Design and Construction of a Portable CPR Machine

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***Abstract*— The aim of study is to design an affordable device to save human life during pre-hospital emergencies. This can automate and standardize the CPR process. In the development of this device, our guidance was taken from scientific literature, engineering principles, and clinical practices to create a safe, effective, and user-friendly system. It will be a significant tool for healthcare professionals and emergency response team's especially pre-hospital CPR application. A device based on a slider crank mechanism is used during the design. Mechanical design is finalized and the mechanism based simulations (Matlab®) are presented in this study.**

Keywords—CPR machine, Mechanical CPR devices, Matlab-Simulink, Slider crank mechanism, chest compression

I. INTRODUCTION

Cardiopulmonary Resuscitation (CPR) is a critical intervention method that saves lives in cases of sudden cardiac arrest. The correct and effective application of this intervention significantly increases the patient's chances of survival. However, errors or inadequate pressure application by healthcare professionals and first responders during CPR can reduce the intervention's effectiveness and pose serious risks to the patient. Brain cells begin to suffer damage due to oxygen deficiency within 4-6 minutes. Irreversible brain damage starts to occur after 6 minutes, and after 10 minutes, this damage typically becomes permanent. These timeframes indicate critical periods of brain damage that will occur if intervention is not provided after cardiac arrest. Brain hypoxia occurs when the brain does not receive enough oxygen. The brain requires a continuous supply of oxygen and nutrients to function. Thus delivering high-quality CPR gets very important.

Research has shown that CPR practitioners make various mistakes such as insufficient pressure, fatigue, and incorrect application. Especially during transport, off-balancing forces can cause disruption. It decreases quality of CPR due to shaking. Within the study, existing CPR devices were examined, and deficiencies were identified. A user friendly solution is proposed to facilitate the training of emergency response teams and health care professionals. When deaths in Turkey are examined according to their causes, circulatory system diseases rank first with 35.4% in the year 2022 [1].

There are many devices in the field, they are generally evaluated in two groups according to the mechanism they employ; load-distributing band or piston-based devices. The effectiveness of manual and mechanical chest compression was compared in out-of-hospital cardiac arrest patients. M.Aygün et al [2] have presented a comprehensive study on mechanical chest compression devices including historical evolution, classification and current practices. Differences are critically based on working principles, the energy consumed and also available electronics. A current classification is given as; piston-driven CPR (PD-CPR), load distributed (LDB-CPR), active compression-decompression (ACD-CPR), simultaneous sterno-thoracic CPR (SST-CPR/X-CPR), Inspiratory Impedance Threshold device (ITD) and ResQCPR (ACD+ID CPR), Phased thoracic-abdominal active compression-decompression CPR (PTA CD-CPR), active compression-decompression CPR with enhanced external counter pulsation and the inspiratory impedance threshold value (AEI-CPR). C. Remino et al. Have also presented a review on CPR devices [3]. A Şener et al. [4] have summarized mechanical versus manual chest compression in out of hospital cardiac arrest by giving names of commercial ones. Lucas is developed since 2002. Now new name and models (Lucas 1-Lucas 2, Lucas 3 with user interface) are available in the market [5] in Fig.1.



Fig.1. LUCAS 3 [5]

2015 CPR Guidelines of the ERC (European Resucitation Council and AHA (American Heart Association) (They are same now.) are listed in Table I [6]. The American Heart Association (AHA) resuscitation guidelines focus on early recognition of cardiac arrest, early activation of the emergency medical services, early onset of CPR with effective chest compression, and rapid defibrillation to improve survival in patients with

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cardiac arrest. Out of hospital cardiac arrest requirements are also listed in Table II [7].

A piston driven device is designed with active compression-decompression in our study. Its simulation and design details are given. Automation details and electronics are not included. Only final mechanical design is revealed. Design, development and prototype details are given with further simulation.

