CORPUS PUBLISHERS

Current Research in Emergency Medicine (CREM)

ISSN: 2832-5699

Volume 5, Issue 1, 2026

Article Information

Received date : 09 February, 2026

Published date: 19 February, 2026

*Corresponding author

O Sullivan J, Biological Science Laboratory Technician, Veterinary Science Directorate, Naval Medical Research Unit San Antonio, 4141 Petroleum Drive | Bldg 3260, JBSA Fort Sam Houston, TX 78234-2644.

DOI: 10.54026/CREM/1060

Key Words

Pharmacokinetics; Epinephrine; Cardiac Arrest; Hypovolemia; Intraosseous

Abbreviations

AHA:American Heart Association; AUC: Area under the Curve; (CPR+Defib):Cardiopulmonary; Resuscitation + Defibrillation ; (Cmax): Concentration Maximum; (DBP):Diastolic Blood Pressure; (ECG):Electrocardiography ; (ETCO2): End Tidal Capnography ; (ECR):European Committee for Resuscitation; (HR):Heart rate; (IV):Intravenous; (MAP):Mean Arterial Pressure; (MC):Mean Concentration ; (SpO2):Oxygen Saturation; (ROSC):Return of Spontaneous Circulation; (s):Second ; (SEM):Standard Error of the Mean; (SIO): Sternal Intraosseous ; (SBP):Systolic Blood Pressure; (Tmax):Time to Maximum Concentration

Distributed under: Creative Commons CC-BY 4.0

Research Article

Effects of Weight-Based Epinephrine on Pharmacokinetics and Survival in Adult Swine in Cardiac Arrest

Johnson D, Blouin D, Brocklehurst K and O Sullivan J*

[1]*Scientist, The Geneva Foundation USA, Washington, USA*

[2]*Research Associate, The Geneva Foundation USA*

[3]*Biological Science Laboratory Technician, Veterinary Science Directorate, Naval Medical Research Unit San Antonio, USA*

Abstract

Background: The purpose of this study was to compare weight-based dose of epinephrine in Sternal Intraosseous (SIO) (0.05 mg/kg), SIO 1mg, and Intravenous (IV) 1 mg Groups in a hypovolemic, cardiac arrest model. Concentration maximum (Cmax), time to maximum concentration (Tmax), Mean Concentration over time (MC), Area Under the Curve (AUC), and frequency of Return of Spontaneous Circulation (ROSC) were compared.

Methods: 32 adult male castrated swine, sus scrofa (65-75kg), were placed into 4 groups: SIO 0.05 mg/kg, IV 1 mg, SIO 1 mg, Cardiopulmonary Resuscitation + Defibrillation (CPR+Defib), and CPR Only. The pigs were anesthetized, placed in cardiac arrest for 2 minutes, and CPR was then started and continued for 2 minutes. Epinephrine was then administered, and samples were collected over 5 minutes. The CPR+Defib Group had just defibrillation and the CPR-Only Group did not receive epinephrine nor defibrillation. Both served as control groups.

Results: The Cmax was significantly higher in the SIO 0.05mg/kg Group compared to the SIO 1 mg and the IV Groups ($p = 0.001$). There were no significant differences in Tmax in any of the groups ($p > 0.05$). The AUC was significantly higher in the SIO 0.05 mg/kg than in the SIO 1 mg and the IV Groups ($p = 0.001$). The MC of the SIO 0.05 mg/kg was higher than the SIO 1 mg and IV Groups at each time interval. The frequency of ROSC rate was 7 out of 8 in the SIO 0.05 mg Group, 3 out of 8 in both the IV and SIO 1 mg Groups, 2 out of 8 in the CPR+Defib Group, and 0 out of 8 in the CPR-Only Group.

Conclusion: The SIO 0.05 mg/kg Group should be used for adult patients in hypovolemic shock who have cardiac arrests.

