IATROGENIC INJURIES ASSOCIATED WITH MECHANICAL CARDIOPULMONARY RESUSCITATION DEVICES

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ABSTRACT

Cardiopulmonary Resuscitation (CPR) is a mechanism that is widely known to sustain life in a critical patient suffering from cardiac arrest. As with most medical techniques, there are risks and benefits to manual CPR. In an effort to mitigate some of the associated drawbacks, mechanical CPR (mCPR) was introduced as a way to make resuscitation more effective. The two types of mCPR devices discussed in this paper are the Zoll Autopulse and the Stryker LUCAS. We endeavor to discuss how a proposed solution to manual CPR may not be a solution at all, but rather a means to cause more harm than good to the patient. This paper examines the efficacy of manual CPR compared to mCPR while incorporating evidence from various case studies and reports. By examining retrospective studies and case reports, we have elucidated that mCPR is a medical technique that causes unnecessary harm whereas manual CPR may not cause such harm. In our discussion, we have identified alarming problems associated with mCPR, and in the future, more research is needed to definitively show whether there is space for it in the medical field for practical use. Future studies should continue to target efficacy of both types of CPR in warranted situations while implementing quality control studies to examine if proper training may make mCPR more safe.

INTRODUCTION

Cardiopulmonary resuscitation (CPR) is an essential piece of treating the patient experiencing cardiac arrest. The primary goal of CPR is to maintain adequate blood flow to the vital organs in the context of a lack of intrinsic pulse. To maintain this perfusion, it is of the utmost importance that proper technique is utilized wherein the provider achieves an average compression depth of 2 inches at a rate of 100-120 beats per minute (bpm). This rate and depth algorithm seeks to optimize ventricular filling time and subsequent ejection of blood into the systemic circulation. With a trained provider and in a controlled setting such as the emergency department or intensive care unit, this is usually achievable.

Regardless of how often manual CPR is used on a daily basis by medical professionals, it presents with certain drawbacks that may further the patient's condition. It has been demonstrated that after a planned pause between cycles of CPR, perfusion to the brain has a lag time of 10 seconds or more to again receive blood flow despite re-initiation of adequate technique.[12]

Manual CPR's effectiveness also depends on the skill-quality of the administrator with regard to proper rate and depth of compression. Because of the variation between providers in skill, training, and setting, the opportunities for faulty administration of manual CPR are augmented. It was also noted in some studies that chest compressions observed in practice tend to be too shallow, whereas in mannequin studies, 30-50% of the compressions were too deep.[19] Unfortunately, a significant amount of cardiac arrest care is performed pre-hospital where staff and space are both limited. Performing CPR in confined spaces and during hospital transport limits the effectiveness of delivery, decreasing the benefit of manual CPR.[16] Lastly, manual CPR is not constant and as such it requires one to ensure oxygen flow via mouth-to-mouth or manual ventilation without continued compression. The discontinuous nature of manual CPR decreases blood and oxygen flow to the brain in an already critical patient; even if temporary, this cessation can prove harmful.[19] Consequently, researchers and innovators have endeavored to solve these drawbacks, and as a result mechanical cardiopulmonary resuscitation (mCPR) was introduced as a solution.

Mechanical CPR (mCPR) devices have been utilized by prehospital personnel while transporting patients experiencing cardiac arrest. Mechanical CPR seeks to eliminate the variable of human error and tauts perfect technique as evidenced by the claim of >99% operational reliability in clinical practice.[11] The types of devices are variable, though the most common are the Stryker LUCAS, a piston-based machine, and the Zoll Autopulse, which uses a load-distributing band. These devices are often placed at the scene and left on the patient for transport to the emergency department. There, they are frequently kept running instead of initiating manual CPR despite having more space and staff to work with. This is the situation that this review seeks to put under investigation. The use of mCPR in lieu of manual CPR may provide temporary benefit for the sustenance of life, but in certain situations it has been shown to cause further and unnecessary injury to the patient.[2,3,8,9,10,13,14,18] As such it is important to denote the situational use of mCPR versus manual CPR in sustaining blood flow and oxygen delivery in the critical patient. Elucidating the injury mechanisms associated with each technique will also be examined. For the sake of this review, the aforementioned LUCAS and Autopulse will be the primary devices investigated.

