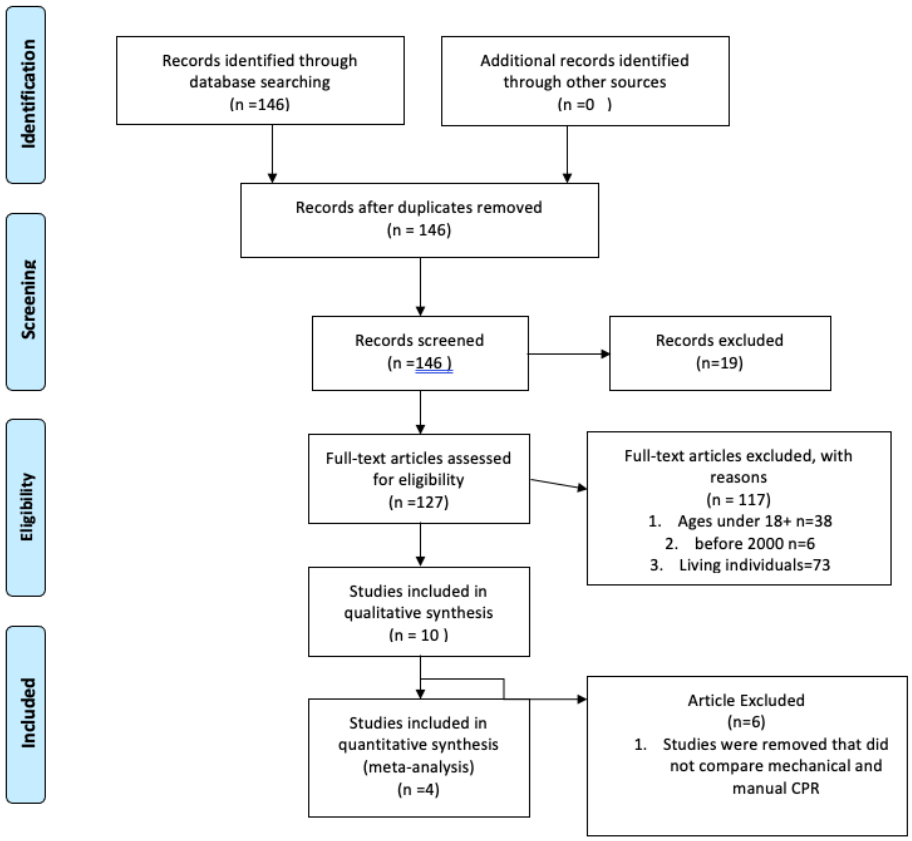

Figure 1. Research process in the determination of studies in accordance with inclusion and exclusion criteria.

Results

Study #1: Friberg, N. "Skeletal and soft tissue injuries after manual and mechanical chest compressions." *Eur Heart J Qual Care Clin Outcomes*. 2019;5(3):259-265. doi:10.1093/ehjqcco/qcy062[5]

Study Objective: To determine the rate of injuries related to CPR in non-surviving cardiac arrest patients when using manual CPR or Lund University Cardiac Assist System (LUCAS™).

Study Design: Patient data was extracted via autopsy referral documents and patient medical records using inclusion and exclusion criteria listed in Table 1. Cardiac arrest data was reviewed within the region at Skane University hospital to determine the rate of missed cases within 1 calendar year. A total of 414 deceased adults of cardiac arrests were included using focused postmortem investigation in comparison of mechanical and manual CPR. 362 cases received care from the LUCAS™ device, while 52 received only manual CPR. Reasons for usage of only manual CPR were commonly cited due to irregular body size or lack of availability of the LUCAS™ device. The LUCAS™ device was updated from gas powered to electrically powered in the LUCAS™ 2 model, which was accounted for by splitting the groups that received mechanical CPR into LUCAS™ 1 and LUCAS™ 2 subgroups.

Cases with and without soft tissue injury were compared by extent of skeletal chest injuries in respect to baseline characteristics of each individual. Cases were divided into six groups according to duration of CPR, rib fracture, and sternal fractures on autopsy.

The LUCAS™ was present in every ambulatory setting with appropriate attachments making it applicable to be used in the hospital in cases of emergency. Mechanical chest compressions were considered the priority treatment in cases of cardiopulmonary resuscitation, and the evaluation for manual CPR was based on the discretion of ambulatory staff or if mechanical compression was deemed non-feasible.