TABLE I. CPR GUIDELINES OF THE ERC (EUROPEAN RESUCITATION COUNCIL AND AHA (AMERICAN HEART ASSOCIATION [6]

Component	**Adults and Teenagers**	**Children**	**Infants**
Compression rate	100-120/min	100-120/min	100-120/min
Compression depth	5 cm	5 cm	4cm
Hand Placement	Two hands on the lower half of the sternum	Two hands on the lower half of the sternum	Two hands on the lower half of the sternum
Chest recoil	Allow full recoil of the chest after each compression; do not lean on the chest after each compression		
Interruption minimization	Limit interruptions in chest compressions < 10 seconds		

TABLE II. OUT OF HOSPITAL CARDIAC ARREST REQUIREMENTS [7]

CPR CRITICAL CHARACTERISTIC	
Dimensions	**<350x200x200 mm**
Weight	<3 kg
Setup Procedure	<20 s
Durability	European standards, 20 years
Chest compression depth	5 cm
Chest compression rate	100 Comp/min
Manual massage allowed during deployment	Yes
Massage types	Thoracic, abdominal, thoracic and abdominal
External force	Compression, decompression, compression and decompression
Defibrillation without stopping massage	Yes
Sensors	Depth, rate, compression waveform
Ventillation	Yes
Signals	acoustic, visual

II. EFFECTIVENESS OF CARDIOPULMONARY RESUSCITATION ON THE CPR MANIKIN

CPR is a lifesaving medical procedure applied to cardiac arrest condition. The survival rate from cardiac arrest is very poor (10%)[1]. There are many reasons effecting CPR performance. They can be counted as fatigue, sweaty hands, broken ribs, and failure determining the necessary point. These problems are mentioned in previous studies. A study based on first aid and basic life support has been performed at Izmir University of Economics in 7 different health programs covering 153 volunteer students in 2017. CPR applied to a CPR mannequin (Ambu Mannequin) to determine duration and effectiveness of action. Students' body positions, blowing capacities, compression depths and compression times were evaluated, and statistically analyzed. Numerical data were analyzed by Student's t-test, analysis of variance and chi square. P-value. Data were analyzed using SPSS version 21 (IBM Corp., Armsonk, NY, USA). Approval was obtained from Izmir University of Economics Ethics Committee for this study. Volunteer students are noted as 60.1% female and 39.9% male. The average age is found as 20.32±03 years. Their average height is 169.20±26 cm. The average effective CPR duration was 2.95 ± 0.86 min, the average pressure depth was 4.33 cm and the average depth of pressures and effective pressure was 0.6 liters. CPR in the prehospital cases, ambulance and emergency an external assistive device is very critical [8, 9]. Fig. 2 shows the correct body position and the arm placement on the manikin.



Fig.2. Body Position-Arm Placement on the Manikin [9].

III. THE PISTON DRIVEN CPR

M.Kizil and L.C.Dulger [10] have presented a design based on active compression-decompression in a previous study. Meanwhile the piston driven different designs are studied. M.M.Alam et al [11] have proposed an automated piston driven CPR device. It has been tested on the CPR manikin with acceptable results and also affordable cost. C.W.Sung et al [12] gave a design, named 'Mechelper' with a pressing unit, sliding and tilting unit, and lifting unit. They have offered a mechanical chest compressor with an exchangeable piston and alterable compression. Its specifications are then compared with other products on the market.

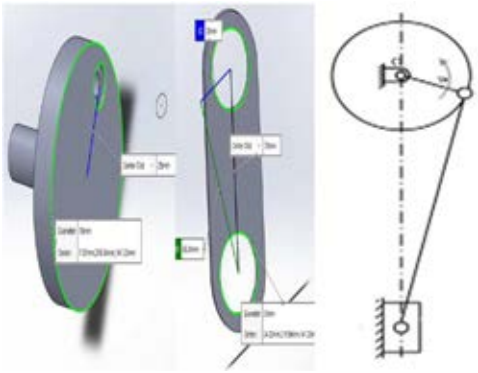
A. Design and Development

In the piston driven designs offer a mechanical piston to exert compression to the sternum. So the cardiac pump theory of blood flow is considered. One of the most important requirements among the objectives of the project was to reduce the length and weight parameters of the parts of the CPR machine as much as possible in order to make it portable. These requirements were taken into consideration while designing the body and leg parts of the CPR machine and the length and weight values of other portable CPR machines on the market were taken as reference. The mechanism of the CPR machine that will compress the human chest was designed. If this were the case, the treatment of 2 different groups could be performed by applying 3 cm of pressure for infants and 5 cm for adults.