Introduction

Bleeding is the number one cause of death on and off the battlefield. Hemorrhage was the leading cause of death in the Vietnam War, Operation Desert Storm, Operation Iraqi Freedom, and Operation Enduring Freedom [1-4]. More recently, hemorrhage caused the death of over one million people in the wars in Iraq, Afghanistan, Pakistan, and Syria. [5] Currently, the horrific events in Israel and Palestine have led to thousands of deaths, many of whom died from bleeding. Deaths from hemorrhage per year represent more than 60,000 deaths in the United States and 1.9 million deaths worldwide. Blood loss causes hypovolemic shock, ultimately leading to cardiac arrest. The military health care prioritize providing care to the US Army, Air Force, Marines, Navy personnel, and their dependents. However, the military also have a rich history of providing care for civilians as well who are victims of trauma and subsequent cardiac arrests from disasters such as hurricanes, earthquakes, and tornadoes. The worldwide mortality rate has been 76,416 deaths per year from natural disasters, most from hemorrhage [6].

Vascular access is essential for successful resuscitation: The chance for survival decreases by 9 % with each minute that passes without resuscitation. [7,8-13]. However, in a cardiac arrest situation, the person's veins collapse, making Intravenous (IV) access extremely difficult, time-consuming, or impossible, particularly for patients in hypovolemic shock. For adults in cardiac arrest, the American Heart Association (AHA) and the European Committee for Resuscitation (ECR) state that regardless of weight, epinephrine should be administered by the IV route (1 mg) or Intraosseous (IO) routes (1 mg) and repeated every 3-5 minutes until Return of Spontaneous Circulation (ROSC) [14-18]. For pediatric patients in arrest, the AHA recommends 0.01 mg/kg of epinephrine administration repeated every 3-5 minutes. These recommendations are based primarily on expert opinion, not on research. In a previous study, we investigated the Concentration Maximum (Cmax) and Time to Maximum Concentration (Tmax) in an adult cardiac arrest model with epinephrine administration and found that Cmax and Tmax for the Sternal IO (SIO) route for epinephrine administration were similar to the IV route; however, we did not evaluate ROSC [19]. In a later adult cardiac arrest study we used the recommended dose of 1 mg for the IV and SIO groups which equates to approximates to 0.01 mg/kg as recommended in the pediatric dose. We found that a SIO Group in both a hypovolemic and normovolemic models achieved ROSC 3 out of 7 subjects compared to 4 out of 7 in an IV Group. [20] In a pediatric cardiac arrest study, we used the AHA recommended weight dose of 0.01 mg/kg and found that 8 out of 8 achieved ROSC. [21] We speculated that the reason for differences in efficacy between the pediatric and adult models was the use of a weight-based dose of epinephrine. No studies have examined the weight-dose requirements for the SIO route of administration in an adult cardiac arrest model. The aim of this study was to compare weight-dose SIO (0.05 mg/kg) compared to the standard dose of 1 mg in a cardiac arrest hypovolemic model. As the pediatric AHA guidelines are 0.01mg/kg for IV and IO administration, and up to 0.1mg/kg for endotracheal administration, we decided to start at the midpoint for this adult study. Specifically, the comparison included Cmax, Tmax, Mean Concentration over time (MC), Area Under the Curve (AUC), and ROSC. The following research questions guided the study:

a. Are there significant differences in SIO weight-dependent dose and standard dosing relative to Cmax, Tmax, AUC, and MC over time when epinephrine is administered?

b. Are there significant differences in the occurrence of frequency and odds of ROSC relative to SIO weight-dependent dose and standard dosing?