Data analysis was performed using Microsoft Excel and R, with categorical comparison being calculated using Fisher’s exact test. Numerical data were compared using Wilcoxon rank sum test or Kruskal-Wallis rank sum test. Calculation of data required a P value of <0.05 in order to be considered statistically significant.

Inclusion Criteria	**Exclusion Criteria**
Above the age of 18	Non-CPR related deaths
History of manual or assisted CPR w/ days before death	Traumatic cardiac arrest
Pathologist w/ experience in CPR	Unknown method of CPR
	Incomplete autopsy or referral autopsy
	Suicide, homicide, death by accident, ongoing drugs/alcohol misuse
	Health-care mistreatment
	Prolonged post-mortem delay
	Decomposition of the body/Difficulty identifying

Table 1. Inclusion and exclusion criteria for skeletal and soft tissue injuries due to manual CPR and mechanical CPR.

Study Results: Soft tissue and skeletal injuries were observed in both manual and mechanical CPR, with no associated injury being the primary cause of death on autopsy report (Table 2). High rates of skeletal injuries of the chest were present in both study groups, and most cases had multiple bilateral rib fractures, with a significant majority belonging to the LUCAS™ 1 and 2 device group. In addition, 12% of the mechanical group (35/291) presented with sternal fractures, while 1.9% (1/52) of the manual group did so.

Duration of CPR performed showed no clinically or statistically-significant difference in rates of rib and sternal fractures amongst both groups. Severity of injury caused by the LUCAS™ 1 and 2 device demonstrated 9 potentially life-threatening injuries, 29 severe injuries and 62 lesser injuries, with the remaining 191 individuals having no soft tissue injury. Comparison of age and gender showed no significant difference of injury patterns. Amongst patients in the LUCAS™ group, those with soft tissue injuries had an average of 12 rib fractures. Those without soft tissue injuries had an average of 10. This was comparable to patients. Amongst those patients, those with soft tissue injuries had an average of 11 rib fractures, and those without had an average of 6.5. (Median difference 2 fractures, 95% confidence interval 1-3; p=0.0018)

89% of individuals treated with the LUCAS™ 1 device suffered three or more rib fractures. Amongst those treated with the LUCAS™ 2, 96% (128/134) of patients had three or more rib fractures. The LUCAS™ 1 device also reported an 11% incidence of severe or potentially life-threatening associated injuries, while only 9.7% were seen in the LUCAS™ 2 device.

There were four cases that were excluded from data analysis, due to extended length of CPR, as these patients may have demonstrated more injuries than their counterparts. There were two of these cases in each group, and their exclusion did not affect the data.

	mechanical CPR (n = 362)	manual CPR (n = 52)	P-value
Study population			
Age (years), median (IQR)	68 (58–75)	66 (59–77)	0.72
Male, n (%)	244 (67)	40 (77)	0.17
CPR duration (min), median (IQR)[a]	40 (25–60)	25 (18–35)	0.013
Skeletal injuries			
Any skeletal fracture of the chest, n (%)	354 (98)	42 (81)	<0.001
Sternal fracture, n (%)	291 (80)	20 (38)	<0.001
Rib fracture, n (%)	349 (96)	40 (77)	<0.001
≥4 rib fractures, n (%)	331 (91)	34 (65)	<0.001
≥4 bilateral rib fractures and sternal fracture, n (%)	190 (52)	10 (19)	<0.001
Number of rib fractures (fractures), median (IQR)[b]	10 (7–13)	9 (6–10)	0.0069
Soft tissue injuries, n (%)			
Life-threatening injuries[c]	9 (2.5)	0 (0)	0.0019[f]
Severe injuries[d]	29 (8.0)	1 (1.9)	
Lesser injuries[e]	62 (17)	3 (5.8)	
No injuries	262 (72)	48 (92)	

[a]CPR duration data were available for 111 cases (31%) and 13 cases (25%) in the mechanical CPR and manual CPR groups, respectively.
[b]Calculated for cases with rib fractures.
[c]That is, rupture of the heart, rupture or severe laceration of the aorta, exsanguination >800 mL.
[d]That is, likely to require intervention/therapy for repair, risk reduction or pain control, expected to prolong hospitalization.
[e]That is, minor visceral bleeding or laceration.
[f]P-value refers to Wilcoxon rank sum test across all soft tissue injury groups, W = 7505.5.

