The Role of Simulation in Cardiac Rhythm Identification During Cardiopulmonary Arrest

***Veronica Mariel Palumbo, MD; Soraya Romina Palletti, MD**

Clinical Simulation Laboratory (LaSiC), Free Chair of Simulated Emergency and Disaster Training, Faculty of Medical Sciences, University of Buenos Aires, Argentina

***Corresponding Author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.903SEDU0761

Received: 09 December 2025; Accepted: 16 December 2025; Published: 30 December 2025

ABSTRACT

Accurate identification of cardiac rhythm during cardiopulmonary arrest (CPA) is crucial for patient survival. According to American Heart Association guidelines [1–3], early defibrillation is essential for shockable rhythms—ventricular fibrillation (VF) and pulseless ventricular tachycardia (VT)—while early epinephrine administration is required for non-shockable rhythms such as pulseless electrical activity (PEA) and asystole.

This quasi-experimental pretest/posttest study aimed to compare rhythm recognition before and after simulation-based training. Seventy-five incoming pediatric residency physicians participated (final posttest sample: 53). Three rhythm-identification items—sinus bradycardia/PEA, VT, and VF—were evaluated in both assessments.

Training took place within an intensive course on pediatric emergency assessment and initial management. Pretest results showed correct recognition rates of 88% for VF, 84% for PEA, and 73.3% for pulseless VT. Posttest data demonstrated improved discrimination between shockable and non-shockable rhythms, particularly by eliminating confusion between PEA and shockable rhythms. However, persistent errors in rhythm interpretation and a statistically significant decline in VF recognition highlighted important weaknesses.

These findings underscore the need for more comprehensive and targeted training to ensure rapid and appropriate decisions during CPA. Although simulation was beneficial in specific aspects, its overall effectiveness for consolidating precise rhythm identification was limited**.** Future iterations of the program should incorporate a dedicated rhythm-recognition station and longitudinal reinforcement strategies.

Keywords: Simulation Training, Cardiopulmonary Resuscitation, Cardiac Arrest, Arrhythmia Recognition, Medical Education, Pediatrics.

INTRODUCTION

The accurate identification of the cardiac rhythm during cardiopulmonary arrest (CPA) is a fundamental pillar for optimizing patient survival, as emphasized by the current guidelines of the American Heart Association (AHA). In the hospital setting, early defibrillation (within three minutes) is crucial for shockable rhythms such as ventricular fibrillation and pulseless ventricular tachycardia. In contrast, the early administration of epinephrine is vital in cases of non-shockable rhythms such as pulseless electrical activity and asystole [1–3]. This differentiation underscores the imperative need for correct rhythm diagnosis in all CPA events.

On the other hand, clinical simulation has emerged as an essential educational tool in contemporary medical training. Its implementation represents a paradigm shift from a traditional teaching approach to a model focused on developing skills and competencies. This strategy allows students to apply knowledge and skills in realistic and controlled situations, fostering confidence and autonomy in professional performance. A

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume IX Issue XXVI December 2025 | Special Issue on Education

distinctive aspect of simulation is its ability to transform errors into opportunities for reflective learning, which contributes to the continuous improvement of future performance [4].

The training of healthcare professionals recognizes clinical simulation as a strategy for amplifying real experiences. Through the use of 3D models and patient software, safe contexts are recreated that enable the transition from novices to experts in both general and field-specific professional skills. This process is carried out under the guidance of an instructor who facilitates practice and provides structured feedback [5].

Clinical simulation, defined as a strategy that allows for replacing or amplifying real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a completely interactive manner, has experienced rapid development in recent years [6]. Its innovative nature facilitates teaching in safe contexts, promoting adequate learning and standardized assessment of the critical skills required in a constantly evolving professional environment.

Traditionally, simulations have been classified based on the concept of fidelity, which refers to the degree to which a simulation reproduces reality [7]. Three main categories are distinguished:

- **Low-fidelity simulations:** Characterized by limited realism, they are used for training specific skills, particularly in novice students.
- **Medium-fidelity simulations:** Introduce additional elements and situations to create a more realistic context, being suitable for students at an intermediate level.
- **High-fidelity simulations:** Offer an immersive experience that faithfully replicates real-world scenarios, proving highly valuable for advanced students, allowing them to develop complex competencies in a safe environment.

Beyond fidelity-based typologies, other classification systems consider contextual factors and available tools, such as the categories proposed by Ziv et al. [8], the technological classification by Gaba [9], and the six-level classification by Alinier [10]. These classifications provide an essential guide for selecting the most appropriate level of simulation based on pedagogical needs and learning objectives.