The Zoll Autopulse is a Load-Distributing-Band device in which the patient is placed on a large backboard that contains a motor, battery, and control panel. A large band is strapped under the armpits bilaterally and across the chest, which compresses uniformly when the device is activated.

The LUCAS is a piston-based device where the patient is placed onto a small back piece, and a circular machine is then clipped over top of the chest. A piston, roughly 6 inches in diameter, is lowered onto the chest,

and will compress when the machine is turned on.

Both of the above devices are widely used today, particularly in fire departments or EMS services. A major benefit is that it eliminates the need to use a valuable provider just for compressions when working on scene or in transport, and the extra attention can be spent on other crucial tasks. Which device is used is simply a factor of what the department chooses to purchase, or what might be gifted to them by these companies.

To better delineate the relationship between these devices and their respective iatrogenic sequelae, PubMed and SCOPUS databases were searched from the date range of 2003 until the present. This cutoff date was established as both the Zoll Autopulse and the LUCAS were both introduced to the market that year. The review was performed using the key terms “mechanical versus manual CPR” AND “injuries” OR “efficacy.” Citation mining was then performed to expand the search results, and 98 primary or secondary publications that compared either the efficacy of, or risk of injury associated with the aforementioned interventions were pooled and reviewed. Exclusion criteria included animal studies or those that contained subjects who suffered cardiac arrest due to traumatic or drowning-type injuries. Following exclusion, 66 studies remained and the findings of which will be discussed in the following sections. This literature review will first compare the risks/benefits of manual vs. mechanical CPR, then will bring to light the relationship between CPR type and the pattern of injuries seen with each. The discussion will close with identification of areas of lacking research and new directions to take.

OVERVIEW

Manual CPR

Manual CPR is a mainstay initial treatment for maintaining perfusion in the critical patient. Many people that have watched current TV shows likely have some understanding of what CPR is and an idea of how to emulate it should the need arise. Furthermore, it is the cornerstone of BLS, ACLS, and PALS, making it one of the few medical practices that the lay person can perform. It is true that anyone can save a life with adequate CPR, making it one of the most widely taught medical practices for non-medical workers.

However, it is not without its criticisms. With CPR, any mistake can be extremely damaging to the patient’s condition – maintaining appropriate rate and depth of compressions in a high pressure situation can be difficult and tiring. It is widely known that manual CPR produces provider fatigue which inevitably decreases the quality of compression rate and depth; this is why switching providers every 2 minutes is highly recommended.[7,15] Medicine is a field in which perfection is highly regarded, and solutions to mitigate any mistake or drawback are praised. Mechanical CPR devices have come into existence and have gained recognition for their own set of benefits with the intention to alleviate provider fatigue.

Mechanical CPR

Mechanical CPR in the United States includes widely used devices such as the Zoll Autopulse and the Stryker LUCAS. Both were marketed as solutions to the imperfections experienced during manual CPR as stated above. Both devices have set rate and depth controls that allow for consistency. They also both have different designs as stated previously, of which we will also dissect in future sections. Zoll and LUCAS are attractive options for healthcare providers; using mechanical CPR frees up an extra set of hands by taking manual CPR out of the equation, they are easy to apply and can be used in cramped spaces such as on ambulances, and they are marketed well by large and trusted healthcare corporations.

With these benefits come considerable risks. MCPR and the different designs associated with Autopulse and LUCAS have proven to cause increased injury patterns to the patient where manual CPR does not cause such injury.[2,3,8,9,10,13,14,18] It seems that after these devices became available without being widely studied for their drawbacks, abnormal injury patterns like aortic dissections and visceral hemorrhage were being noticed more frequently; this leads us to believe that these devices were made available for public use prematurely.[8,10,13] We will examine the patterns of injury and associated case reports with mCPR compared to manual CPR hereafter.

LUCAS and Autopulse

Observational studies that included retrospective and prospective cohort studies analyzed the efficacy of mechanical chest compressions specifically using the AutoPulse device and the LUCAS device. Within these studies and reviews it was determined that the efficacy of mechanical chest compressions did not improve return of spontaneous circulation (ROSC) when compared to manual chest compressions at a confidence interval of 95%.[17]

A separate clinical evaluation of AutoPulse for cardiac arrest patients in the northern district of Shanghai, China showed that the AutoPulse device effectively had an ROSC rate around 44.9%. This study also noted increased return of spontaneous breathing (ROSB) and improved cerebral perfusion compared to manual CPR, but additional injuries to patients were inconclusive and required further examination due to the lack of postmortem analysis.[4]