Methods

Study design and selection of subjects

This was a prospective, (within and between) subjects, design approved by the Institutional Animal Care and Use Committee supporting the Naval Medical Research Unit-San Antonio. Thirty-two adult male castrated swine, sus scrofa (65-75kg), were placed into 4 groups: SIO 0.05 mg/kg, IV 1 mg, SIO 1 mg, CPR + Defibrillation (CPR+Defib), and CPR Only. The sequence of using each animal was determined by assignment using a random number generator (https://www.random.org). Castrated male subjects were used to avoid potential hormonal effects. To maintain consistency and health, we used subjects procured from Oak Hill Genetics, Ewing, IL, a supplier of purpose-bred swine to research facilities. The rationale for using the weight range was this represents the average weight of the male US soldier [22].

Procedures

Swine were observed for 3 days to make sure they were healthy. The day before the experiment, the subjects were NPO after midnight for food but allowed water ad-lib. Animals were sedated with 4-8 mg/kg of Telazol (Tiletamine/Zolazepam; Zoetis, NJ) intramuscularly, and Buprenorphine HCl (Par Sterile Products, LLC, MI) 0.01-0.1 mg/kg was administered subcutaneously 30 minutes before instrumentation. Induction was by face- mask delivery of inhaled isoflurane (1-5%) delivered in 100% oxygen. After placement of an endotracheal tube, the isoflurane concentrations were reduced to a maintenance dose (e.g. 1-3%) with an FiO_2 between 0.21-0.24 using a Drager Apollo anesthesia machine (Dräger AG & Co., Lübeck, Germany). The animals were maintained on mechanical ventilation and physiological parameters were monitored continuously. Heart Rate (HR), Electrocardiography (ECG), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Mean Arterial Pressure (MAP), Oxygen Saturation (SpO_2), end Tidal Capnography ($ETCO_2$) and body temperature (°C) were monitored using an Infinity Delta XL monitoring system (Draeger Medical Systems Inc., Telford, PA, USA). Body temperature was maintained at ≥36°C by placing the animal on a HotDog® veterinary warming system (Augustin Surgical Inc. Eden Prairie, MN).

For each animal, bilateral 18-gauge, 1.25-inch peripheral catheters (Terumo Medical Products, Somerset, NJ, USA) were placed percutaneously in an auricular vein of each swine. Patency was maintained with a Lactated Ringer's Solution at a rate of 5-10 mL per hour. The left femoral and carotid arteries were cannulated with 7 Fr x 60 cm silicon catheters (Norfolk Access Technologies, IL) using an open surgical approach, and secured in place. The left carotid arterial line was used for continuous hemodynamic pressure monitoring. The left femoral arterial line was used for hemorrhage, bio-sampling, and continuous Cardiac Output (CO) and Stroke Volume (SV) monitoring using a Vigileo™ hemodynamic monitor (Edwards Lifesciences, Irvine, CA, USA). A 15-gauge, 25 mm Arrow® EZ-IO device (Teleflex Medical, Wayne, PA, USA) was surgically placed per manufacturer's directions in each subject's non-segmented region of the sternum for the SIO groups.