Despite the various classifications, there is a consensus in recognizing simulation as an educational strategy aligned with new paradigms and theories that promote experiential learning. Simulation in medical education, therefore, has a solid theoretical foundation, and its application has become widespread in the training of healthcare professionals today.

Regarding debriefing, it is defined as the moment of structured reflection on the events that occurred during a simulation [11]. It constitutes a crucial opportunity to identify successes and errors, as well as to argue and analyze the most appropriate actions to implement in a similar case. The primary objective of debriefing is to foster active and participatory student learning, facilitating the identification of positive aspects to reinforce and areas for improvement for future practice.

For their part, Ericsson [12] emphasizes the importance of critical reflection on practice, both during simulation and in real medical practice, as a fundamental element for the refinement of professional skills. During simulation, it is essential that participants make an accurate diagnosis, decide on interventions to execute, evaluate the results, and manage potential complications. This process allows students to recognize their mistakes and successes, contributing to significant and lasting learning.

In this context, the active promotion of critical reflection and reflective learning among participants is sought. Anijovich et al. [13] argue that critical teaching involves the ability to reflect on one's own practice and emphasize the need to dedicate adequate time and spaces for this purpose. Reflection, enriched by the integration of theoretical frameworks, helps to strengthen working hypotheses and improve action strategies. This reflection, in its different stages and levels, is key to professional growth and knowledge construction. Through curiosity to learn, critical analysis, and the adoption of new perspectives, professionals can optimize their performance and adapt effectively to emerging challenges.

Objectives

The general objective of this work is to compare the recognition rate of cardiac rhythms present during cardiopulmonary arrest before and after practical simulation-based training.

The specific objectives are:

- To assess the recognition rate of cardiac rhythms associated with cardiopulmonary arrest (CPA) by medical personnel before receiving practical simulation-based training.
- To identify possible differences in diagnostic accuracy between shockable and non-shockable rhythms before and after simulation-based training.
- To determine the impact of practical simulation-based training on the recognition of cardiac rhythms during CPA by comparing pre- and post-training results.

MATERIAL AND METHODS

This work was conducted within the context of an intensive training course focused on the assessment and initial management of pediatric patients in the emergency department. This program is specifically designed for final-year medical students, recently graduated physicians, and professionals working in the prehospital setting who, without being pediatric specialists, require fundamental competencies in the initial care of pediatric patients in emergency situations.

The training was structured in two phases. The first was an asynchronous theoretical phase, in which participants were provided with a series of video-recorded lectures, hosted on the laboratory's YouTube channel, ten days prior to the in-person session. This didactic material covers the principles of initial assessment and stabilization of pediatric patients in the emergency context, allowing students to acquire fundamental theoretical knowledge at their own pace.

The second phase was synchronous and practical, in which each group of eight students attends an eight-hour intensive session at the LaSiC. This phase begins and ends with the administration of a clinical case and arrhythmia recognition questionnaire, conducted via Google Forms. The purpose of this pre- and post-intervention assessment is to determine the evolution of participants' knowledge and diagnostic and decision-making skills after completing the practical stations.

The practical stations are designed to offer a progressive learning experience. Considering the classification by Roussin and Weinstock (Zone 1 and Zone 2 for clinical skills assessment), the following were conducted:

Zone 1 Stations:

1. **Initial Assessment Based on Simulated Clinical Cases.** Participants interact with six videos of pediatric patients arriving at the emergency department, each connected to a multiparameter monitor, presenting various clinical conditions and degrees of severity. Relevant clinical information is provided, and they are challenged to make decisions about initial actions. Each case is followed by a debriefing to foster reflection and learning.
2. **Pediatric Basic Cardiopulmonary Resuscitation.** Intensive practice of basic CPR maneuvers adapted for infants and children, using partial-task simulators or CPR training manikins.
3. **Pediatric Basic Airway Management.** Training in the placement of oropharyngeal cannulas and the use of supraglottic devices (e.g., laryngeal masks) on infant and child models.
4. **Pediatric Advanced Airway Management.** Each student performs orotracheal intubation on neonate, infant, and child head simulators, acquiring skill in this critical competency.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume IX Issue XXVI December 2025 | Special Issue on Education

5. **Intraosseous Access:** As this is a fundamental alternative for vascular access in pediatric emergencies, participants, in turns, perform the placement of an intraosseous line on a scaled model of infant legs.