B. Slider Crank Mechanism

A slider crank mechanism to compress the chest by 5 cm, a crank arm with a diameter of 5 cm and a radius of 2.5 cm and a connecting rod of 7 cm were designed. The ratio of the

connecting rod to the crank arm, i.e. 'n', is an important parameter during design. The value of n was found and the accuracy of the movement of the system was confirmed from Matlab® application. The n value was found to be 2.8 and it is observed that the motion of the slider crank is close to sinusoidal and therefore the motion is smooth. It was mentioned that the mechanism's motion is sinusoidal when the value of (n) is less than 0.007 or greater than 3. Fig.3 (a)-(b) show the designed crank and the connecting rod with schematically drawing. Matlab® simulation of the mechanism is included in Fig.4.



(a) (b)

Fig.3. The crank-The connecting rod

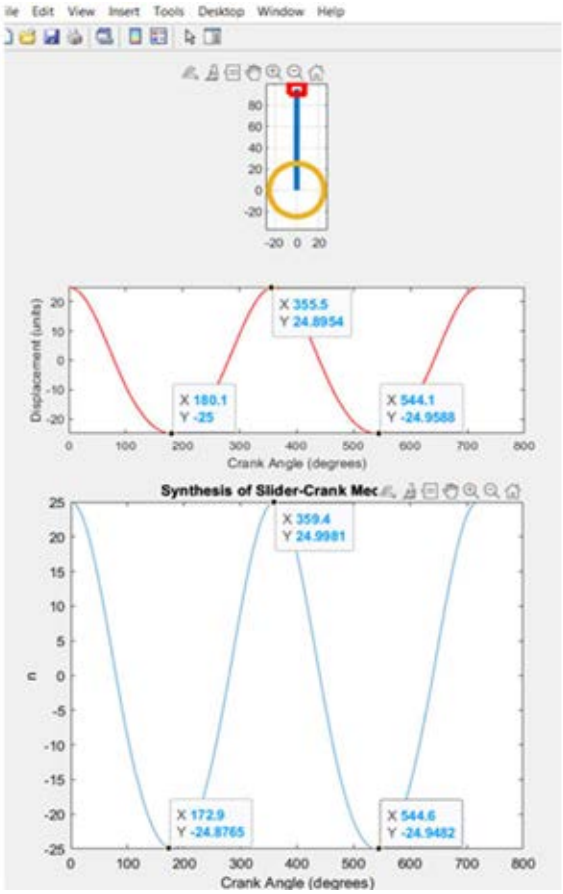


Fig.4. Matlab-Simulation Example

C. *Production of Prototype*

In order to integrate this dynamic system into the main body of the CPR machine built in the project, some changes were made to the initial design. Additional parts were designed and manufactured. When it came to the production phase, some difficulties were encountered due to the production technique. In order to minimize the budget and production time, it was decided to produce the parts on a 3D printer, but when the production phase started, some parts had to be reduced in size for printing due to the limits of the production machine, so the design was changed again.

A plate to be placed under the patient was considered in the initial design of the project, but since this part was difficult to use and the production of this part would increase the budget, it was decided to remove this part from the design. Due to the cancellation of the part, the leg parts in the design had to be extended as the height of the CPR machine would change. Since this part could not be produced in one go due to the production technique, the leg part was divided into 3 and a new design was worked on. Similar applications were applied to other parts that could not be produced due to their size. Figure 5 shows the initial design and the final design. Components of the design are shown in Figure 6 with dimensions.