After a 15-minute stabilization period, an American College of Surgeons Class III hemorrhage was achieved by exsanguinating 31% of each swine's blood volume using gravity drainage and controlled suction of the femoral artery catheter. The blood volume was calculated using a factor of 70 mL/kg of body weight. For example, a 70 kg swine has 4900 mL of blood. Thirty-one percent of 4900 mL is 1519 mL. The TIF electronic scale (Thermal Industries of Florida, Owatonna, MN, USA) was used to accurately and precisely measure the hemorrhaged blood volume. The scale was zeroed with a collection blood bags in place to control for weight variation. Suction was applied to exsanguinate approximately 100 mL of blood per minute. After exsanguination, the swine were placed into Cardiac Arrest (CA) by passing an electrical current through the heart as developed by the investigators [23]. Isoflurane anesthesia was discontinued, and midazolam 6 mg IV and buprenorphine 0.6 mg IV were administered. After 2 minutes in CA without intervention, mechanical chest compressions were administered using a Mechanical Compression Device, Model 1008 (Michigan Instruments, Grand Rapids, MI, USA) at 100 compressions per minute. Manual ventilations were delivered at a rate of 6 to 10 per minute. Quality of chest compressions was confirmed by observing the arterial line and capnographic waveforms. After 4 minutes of CA, epinephrine (SIO 0.05 mg/kg, IV 1 mg, SIO 1 mg) was administered to IV and SIO groups followed by a 20 mL NS flush. The CPR+Defib and CPR-Only Groups served as control groups and were not administered epinephrine. Serial blood specimens (10 mL) were collected at 30, 60, 90, 120, 150, 180, 240, and 300 seconds (s) from the left femoral arterial line after epinephrine injection. Before each specimen collection, the investigators aspirated and discarded 10 mL of blood to avoid residual epinephrine. After each specimen was collected, 10 mL of NS was injected to clear the arterial line. Resuscitation continued until ROSC or 30 minutes had passed. Those subjects that achieved ROSC were monitored for 30 minutes. ROSC was operationally defined as a palpable pulse, a perfusing rhythm to maintain adequate end-organ perfusion as measured by arterial blood pressure (a minimum of 60 mm/Hg) and cardiac output. Defibrillation was initiated after 2 minutes after CPR was begun and repeated every 2 minutes until ROSC or 30 minutes had elapsed. For those subjects in the epinephrine groups, the drug was repeated every 4 minutes until ROSC or 30 minutes had elapsed. The exsanguinated blood was administered after 15 minutes of cardiac arrest. The rationale for this time was this represents the period necessary to cross and match and to acquire the blood. (See Table 1 for a timeline summary)

Table 1: Brief summary of methodology.

Time	Start (Min)		0-2	2	4	4-9	10	10-20	20-50
Event	Hemorrhage Begins	X							
	Cardiac Arrest (clock starts)		X						
	CPR starts at 2 min mark, continuous			X					
	Defibrillation, every 2 min				X				
	Epinephrine Given, first dose				X				
	Sampling Occurs, 8 samples					X			
	Epinephrine Given, every 4 m						X		
	IF No Rosc- terminate after 20m							X	
	IF Rosc- continue additional 30m								X

Statistical Analyses

An α of 0.05 was used for significance for all comparisons. Multivariate Analyses of Variance (MANOVA) was used to determine if there were any significant differences in the groups relative to the pretest data, including SBP, DBP, MAP, SpO_2, temperature, amount of hemorrhage, SV, CO, $ETCO_2$, and weight. A MANOVA was also used to determine if there were significant differences in groups relative to Cmax, Tmax, and AUC. A Repeated ANOVA was used to compare the groups relative to MC at 30, 60, 90, 120, 150, 180, 240, and 300-s intervals. When significance was found, we used a post-hoc Least Significant Test (LSD) to determine where the significance was. A Fisher's Exact test was used to determine if there were significant differences in the frequency of ROSC between the groups. The odds ratio was used to compare ROSC between the groups (MedCal.org.calc/odds_ratio,php).

Sample Size Estimation

The investigators used the means and standard deviations of Cmax, Tmax, and plasma MC over time from similar pharmacokinetic studies and calculated a medium effect size of 0.6. [20,24] Using an α of 0.05, an effect size of 0.6, and a power of 0.80, we determined a sample size of 8 was needed for each group. Power analysis was performed using G*Power 3.1 for Windows (Heinrich Heine University).

Results

There were no significant differences in pretest data in the groups, indicating that the groups were equivalent on these variables ($p > 0.05$). The means and Standard Error of the Mean (SEM) for Cmax in ng/mL were calculated and compared. The Cmax was 2091 ± 328, 819 ± 152, and 572 ± 159 for the SIO 0.05 mg/kg, IV, and SIO 1 mg Groups, respectively. The Cmax was significantly higher in the SIO 0.05mg/kg Group compared to the IV ($p = 0.001$) and the SIO 1 mg ($p = 0.001$) Groups, and no significant difference in the IV and SIO 1 mg Groups ($p = 0.41$) (See Figure 1 for a summary).