Studies targeted toward the efficacy of the LUCAS mechanical chest compression device included randomized trials, cohort studies, and 4 animal studies. The results showed that the LUCAS had high efficacy in regards to physiological parameters but not an advantage in ROSC or survival when compared to manual chest compression.[6]

MECHANICAL AND MANUAL CPR

Patterns of Injury

The Zoll Autopulse and LUCAS were both employed in a prospective study to assess their associated patterns of injury in patients with nontraumatic out of hospital cardiac arrests (OHCA). Truhlar, et. al reported that 87.5% of patients who received Autopulse care had related injuries (n=8). Additionally, 72.7% who received LUCAS had related injuries (n=11). Using Fisher's exact test as data analysis, p=0.02 for total injuries sustained.[18] Although the number of patients treated is quite minimal and efficacy is limited by this, the type of injury is notable.

The Zoll Autopulse was found to have caused mediastinal hematomas in 62.5% of patients, whereas LUCAS reported the same injury in 18% of patients (p=0.003). Furthermore, pericardial effusions and adventitial aortic hematomas were observed in patients of the Autopulse group only (p=0.06, p=0.002). The statistical significance of this study and the unnecessary injuries sustained using the Zoll Autopulse has preliminarily defined its use as detrimental in OHCA.[18]

Although larger studies are to be done in comparing Autopulse and LUCAS, this prospective study has given important insight into the dangers of using mechanical CPR, and it should prompt important thought regarding what healthcare providers are willing to sacrifice for the sake of time effectiveness and convenience.

Injury Comparison

As indicated in previous sections, LUCAS is one of the most common mCPR devices, and with its use comes a risk of injury. Within a specific case report, a 68 year old man with a history of hypertension presented to the emergency room for a cardiac arrest and after the use of a LUCAS device suffered an aortic dissection.[8] This circumstance was thought to be due to improper positioning of the LUCAS device by care providers. Furthermore, frequency and use of mCPR devices within an emergency setting is thought to be directly correlated with the frequency of cardiac arrest cases within an emergency room and the possible need of long duration resuscitations.[21] The obvious risk for injuries with these devices cannot be ignored, and future guidelines and regulations should be installed to make manual CPR the standard of care after mCPR use en route to the ED in order to avoid such catastrophes, even if uncommon. Further investigations of intrathoracic and aortic injury resulting from improper use of these devices are also warranted.

In Denmark, a series of autopsies were performed on individuals who received mCPR via LUCAS and were over the age of 18 and not pregnant, and experienced non-traumatic cardiac arrest. Out of the 50 autopsies that were performed, 10% of patients had characteristic skeletal or visceral injuries that would have been life-threatening had they survived mCPR. These injuries included two cases of pericardial tamponade, two cases of respiratory complications, and

one case of multiple organ damage due to severe hemorrhage.[14] They had no extensive injuries prior to cardiac arrest, leading suspicions to point to LUCAS as the culprit for such injuries. Furthermore, one post-mortem CT of a patient who died via suicide by overdose showed tension pneumothorax, which could have only been caused by mCPR. Additionally, two injuries were so extensive that homicide and strangulation had to be ruled out as a cause of death.[14] The injuries described may not have occurred to such an extent had manual CPR been administered instead. Human hands are objectively weaker than a metal piston which covers six inches of diameter across the chest, and therefore it can be reasonably postulated that manual CPR would do far less damage to visceral organs, major vasculature, and the skeletal framework than mCPR. In fact, although mainly skeletal injuries are sustained from mCPR, other studies have shown that 14.3% of mCPR patients in a cohort had sustained visceral injuries compared to manual CPR, which comprised 1.1% of the cohort. The injuries were deemed to be associated with the duration of chest compression.[13] These numbers are nothing short of alarming, and warrant further investigation into the legitimacy and use of mCPR for the critical patient.