Table 2. Autopsy report of injury and sample size of mechanical and manual cardiopulmonary resuscitation.

Source: Friberg, N. "Skeletal and soft tissue injuries after manual and mechanical chest compressions." *Eur Heart J Qual Care Clin Outcomes*. 2019;5(3):259-265. doi:10.1093/ehjqcco/qcy062[5]

Study Critiques: During data collection, there were certain factors that existed that could not be clinically evaluated due to the nature of the study**.** Since osteoporosis can go undiagnosed, the data could be skewed in populations with higher incidence or poorer access to healthcare. Selection bias is also impossible to exclude in cases where CPR-related mortality was not approved for autopsy, especially since reasons were not always specified.

Study #2: Smekal D. "CPR-related injuries after manual or mechanical chest compressions with the LUCAS™ device: a multicentre study of victims after unsuccessful resuscitation." *Resuscitation*. 2014;85(12):1708-1712. doi:10.1016/j.resuscitation.2014.09.017[6]

Study Objective: To interpret the incidence of CPR-related injuries by manual chest compression compared to mechanically-assisted CPR using the LUCAS™ device in non-surviving out of hospital cardiac arrests.

Study Design: Randomization took place using closed-letter design in settings of cardiac arrest. Manual chest compressions were performed on all patients during the process of randomization. Groups were each divided by case into standard CPR guidelines or LUCAS™ device resuscitation. 746 total patients were screened for inclusion and exclusion criteria, with 222 cases meeting requirements, as seen in Table 3. Data was analyzed with IBM SPSS statistics. All injuries not considered to be CPR-related were excluded. Injuries deemed highly suspicious by a pathologist or too extensive to definitively conclude the mechanism were still included in the study. A two-sided $p < 0.05$ was considered statistically significant. One hundred thirty nine cases were treated with mechanical CPR and 83 with manual CPR. Review of bodies for autopsies occurred in 3 sites at one center for forensic medicine in Uppsala, Sweden. Pathologists recorded all findings using standardized study protocol for internal and external injuries with questionnaires that included different types of injuries and their possible relationship to CPR.

Pathologists worked in conjunction with the forensic scientists in review of 22% of autopsies when major injury and severe etiology concerns were noted. Chest compression guidelines were followed in both manual and mechanical CPR; however, there was a switch from gas powered LUCAS™ 1 to the LUCAS™ 2, which is electrically-powered. A fixed depth of 4-5cm with a constant rate of 100/min were maintained in both devices in compliance with the 2005 CPR guidelines.

Inclusion Criteria	**Exclusion Criteria**
Above the age of 18	Traumatic cardiac arrest
High clinical suspicion for CPR related injury	<18 years of age
Damage that made CPR non-definitively attributed	Pregnancy
	Defibrillated before LUCAS™

Table 3. Inclusion and exclusion criteria for manual chest and mechanically assisted chest compressions.

Demographic and baseline data of autopsy population.

	Manual CPR, $N = 83$	Mechanical CPR, $N = 139$	p value
Age (years)[a]	66.3 (22–90)	67.7 (21–100)	0.541
Sex (female)[b]	28 (34%)	42 (30%)	0.585
CPR time[c]	34.7 (16.0)	35.0 (17.3)	0.904
Osteoporosis	18 (24.7%)[d]	28 (27.5%)[e]	0.679
Bystander CPR	51 (61.4%)	77 (55.4%)	0.377

[a] Mean (range).
[b] Number of patients (%).
[c] Mean (SD).
[d] 10/83 patients treated with manual CPR with missing data concerning osteoporosis.
[e] 37/139 patients treated with Mechanical CPR with missing data concerning osteoporosis.

Table 4. Demographic report of autopsied patients.