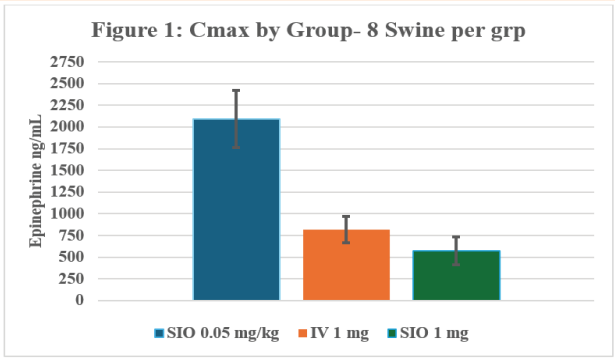

Figure 1: Cmax by group- 8 swine per grp.

The means and standard deviations of the Tmax means in s were calculated and compared by group. The Tmax was 168 ± 27 s, 168 ± 18 s, and 120 ± 28 s for the SIO 0.05 mg/kg, IV, and SIO 1 mg Groups respectively. There were no significant differences in any of the Groups ($p > 0.05$) (See Figure 2 for a summary).

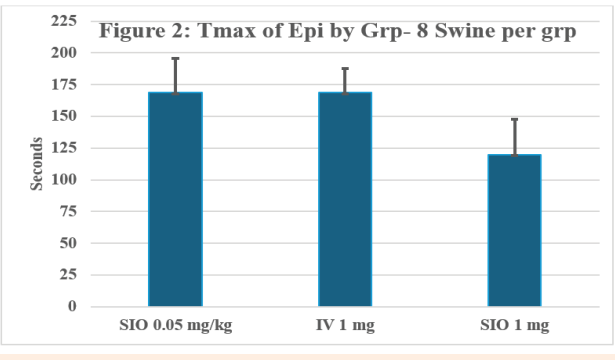

Figure 2: Tmax of epi by grp- 8 swine per grp.

The means and SEM for the AUC in ng/mL were calculated and compared by group. The AUC was 329,544 ± 58,113; 106,453 ± 23,605; and 81,165 ± 5,709 for the SIO 0.05 mg/kg, IV, and SIO 1 mg Groups, respectively. The AUC was significantly higher in the SIO 0.05 mg/kg than in the IV Group ($p = 0.001$) and the SIO 1 mg Group ($p = 0.001$), but there was no difference between the IV and SIO 1 mg Group (0.627) (See Figure 3 for a summary).

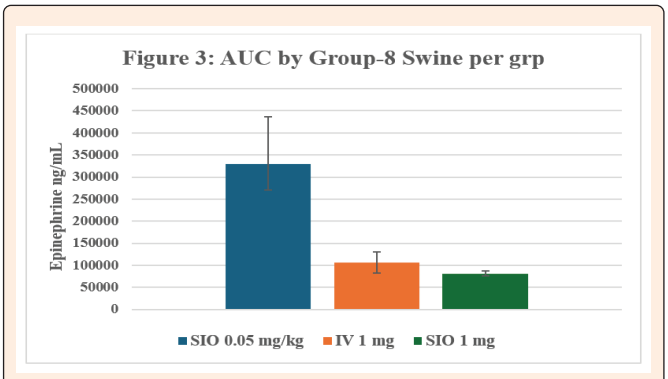

Figure 3: AUC by group-8 swine per grp.