Second to LUCAS, the Zoll Autopulse is a common device for use in patients experiencing cardiac arrest. Although the number of studies that have been done on Autopulse are fewer than LUCAS, the outcomes of those studies are similar. As previously stated, this device uses a load distributing band that is strapped across the chest and compresses uniformly. While LUCAS uses a piston, both it and the Autopulse have proven to cause unnecessary injury to the patient. In a retrospective study, the Autopulse device was shown to contribute to posterior rib fracture, hemoperitoneum, and retroperitoneal hemorrhage more so than manual CPR.[10] This could be due to the load distributing band extending laterally across the body and under the arms. Compression from all sides, not just superiorly onto the chest like in manual CPR, may have contributed to surprising postmortem findings such as retroperitoneal hemorrhage. Another study demonstrated that the Autopulse compared to LUCAS or manual CPR had the most associated injuries.[18] The most prevalent injuries relative to the other methods were mediastinal hematoma, pericardial effusion, and adventitial aortic hematoma.[18] Other studies also demonstrated increased prevalence of pneumothorax after using Autopulse compared to manual CPR and LUCAS. These studies have postulated that the design of the Autopulse increases intrathoracic pressure and therefore increases the risk of pneumothorax as well as posterior rib fracture.[18]

Outcomes

One of the claims made by the companies advertising mCPR devices is that they provide a survivability advantage when compared to manual CPR.[11] Unfortunately, on review of the literature, this does not appear

to be the case. Of the 36 studies that were pooled during the research phase of this investigation, 25 showed no significant differences in survival of patients experiencing cardiac arrest. Of these studies, Bonnes et al performed a meta analysis in 2016 that included a total of 20 studies, with a large patient pool (n=21,363). They concluded that there were no statistically significant differences between neurological outcomes or survival of these patients to hospital discharge, and ultimately recommended against constitutive use of the devices until further improvements can be made.[1]

Furthermore, 9 of the studies showed that mechanical CPR had worse outcomes and survival rates, while only 2 stated a survival benefit of mCPR. This decreased survival rate has been investigated seldomly, though a study performed by Fohle et al postulated that this may be due to the cumbersome nature of the devices and the time it takes to apply them to the patient.[2] This was confirmed by a study performed by Yost et. al in 2012, where the time to apply the devices was measured and compared to the providers' best estimate of the perceived interruption time. They discovered that interruptions lasted 32.5 s on average. Interestingly, the providers' estimate was less than half of this number, indicating that they do not have an accurate interpretation of the time it takes to apply the device, which may further impact the quality of CPR administration.[20] Ultimately, the time taken to apply these mechanical devices has been shown to be much longer than estimated, and this alone may correlate with poor outcomes in those receiving CPR. The multitude of retrospective and prospective studies that have been done on these two devices is extensive, and they demonstrate an alarming trend whereby mechanical devices are not designed well enough to prolong human life without simultaneously causing significant and unnecessary injury. Manual CPR has not yet proven to cause injuries to the same extent, and as such, it is a much safer and well-known option to use on patients experiencing cardiac arrest. Although mCPR is convenient, we must weigh that convenience against positive patient outcomes and hopefully conclude that the latter is much more important.

Use in the Present Day

Autopulse and LUCAS are attractive options for healthcare providers; using mechanical CPR frees up an extra set of hands by taking manual CPR out of the equation, they are easy to apply and can be used in cramped spaces, and they are marketed well by large healthcare corporations. It is unclear whether these companies give financial incentives for providers that choose to use their product. It is clear however, that these devices have entered the healthcare market prematurely, before well-conducted studies were able to elucidate their benefits and drawbacks in emergency situations. Here we outline a few reasons that postulate why these devices are still so widely used even after studies have shown the drastic risks associated.

As stated earlier, using mCPR in small spaces where maneuvering around a patient is near-impossible may be indicated and beneficial to overall survival. Another situation in which mCPR may be beneficial is before organ donation; ensuring adequate perfusion to organs when the patient is already deceased may be beneficial in maintaining the vitality of such organs without the risk of causing further harm to the patient.

Perhaps using supplemental mCPR on individuals who meet a specific minimum weight requirement may increase survival, as the rate and depth of CPR compressions vary widely in different age groups and mCPR may not be as reliable with smaller patients due to their size. Further studies may be able to examine certain age and weight ranges that seem to have increased survival from mCPR.

CONCLUSION

Choosing Carefully

Regardless of the situation which requires CPR, if it is chosen for use by providers, it should not replace manual CPR, but rather it should complement manual CPR when providers experience fatigue or other complications with maintaining adequate perfusion. Because emerging studies are elucidating the risks associated with use of mCPR, it should not simply be used as a shortcut in providing optimal care out of convenience. Until more conclusive studies are available, caution should be used when using these devices, and manual CPR should remain the mainstay treatment for immediate perfusion of ischemic tissue.