Zone 2 Station:

6. A Zone 2 simulation session with structured debriefing presenting two clinical cases for the initial management of a patient in the emergency department who subsequently experiences cardiopulmonary arrest. After each case, a debriefing is conducted to highlight appropriate decision-making and identify behaviors to improve in future interventions. This station integrates all previously acquired skills and adds the advanced management protocol for arrest, as well as the development of communication, teamwork, and leadership skills. Using a high-fidelity simulator connected to an arrhythmia simulator, students manage a complex scenario that includes the advanced management of a cardiopulmonary arrest, thus consolidating their competencies in a realistic environment, with high psychological safety for the student and high safety for patients.

This strategy seeks to ensure that participants develop not only theoretical knowledge but also the practical skills and clinical judgment necessary for effective initial care of pediatric patients in emergency situations.

This study focused on evaluating the improvement in the recognition of cardiac rhythms associated with cardiopulmonary arrest (CPA). For this purpose, three specific items from the pretest were selected, which were replicated in the post-test to allow a direct and quantifiable comparison of participant performance. The analysis focused on determining the existence and magnitude of progression or regression in the ability to correctly identify these rhythms.

Study Design and Methodological Considerations

This study followed a quasi-experimental, exploratory pretest/posttest design without a control group. While this approach allows assessment of immediate educational effects, it limits causal attribution exclusively to the intervention.

RESULTS

The following three questions were asked:

1. An image of an ECG showing sinus bradycardia was presented, and it was asked: If a patient is in arrest and the monitor shows the following tracing, identify which of these conditions it could be: (image 1)

2. An image of an ECG showing ventricular tachycardia was presented, and it was asked: If a patient is in arrest and the monitor shows the following tracing, identify which of these conditions it could be: (image 2) An image of an ECG showing ventricular fibrillation was presented, and it was asked: If a patient is in arrest and the monitor shows the following tracing, identify which of these conditions it could be: (image 3)

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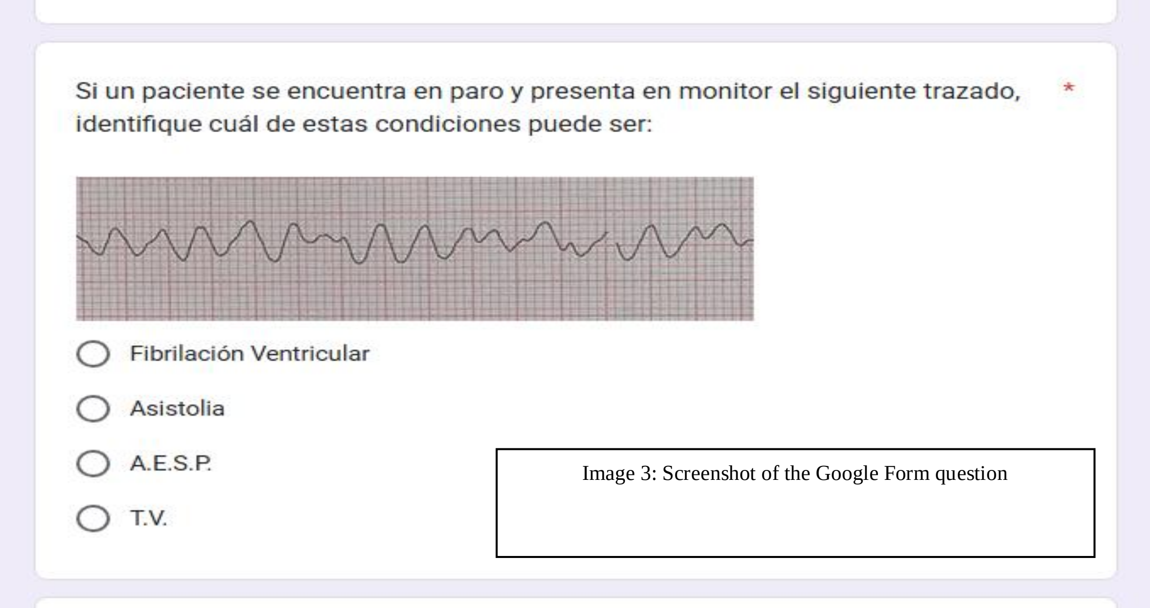

Si un paciente se encuentra en paro y presenta en monitor el siguiente trazado, identifique cuál de estas condiciones puede ser: *