The concentration of means and SEM were calculated and compared by the group over 300 s. The MC of the SIO 0.05 mg/kg was significantly higher than the IV Group at the 120 s ($p = 0.021$), 150 s ($p = 0.008$), 180 s ($p = 0.002$), 240 s ($p = 0.001$), and 300 s ($p = 0.001$). The MC of the 0.05 mg/kg SIO was significantly higher than the SIO 1 mg Group at the 90 s ($p = 0.043$) 120 s ($p = 0.009$); 150 s ($p = 0.003$); 180 s ($p = 0.002$); 240 s ($p = 0.001$); and 300 s ($p=0.001$). There were no significant differences between the IV and 1 mg SIO at any time ($p > 0.05$) (See Figure 4 for a summary)

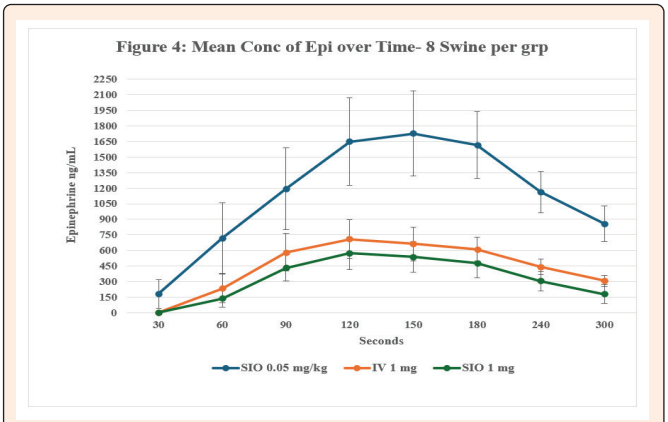

Figure 4: Mean conc of epi over time- 8 swine per grp.

The SIO 0.05 Group had a significantly higher occurrence of ROSC than SIO 1 mg ($p = 0.022$) and the IV Group ($p = 0.022$). The rate of ROSC was 7 out of 8 in the SIO 0.05 mg Group, 3 out of 8 in both the IV and SIO 1 mg Groups, 2 out of 8 in the CPR+Defib Group, and 0 out of 8 in the CPR-Only Group. The odds of ROSC were 12 times greater for the SIO 0.05 mg/kg Group compared to the IV and SIO 1 mg Groups. The odds of ROSC were 21 times greater for the SIO 0.05 mg/kg Group compared to the CPR+Defib Group and 85 times greater than the CPR-Only Group. (See Figure 5 for a summary)

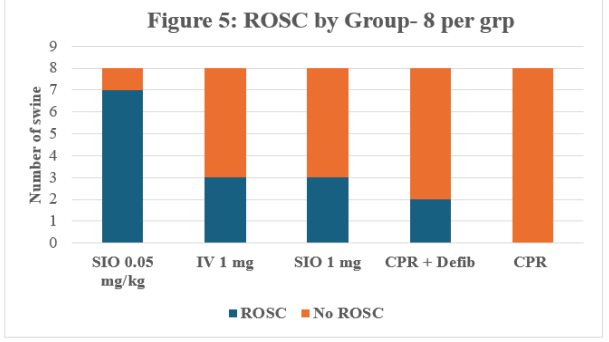

Figure 5: ROSC by group- 8 per grp.

Limitations

The major limitation of this study is the small sample size, although we had enough power to find statistically significant differences. Another limitation was the use of single species, male only sample. Generalizations may not translate to humans; however, cardiovascular, pulmonary, and bone physiology are very similar to humans. Researchers conclude that the swine model is appropriate for this type of study [25,26]. Another limitation was that the researchers were not blinded to the group assignment or during rescuscitation; however, the individual analyzing the pharmacokinetics of the samples was blinded. Although we were not blinded, we had a noninterested observer making sure that all the guidelines were followed for each subject in each group. Also, a limitation of note, was there was an absence of any neurological outcome assessment post-ROSC.