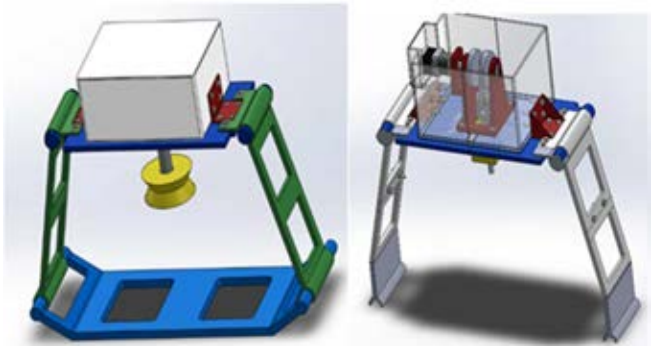


Fig.5. Initial Design-Final Design

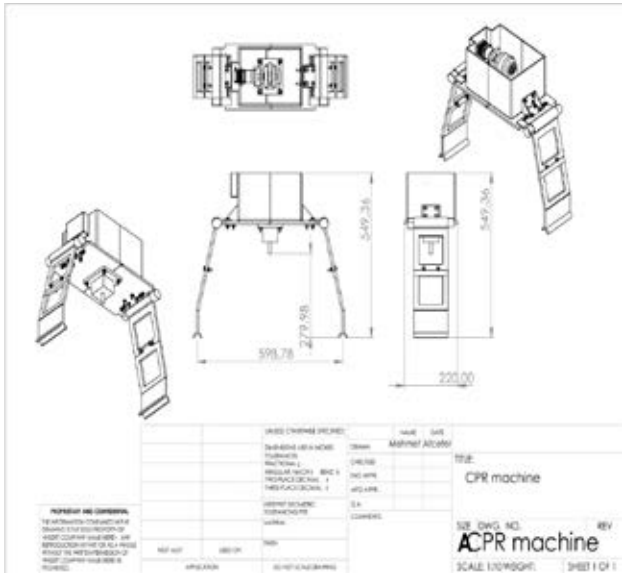
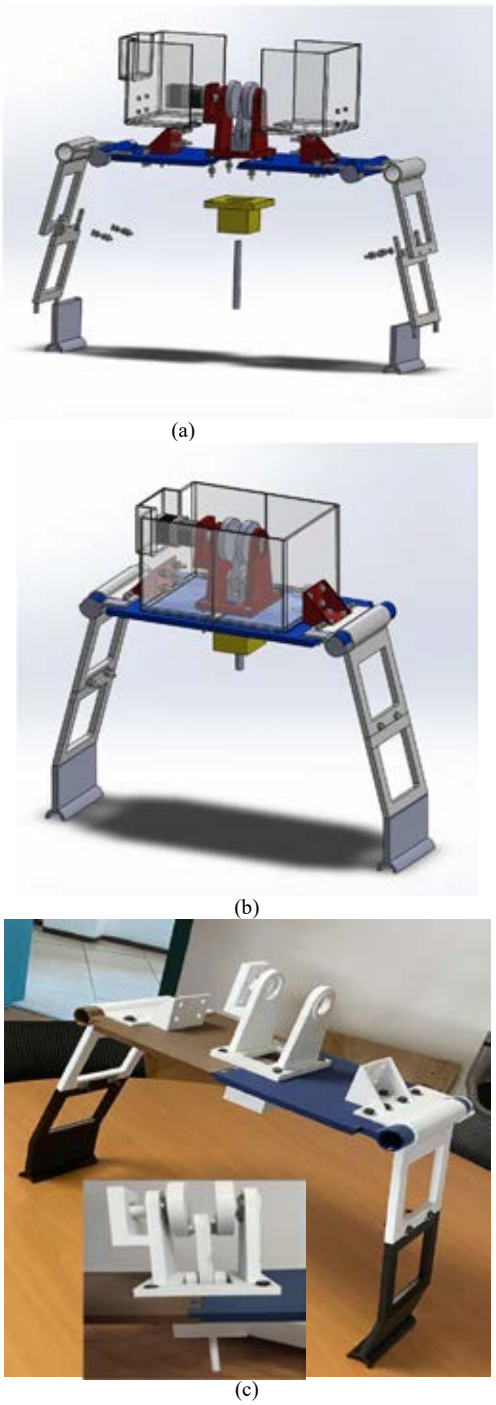


Fig 6. Detailed Drawing

Then the design made in the first part of the study and the final design are compared. This comparison resulted in the changes in the leg part and the box part that houses the dynamic system and the motor. Fig. gives the exploded view, the assembly and 3D Printer Prototype CPR device where the automation part is not availble at the moment.