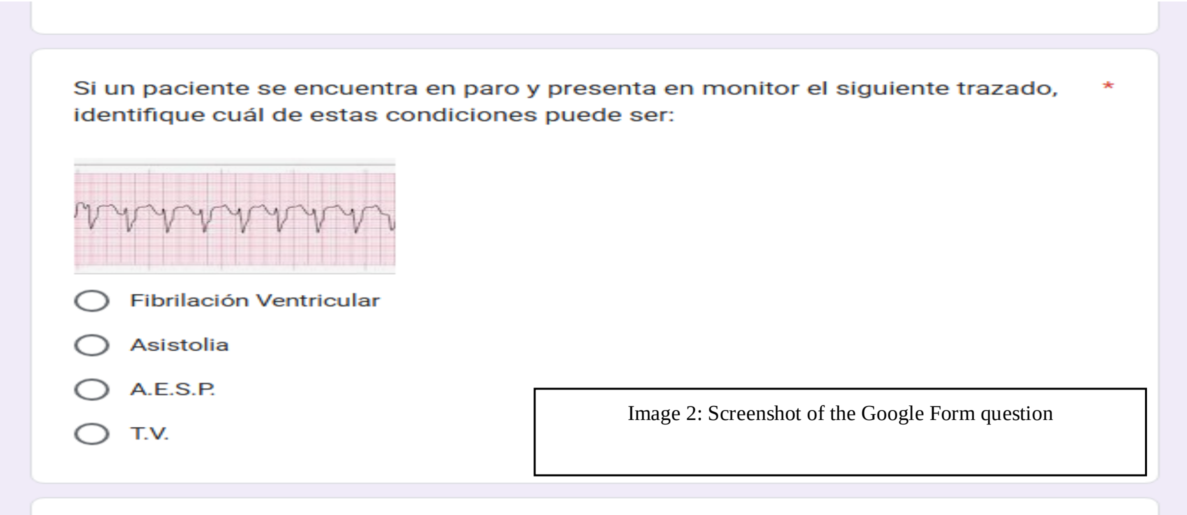
Fibrilación Ventricular

Asistolia

A.E.S.P.

T.V.

Image 3: Screenshot of the Google Form question


Si un paciente se encuentra en paro y presenta en monitor el siguiente trazado, identifique cuál de estas condiciones puede ser: *

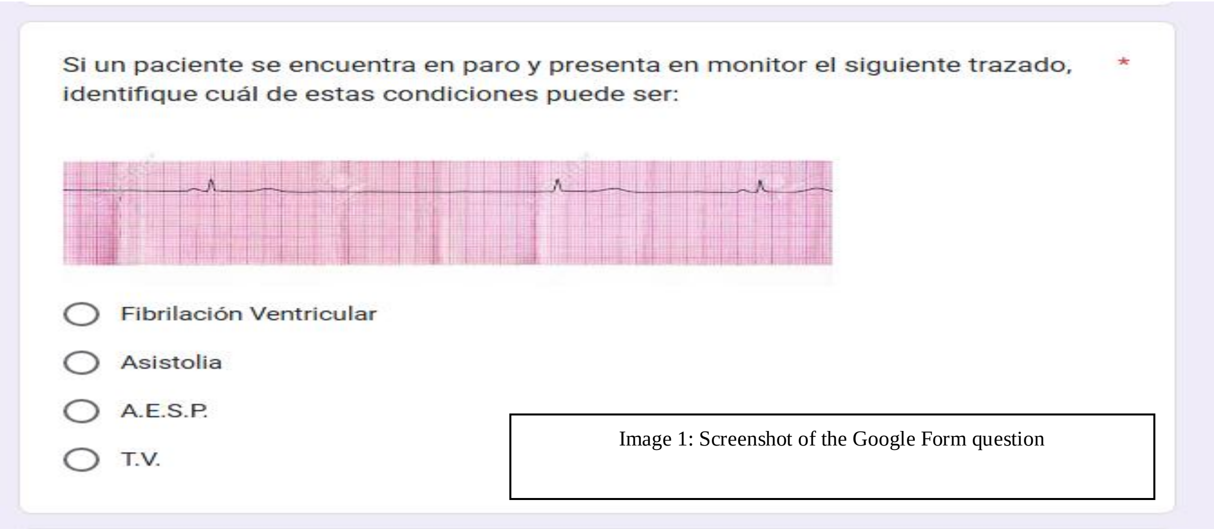
Fibrilación Ventricular

Asistolia

A.E.S.P.

T.V.