As discussed in the prior sections, mCPR devices are not without drawbacks. It may be tempting to use these machines on every patient experiencing cardiac arrest, though this would be reckless. While there is no specific evidence reported on these variables, it is not difficult to imagine scenarios in which the use of mechanical CPR might be relatively contraindicated. Elderly and pediatric patients, patients undergoing chemotherapy, or those with a history of degenerative disease of the bone would likely be more prone to iatrogenic injury and as a result, soft tissue damage. Additionally, patients with multisystem trauma would likely be at a greater risk of injury from these machines. It is difficult to identify every injury or chronic condition a patient may have at the scene of an accident, so to place an mCPR device over several fractured ribs or on a patient with degenerative bone disease may precipitate a pneumothorax for example. Regardless of injury pattern, if a trauma patient arrives to the emergency department and is undergoing CPR, they will more than likely receive several interventions to the thorax (chest tube, thoracostomy, thoracotomy) and the physician will require unopposed exposure to the lateral chest walls to perform these procedures. Both the Autopulse and LUCAS machines obstruct the lateral thorax by design, making this not feasible if concurrent compressions are desired.

Several studies have indicated that mechanical CPR devices are associated with a higher risk of hemorrhagic injuries on average compared to manual CPR techniques.[3] Other studies comprising almost 3,000 patients across 11 trials have further shown that specific injuries such as sternal and vertebral fractures are far more common in mechanical CPR.[5] Other studies have even shown no significant difference in the return of circulation between mechanical and manual CPR but a dramatic decrease in the 30 day survival rate of patients treated with mCPR.[9]

Again, while there is no published literature at the moment to delineate the indicating and contraindicating conditions in which one might use an mCPR device despite increased risk of possible injury, this is certainly a hot topic and will require further attention.

Next Steps

In this review, we have outlined the uses, benefits, and risks associated with mechanical CPR (mCPR) compared with manual CPR. Through a careful investigation of current studies and individual case reports regarding survival outcomes in out of hospital non-traumatic cardiac arrest, we have concluded that mCPR is associated with injuries not previously seen with manual CPR, making it unsuitable as a replacement for manual CPR. The Autopulse and LUCAS devices, while similar, present different challenges and therefore have different injury patterns due to the structure of the devices and the ways that they exert force on the human body. The Autopulse device has been associated with increased incidence of retroperitoneal hemorrhage amongst other injuries like posterior rib fracture and pneumothorax which was discovered on postmortem analysis. LUCAS, which is more widely used than Autopulse, has been associated with cases of aortic dissection and pericardial tamponade amongst other visceral injuries.

These devices are marketed well, are easy to use in small spaces, and guarantee positive outcomes, making them appealing to healthcare workers both in the field and in the hospital. They also are convenient to use as they free up an extra set of hands, are automatic devices, and reduce the human error associated with manual CPR. They are marketed by large companies but it is unclear whether there is a financial incentive associated with use of these devices. To healthcare workers who are presented with a solution to problems associated with manual CPR, these devices are a godsend.

Upon further investigation of these products, it is plausible to deduce that lives have been lost in association with the use of mCPR. Educating healthcare professionals on the use of these devices in conjunction with manual CPR instead of in place of it is crucial; it must be heavily emphasized that sacrificing quality of care for convenience never leads to positive outcomes. Further studies must be performed on the indications and contraindications of use of these devices in order to maximize their benefits.

Furthermore, investigating a minimum patient weight requirement in addition to age and comorbidities for use of mCPR may provide insight into the populations that are more likely to be harmed by mCPR, including but not limited to the elderly and pediatric populations, patients undergoing chemotherapy, and post-menopausal women not undergoing hormone replacement therapy.

Lastly, educating providers on proper usage of mCPR may help improve outcomes of care. Proper technique when applying these devices can help minimize injuries. Frequent training about the proper use of these devices for all healthcare professionals may help maximize their effectiveness. And, being transparent and realistic about the potential for injury with mCPR may sway providers to think carefully about using mCPR and perhaps use it only when necessary and in conjunction with manual CPR instead of as a mainstay for treatment.

As more studies investigate the indications and the safety of mCPR, we are hopeful that it can be safely integrated into patient care as a positive measure; until then, using care and caution with mCPR is crucial to decrease unnecessary harm and detrimental outcomes.

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