(a)

(b)

(c)

Fig.7. Exploded-Assembly-Prototype

IV. CONCLUSIONS

This project aims to standardize the CPR process and design a device that can apply it flawlessly. The designed device will automatically perform chest compressions according to specific pressure and rhythm values, minimizing the errors and risks associated with manual CPR application. Within the project scope, existing CPR devices were examined, deficiencies were identified, and a prototype design of a new device was created. Technological innovations and engineering solutions used in the device's design aim to enhance the effectiveness and safety of CPR. Additionally, the user-friendly interface of the device will facilitate the training of emergency response teams and healthcare professionals, making it quickly deployable. This work aims to take an important step in CPR application, increasing the chances of survival for patients in life-threatening situations and enhancing the quality of emergency interventions.

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REFERENCES

[1] https://data.tuik.gov.tr/Bulten/Index?p=Death-and-Causes-of-Death-Statistics-2022-49679).

[2] Aygün, M., Yavan H.E., Genç, A., Karadağlı F., Eren N.B, Mechanical Chest Compression Devices: Historical Evolution, Classification and Current Practices, A short Review, Eurasion Journal of Emergency Medicine Review, 2016; 15: 94-104.

[3] Remino, C., Baronio, M., Pellegrini, N., Aggogeri, F., and Adamini, R., "Automatic and manual devices for cardiopulmonary resuscitation: A review", Advances in Mechanical Engineering, 10 (1): 1–14 (2018).

[4] A.Şener, G.P.Günaydın, F.Tanrıverdi, Mechanical Versus Manual Chest Compression: A Retrospective-Cohart in Out of Hospital Cardiac Arrest, Acta Medica, 2021; 52(4): 325-331.

[5] https://ww.lucas-cpr.com, Assessed 03/08/2024

[6] Zideman, D.A., De Buck, E.D.J., Singletary, E.M., Cassan, P., Chalkias, A.F., Evans, T.R., Hafner, C.M., Vandekerckhove, P.G., European Resuscitation Council Guidelines for Resuscitation 2015, S.9, First aid Resuscitation, 95, 278-287.

[7] Neumar RW, Shuster M, Callaway CW, Gent LM, Atkins DL, Bhanji F, Brooks SC, de Caen AR, Donnino MW, Ferrer JM, Kleinman ME, Kronick SL, Lavonas EJ, Link MS, Mancini ME, Morrison LJ, O'Connor RE, Samson RA, Schexnayder SM, Singletary EM, Sinz EH, Travers AH, Wyckoff MH, Hazinski MF, Part 1: Ex. Summary: 2015 American Heart Ass. Guidelines,, Cardiopulmonary Resuscitation and Emergency Cardiovascular Care., Circulation. 2015, Nov3;132,S315-67.

[8] Kızıl, M., Şemin,M, Determination Of Cardiopulmonary Resusitation Effectiveness On The Cpr Manikin,.EUSEM 2018, 12th European Emergency Medicine Congress, Glasgow-UK

[9] M. Kızıl, Determining the effectiveness of Cardiopulmonary Resuscitation using a manikin CPR, December 2022, Hastane Öncesi Dergisi 7(3), DOI: 10.54409/hod.1150760, pp.303-316.

[10] M.Kızıl and L.C.Dülger, Design of a Device for CPR (Cardiopulmonary Resuscitation, Yıptekno 2022, 31 Ekim-2 Kasım 2022, Belek-Antalya.

[11] M.M.Alam, M.Hussain, M.A.Amin, M.M.Khan, Design of a Low-cost Automated Cardiopulmonary Resuscitation Device with Piston-Driven Chest Compression System, 4th Int. Conf. On El.Eng. and Inf. And Comm. Tech., 2018-IEEE.

[12] C.W. Sung, H.C. Wang, J.S. Shieh, F.S.Jaw, A novel mechanical chest compressor with rapid deployment in all population cardiopulmonary resuscitation, Scientific Reports-2020, 10:6099.