Source: Smekal D. "CPR-related injuries after manual or mechanical chest compressions with the LUCAS^{TM} device: a multicentre study of victims after unsuccessful resuscitation." *Resuscitation*. 2014;85(12):1708-1712. doi:10.1016/j.resuscitation.2014.09.017[6]

Study Results: The total number of patients included in the study were 222, 83 who had been treated with manual CPR and 139 with mechanical CPR (Table 4). All patients in the mechanical group also received manual compressions prior to mechanical intervention. Initial manual chest compression averaged 3.4 minutes with a range between 0 and 16 in the study group receiving manual chest compression followed by mechanical chest compression. Manual CPR performed by medical professionals before the initial mechanical compression were noted in 44.6% of cases.

75.9% of patients treated with strictly manual CPR had at least 1 one injury, while individuals treated with both CPR and manual chest compressions were seen to have at least 1 injury 91.4% of the time. (p=0.002, 3.4 CL 1.55-7.31)

Rib fractures and sternal fractures demonstrated similar trends. Manual CPR resulted in at least 1 rib fracture 64.6% of the time, and multiple rib fractures 57.3% of the time. In the mechanical group, 78.8% of patients had at least 1 rib fracture, and 65% had multiple. (p=0.02, CL 2.0 Cl 1.11-3.75). Sternal fractures were found in 54.2% of patients with manual CPR and 58.3% of the patients with mechanical CPR. (p=0.56 1.18 cl 0.68-2.04)

An age correlation was noted in this study. The group that presented with at least 1 injury were older, with a mean age of 69.1 years in the mechanical group and 55.8 years in the manual group. (p=0.001). 77.1% of female patients sustained rib fractures; while men presented with rib fractures 70.4% of the time, with a p=0.33. This data was not considered statistically significant. Sternal fractures were seen 60% of the time in women and 55.3% of the time in males with a p=0.51. This data was also not considered statistically significant.

Groups were subdivided even further into individuals who presented with either a confirmed diagnosis of osteoporosis or a high clinical suspicion of the disease. Of the patients in this group, all presented with at least 1 rib fracture, and 82.6% had sternal fractures. Non-osteoporotic patients were found to have rib fractures of 63.8% and sternal fractures of 47.3% both of which showed a high statistical and clinical significance of $p<0.001$.

Rib and sternal fractures.

Injury	Manual CPR, n (%)	Mechanical CPR, n (%)	p value	Odds ratio estimate, (95% Wald confidence limits)
Any rib fracture	53 (64.6%)	108 (78.8%)	0.021	2.0 (1.11–3.75)
≥3 rib fractures	47 (57.3%)	89 (65.0%)	0.259	1.4 (0.79–2.42)
≤2 rib fractures	6 (7.3%)	19 (13.9%)	0.140	2.0 (0.78–5.34)
Sternal fractures	45 (54.2%)	81 (58.3%)	0.555	0.76 (0.16–3.55)

Table 5. Rib and sternal fractures seen in mechanical and manual CPR.

Source: Smekal D. "CPR-related injuries after manual or mechanical chest compressions with the LUCAS™ device: a multicentre study of victims after unsuccessful resuscitation." *Resuscitation*. 2014;85(12):1708-1712. doi:10.1016/j.resuscitation.2014.09.017[6]

Study Critique: Patients in the mechanical group of this study all received manual CPR in order to avoid a delay in care while the mechanical device was located. This could potentially skew the results in several ways. First, this adds to the total length of time that CPR is performed, which increases the rate of injury. This also makes it impossible to determine if injuries were sustained during the manual or mechanical phase of compressions. In addition, the study took place in only one forensic center in Sweden. This is problematic, as the LUCAS™ device can be programmed for different settings according to the region's CPR protocols. By including only one region, all LUCAS™ patients will receive a similar treatment. To analyze all possible CPR injuries, a study should include data from multiple regions that may have slight variations in protocol.

Study #3: Lardi, C "Traumatic injuries after mechanical cardiopulmonary resuscitation (LUCAS2): a forensic autopsy study." *Int J Legal Med*. 2015;129(5):1035-1042. doi:10.1007/s00414-015-1146-x[4]

Study Design: This retrospective cohort study was conducted in Geneva, Switzerland from 2011-2013. Researchers examined the autopsies of 58 deceased patients following cardiac arrest and unsuccessful CPR. The patients presented from a variety of settings, with CPR performed both out-of-hospital by EMS crews and in-hospital by medical staff. Full inclusion and exclusion criteria can be found in Table 6 below. The deceased patients were then divided into groups based on compressions performed manually or with the LUCAS™ device. The type and frequency of thoracic injuries were then quantified. The mean time between death and autopsy was less than 37 hours in both groups to reveal the full extent of any injuries before any healing could occur. A p value < 0.05 was considered a significant result.