Discussion

The purpose of this study was to compare weight-based dose of epinephrine sternal intraosseous (SIO) (0.05 mg/kg), SIO 1mg, and Intravenous (IV) 1 mg Groups in a hypovolemic, cardiac arrest model. Cmax, Tmax, MC, AUC, and frequency of ROSC were compared. We found that the SIO 0.05 mg/kg Group achieved higher Cmax, AUC, MC, and frequency of ROSC compared to the SIO 1 mg and IV Groups. It is essential to gain vascular access to acquire ROSC. Studies show that starting an IV may take as much as 49 minutes. Leidel et al. found that IV failure rates were from 10 to 40% in patients not in arrest and that the average time for obtaining IV access was 2.5 to 16 minutes and, in extreme cases, as long as 55 minutes in critically ill patients who were not in arrest. [27-29] Therefore, more time-saving and effective routes must be investigated. Our experience shows that the that the IO device can be inserted in less than 5 seconds. The saved time may translate into greater frequency and faster ROSC return. Furthermore, in trauma particularly in a wartime scenario, extremities may be injured so neither IV nor IO can be used at these sites. Based on our findings, the SIO 0.05 mg/kg supports further investigation and potential translational relevance. These findings are based on an animal hypovolemic arrest model. Our findings are hypothesis generating. Without further research confirmation, our results although significant, are not yet practice changing. Although swine are an excellent model for trauma research, unfortunately findings are often not translational to humans. Moving forward there is a need for dose finding human trials. Also, importantly, future studies should investigate using the dose by weight in the IV, tibial and humerus IO sites in both hypovolemic and normovolemic models of arrest. Evidence of this study indicates there may be a guideline- evidence mismatch.

References

1. McCaughey BG (1991) Observations about battle fatigue: its occurrence and absence. Mil Med 156(12): 694-695.
2. McCaughey BG, Garrick J, Carey LC, Kelley JB (1987) Naval support activity hospital danang combat casualty deaths january to june1968. Mil Med 152(6): 284-289.
3. McCaughey BG, Garrick J, Carey LC, Kelley JB (1988) Naval support activity hospital, danang, casualty blood utilization: january to june 1968. Mil Med 153(4): 181-185.
4. McCaughey BG, Garrick J, Kelley JB (1988) Combat casualties in a conventional and chemical warfare environment. Mil Med 153(5): 227-229.
5. Crawford N DM, Chaturvedi A, MacIntire, IC (2018) Human cost of post 9/11 wars: lethality and transparency. Watson Institute of International and Public Affairs, Brown University, USA.
6. Hendrickson RG HBDpITJ, Stapczynski JS, Ma OJ Tintinalli, JE, Thomas SH, et al. (2018) (eds.): Tintinalli's emergency medicine: a comprehensive study guide. 9th ed. New York, NY: McGraw-Hill Education, USA.
7. Larsen MP, Eisenberg MS, Cummins RO, Hallstrom AP (1993) Predicting survival from out-of-hospital cardiac arrest: a graphic model. Ann Emerg Med 22(11): 1652-1658.
8. Anson JA (2014) Vascular access in resuscitation: is there a role for the intraosseous route? Anesthesiology 120(4): 1015-1031.
9. Anson JA, Sinz EH, Swick JT (2015) The versatility of intraosseous vascular access in perioperative medicine: a case series. J Clin Anesth 27(1): 63-67.
10. Hoskins SL, do Nascimento P, Lima RM, Espana-Tenorio JM, Kramer GC (2012) Pharmacokinetics of intraosseous and central venous drug delivery during cardiopulmonary resuscitation. Resuscitation 83(1): 107-112.
11. Yauger YJ, Beaumont DM, Brady K, Schauer SG, O'Sullivan J, et al. (2022) Endotracheal administered epinephrine is effective in return of spontaneous circulation within a pediatric swine hypovolemic cardiac arrest model. Pediatr Emerg Care 38(1): 187-192.
12. Yauger YJ, Johnson MD, Mark J, Le T, Woodruff T, et al. (2022) Tibial intraosseous administration of epinephrine is effective in restoring return of spontaneous circulation in a pediatric normovolemic but not hypovolemic cardiac arrest model. Pediatr Emerg Care 38(4): 1166-1172.
13. Hansen M, Schmicker RH, Newgard CD, Grunau B, Scheuermeyer F, et al. (2018) Time to epinephrine administration and survival from nonshockable out-of-hospital cardiac arrest among children and adults. Circulation 137(19): 2032-2040.
14. Daudre-Vignier C, Bates DG, Scott TE, Hardman JG, Laviola M (2023) Evaluating current guidelines for cardiopulmonary resuscitation using an integrated computational model of the cardiopulmonary system. Resuscitation 186: 109758.
15. Goyal A, Sciammarella JC, Cusick AS, Patel PH (2023) Cardiopulmonary resuscitation. StatPearls.
16. Perkins GD, Graesner JT, Semeraro F, Olasveengen T, Soar J, et al. (2021) European resuscitation council guidelines executive summary. Resuscitation 161: 1-60.
17. Perkins GD, Grasner JT, Semeraro F, Olasveengen T, Soar J, et al. (2021) [Executive summary]. Notf Rett Med 24(4): 274-345.
18. Rank W (2021) AHA update: BLS, ACLS, and PALS. Nursing 51(6): 22-27.
19. Burgert J, Gegel B, Loughren M, Ceremuga T, Desai M, et al. (2012) Comparison of tibial intraosseous, sternal intraosseous, and intravenous routes of administration on pharmacokinetics of epinephrine during cardiac arrest: a pilot study. AANA J 80(4): 6-10.
20. Burgert JM, Johnson AD, O'Sullivan JC, Blalock WJ, Duffield BC, et al. (2019) Pharmacokinetic effects of endotracheal, intraosseous, and intravenous epinephrine in a swine model of traumatic cardiac arrest. Am J Emerg Med 37(11): 2043-2050.
21. Johnson D, Hensler JG, Blouin D, Yauger Y, O'Sullivan J (2024) Sternal intraosseous epinephrine administration in a hypovolemic pediatric cardiac arrest model. EJPMR 11(11): 56-62.
22. Knapik JJ, Burse RL, Vogel JA (1983) Height, weight, percent body fat, and indices of adiposity for young men and women entering the U.S. Army. Aviat Space Environ Med 54(3): 223-231.