Inclusion Criteria	**Exclusion Criteria**
Age > 18	Age < 18
Deceased with CPR performed manually or by LUCAS device	Traumatic injuries to the thorax
	Pregnant patients
	More than one round of CPR (i.e., return of spontaneous circulation followed by asystole and further compressions)

Table 6. Inclusion and exclusion criteria of Lardi et al.

Study Results: Of the patients in the LUCAS™ group (n=26), there were a total of 171 rib fractures, with a mean of 6.6 fractures per patient. Patients in the control group (n=32) only experienced a mean of 3.1 rib fractures per patient, with 100 fractures overall. In both groups, the majority of these were anterior rib fractures and were more common in older, female patients.

Anterior chest lesions, such as ecchymoses and abrasions, also occurred more frequently in the LUCAS™ group. 18/26 patients experienced anterior chest lesions in this group, compared to 6/32 patients in the control group. Frequency of rib fractures and anterior chest lesions were the only statistically significant differences between the groups, and there was no significant difference in the rate of sternal fractures between the two groups. Both groups experienced several traumatic injuries to internal organs, including the heart, lungs, and liver, but none were deemed life-threatening. There was no significant difference in the rate of internal organ injuries.

Injuries	Control group (32)	LUCAS™2 group (26)	LUCAS™2 (CPR time≤60 min) (20)	*p* value
No injury	9	5	4	NS*/NS*
Chest cutaneous anterior lesions	6	18	13	<0.001/0.001
Chest cutaneous posterior lesions	1	3	2	NS*/NS*
Sternal fractures	7	9	7	NS*/NS*
Rib fractures	100	171	128	NS*/NS*
Average number of rib fractures	3.1	6.6	6.4	0.007/0.017
Maximal number of rib fractures	11	18	18	NS*/NS*
Posterior localisation of rib fractures	0	3	3	NS*/NS*
Associated trauma injury to viscera	8	5	2	NS*/NS*
Great vessel hematoma (ascending aorta)	0	2	1	NS*/NS*
Heart injury (subepi-/subendocardial hematoma)	2	1	1	NS*/NS*
Pulmonary contusion	5	1	0	NS*/NS*
Liver injury (subcapsular/ parenchymal hematoma)	1	1	0	NS*/NS*
Right renal hilary hematoma	1	1	1	NS*/NS*

*Non-significant

Figure 7: Results from Lardi et al.

Source: Lardi, C "Traumatic injuries after mechanical cardiopulmonary resuscitation (LUCAS2): a forensic autopsy study." *Int J Legal Med*. 2015;129(5):1035-1042. doi:10.1007/s00414-015-1146-x[4]

Study Critique: Patients in the LUCAS™ group received compressions far longer (mean duration of 51.5 minutes) compared to control patients (mean duration of 29.4 minutes). This could possibly be due to the preferential use of LUCAS™ in longer EMS transports, and the fact that provider fatigue is less of a factor when using a mechanical device. To control for this confounding variable, the researchers created a subgroup of LUCAS™ patients with a mean duration of only 34 minutes of compressions. However, this subgroup also revealed a higher frequency of rib fractures and anterior chest lesions, suggesting duration is not a significant confounder.

Another confounding variable is the fact that many LUCAS™ patients received manual compressions in the out-of-hospital setting while laymen waited for EMS crews to arrive. The LUCAS™ group received a mean of 9.3 minutes of manual compressions before the mechanical device could be applied. For this reason, the researchers argue the rate of injuries from the LUCAS™ device might be overestimated. Given that it is unethical to wait to begin compressions on cardiac arrest victims, the variable of time can only be controlled in animal studies. Indeed, porcine models actually show a higher incidence of traumatic injuries through exclusively manual compressions than with mechanical devices. The researchers argue that this supports the hypothesis that LUCAS™ injuries are overestimated in the human population.

Study #4: Ondruschka B, "Chest compression-associated injuries in cardiac arrest patients treated with manual chest compressions versus automated chest compression devices (LUCAS II) - a forensic autopsy-based comparison." *Forensic Sci Med Pathol*. 2018;14(4):515-525. doi:10.1007/s12024-018-0024-5[7]

Study Design: This retrospective cohort study was conducted in Leipzig, Germany between 2011 and 2017. Similar to the other studies, researchers examined autopsies of fatal cardiac arrest victims for type and incidence of injuries. The study included only adult deceased patients and excluded any patients with non-natural cause of death involving injuries to the trunk, such as assault. The study also excluded any patients who attained return of spontaneous circulation (ROSC) and survived for more than 12 hours before becoming pulseless again. Similar to Lardi et al, all patients were deceased after the first round of CPR. 1338 autopsy cases were divided according to the patient receiving manual chest compressions (mCC, n = 501) or an automated chest compression device (ACCD, n = 113). The automated device in this case was the LUCAS™. This study had a much larger sample size than others, with greater statistical power. A p value < 0.05 was considered significant, and p < 0.001 was considered highly significant.

Study Results: All injuries found in the autopsies were more common in the ACCD group than the mCC group, but none of the differences were statistically significant. Many injuries when compared between the groups had odds ratios barely above 1.0. The mean number of rib fractures was actually higher in the mCC group (6.5) than the ACCD group (5.9). However, a higher percentage of patients in the ACCD group (74.3%) had rib fractures compared to the mCC group (59.7%). These percentages were also higher for skin injuries, sternal fractures, and lesions to the heart, lungs, and liver. Hemothoraces and pneumothoraces were also more common in the ACCD group.

Great vessel injuries were detected in both groups, including bleeding of the thoracic aorta, rupture of the internal thoracic artery, laceration of the RCA, and straining of the IVC. None of the associated injuries were deemed fatal.

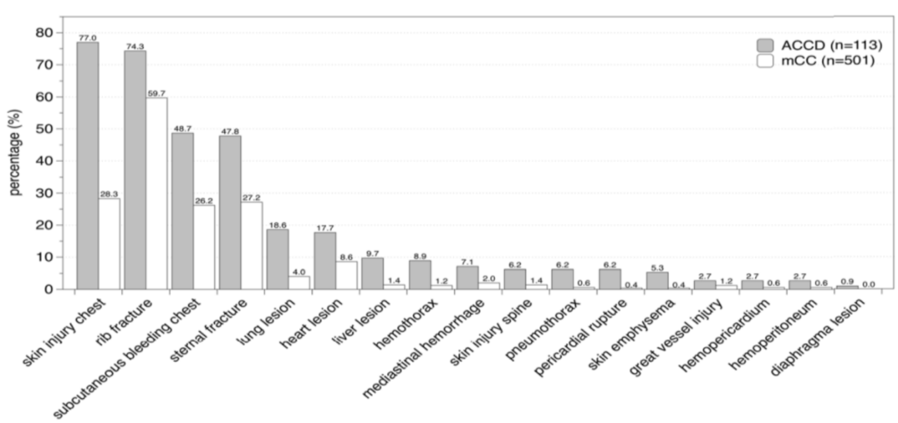

Figure 8. Results from Ondruschka et al.

Source: Ondruschka B, "Chest compression-associated injuries in cardiac arrest patients treated with manual chest compressions versus automated chest compression devices (LUCAS II) - a forensic autopsy-based comparison." *Forensic Sci Med Pathol*. 2018;14(4):515-525. doi:10.1007/s12024-018-0024-5[7]

Study Critique: Unlike Lardi et al., this study concluded no statistically significant difference between the incidence of thorax injuries sustained from manual compressions compared to automated compressions from the LUCAS™ device. Severity of injuries also showed no significant difference. However, a higher overall percentage of LUCAS™ patients sustained injuries of every type as examined by the study. The researchers concluded that injuries, especially rib and sternal fractures, correlated more strongly with age of the patient and duration of CPR rather than type of compressions received. Unlike Lardi et al., this study did not create subgroups to equalize the duration of compressions.

The researchers also suggested there is no way to control for age-related factors, such as osteoporosis influencing results, due to the sudden nature of cardiac arrests. They further suggested that younger patients may receive more aggressive CPR for a longer amount of time than geriatric patients, possibly skewing the results. Finally, the researchers suggested that provider experience with the LUCAS™ device may be a confounding variable. An inexperienced provider may apply the device incorrectly, resulting in forceful compressions located over the ribs rather than the sternum.