23. Burgert JM, Johnson AD, Garcia-Blanco JC, Craig WJ, O'Sullivan JC (2015) An effective and reproducible model of ventricular fibrillation in crossbred yorkshire swine (sus scrofa) for use in physiologic research. Comp Med 65(5): 444-447.

24. Yauger YJ, Beaumont DM, Brady K, Schauer SG, O'Sullivan JC, et al. (2022) Endotracheal administered epinephrine is effective in return of spontaneous circulation within a pediatric swine hypovolemic cardiac arrest model. Pediatr Emerg Care 38(1): 187-192.

25. Hannon JP, Bossone CA, Wade CE (1990) Normal physiological values for conscious pigs used in biomedical research. Laboratory animal science 40(3): 293-298.

26. Swindle MM, Makin A, Herron AJ, Clubb FJ, Frazier KS (2012) Swine as models in biomedical research and toxicology testing. Veterinary pathology 49(2): 344-356.

27. Leidel BA, Kirchhoff C, Bogner V, Braunstein V, Biberthaler P, et al. (2012) Comparison of intraosseous versus central venous vascular access in adults under resuscitation in the emergency department with inaccessible peripheral veins. Resuscitation 83(1): 40-45.

28. Leidel BA, Kirchhoff C, Bogner V, Stegmaier J, Mutschler W, et al. (2009) Is the intraosseous access route fast and efficacious compared to conventional central venous catheterization in adult patients under resuscitation in the emergency department? A prospective observational pilot study. Patient Saf Surg 3(1): 24.

29. Leidel BA, Kirchhoff C, Braunstein V, Bogner V, Biberthaler P, et al. (2010) Comparison of two intraosseous access devices in adult patients under resuscitation in the emergency department: A prospective, randomized study. Resuscitation 81(8): 994-999.