Discussion

One study (Friberg et al.) demonstrated a statistically significant higher number of rib fractures, sternal fractures, and soft tissue injuries in those patients who received mechanical chest compressions with the LUCAS™ device compared to manual CPR.[5] Two of the four studies (Smekal et al and Lardi et al) also demonstrated a significantly higher number of rib fractures amongst LUCAS™ patients.[4,6] A fourth study (Ondruschka et al.) did not find a statistically significant difference in any injuries when comparing the two means of CPR;[7] however, it did show a higher overall incidence of injuries from mechanical compressions. It should be noted that this study had the largest sample size and therefore the best statistical power of the four studies reviewed in this paper.[7]

Several confounding factors have been discussed within each study. First, CPR is typically performed on an older patient population, in which there are higher rates of osteoporosis. Only one of the studies created a subgroup to specifically examine osteoporotic patients and demonstrated much higher rates of chest injury regardless of the type of CPR.[6] The other three studies did not control for this confounding variable, which may have skewed the results towards a greater percentage of injury. Second, LUCAS™ patients typically receive manual CPR for several minutes, as manual CPR can be performed immediately while the LUCAS™ device takes time to set up. Additionally, in the out-of-hospital setting, the device is provided by EMS crews, which may take several minutes to arrive on scene. This overlap in technique may skew results for the LUCAS™ groups; however, it is clearly unethical to delay beginning CPR to control for this factor. Controlling for this variable can be done using porcine models, which actually show a lower incidence of injury from mechanical compressions.[4] Third, LUCAS™ patients tend to receive compressions for much longer than those receiving manual compressions. This is likely because the device eliminates provider fatigue, is generally used in longer EMS transports, and it frees providers to continue performing additional life-saving measures. Only one of the four studies created a subgroup to control for this longer duration of

CPR, which still concluded a statistically significant difference of a higher rate of injury amongst LUCAS™ patients.[4] Finally, there may be provider error when applying the LUCAS™ device, such as not placing the suction cup directly over the sternum or positioning the device at an angle. This is difficult to control for but should not be considered a confounding variable, as there is a greater degree of provider error when performing manual CPR, due to provider inconsistencies.[2]

Conclusion

Cardiopulmonary resuscitation is a life-saving procedure that combines chest compressions with ventilation. Mechanical and manual chest compressions have been more commonly incorporated in the medical management of patients in both inpatient and outpatient management. LUCAS™, which is a form of mechanical compression, has been seen on rescue ambulances, where consistent compressions are necessary despite changing locations.[3] The overall goal of CPR is to increase blood flow, which diminishes the risk of physical and neurological deficits in the event of successful resuscitation. A constant rate of depth and compression optimizes overall perfusion.

There is an increased need for mechanical chest compressions due to the inadequate number of medical providers and variations in training amongst individuals performing CPR. The standard for quality CPR consists of mouth to mouth breathing at a ratio of 30:2 compression to breaths. A trained provider of CPR should be expected to perform up to 100-120 compression per minute at a depth between 5-6cm, or about 2 inches. Deviations from this standard could lead to inadequate perfusion, new injury, or further exacerbation of injury. The LUCAS™ device was developed to remove variables that may make these standards not feasible due to weight, gender, or lifestyle discrepancies between provider and patient. The mechanical device leads to more consistent compressions and more hands-on time for CPR, which may lead to better perfusion.[8]

The most common compression-related CPR injuries are soft-tissue, muscle, and bone. The goal of this literature review was to evaluate if mechanical compression, while consistent in standard of care, leads to increased risk of injury. When comparing mechanical to manual compressions, three of the four noted statistically significant differences in the number of rib fractures, with one of these also demonstrating a higher number of sternal fractures and soft-tissue injuries.[4,5,6] The fourth study demonstrated a higher overall incidence of injury amongst mechanically-resuscitated patients.[7] Given these results, while not always statistically significant, there does seem to be a higher incidence of chest injuries amongst patients who receive mechanical CPR with the LUCAS™ device. However, this information should be considered with the body of evidence that demonstrates more effective compressions and reperfusion achieved using the LUCAS™ system.[8] The benefit of better perfusion may outweigh the risk of injury, as CPR is a life-saving measure.

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