Image 2: Screenshot of the Google Form question


Si un paciente se encuentra en paro y presenta en monitor el siguiente trazado, identifique cuál de estas condiciones puede ser: *

Fibrilación Ventricular

Asistolia

A.E.S.P.

T.V.

Image 1: Screenshot of the Google Form question

Statistical Analysis

To determine if the observed change in the proportion of correct rhythm recognition was statistically significant before and after the simulation-based training, the **McNemar's Test** was applied to each question. This test is appropriate for analyzing changes in dichotomous data (Correct/Incorrect) on the same subjects measured at two different time points (pre- and post-test).

A. The results obtained in the pre-test were as follows:

- **Question 1 (Pulseless Electrical Activity - PEA)**
  - Total responses: 75 participants.
  - Correct answers (PEA): 63 responses (84%).
  - Main errors: Asystole: 10 responses (13.3%). Ventricular Fibrillation (VF) and Ventricular Tachycardia (VT): 1 response each (1.3%).
  - Interpretation: The majority correctly identified PEA, but 13.3% confused it with asystole, suggesting difficulty differentiating rhythms with organized electrical activity from those without activity. From a clinical standpoint, this has few implications since both rhythms are managed equally according to the protocol. (image 4).

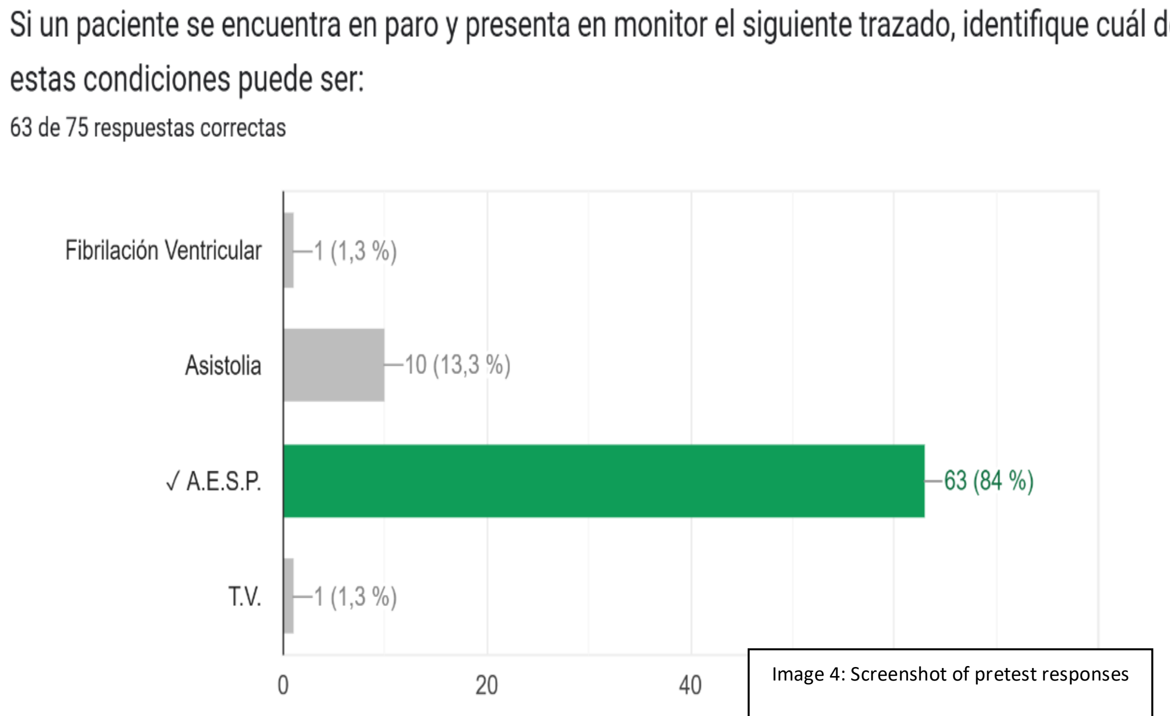


Image 4: Screenshot of pretest responses

- **Question 2 (Pulseless Ventricular Tachycardia - VT)**
  - Total responses: 75 participants.
  - Correct answers (VT): 55 responses (73.3%).
  - Main errors: Ventricular Fibrillation (VF): 15 responses (20%). PEA: 4 responses (5.3%). Asystole: 1 response (1.3%).
  - Interpretation: 73.3% recognized VT, 20% confused it with VF, indicating possible failures in distinguishing fast, organized shockable rhythms (VT) from chaotic ones (VF). This would not have major clinical implications in arrest, as both rhythms require defibrillation and antiarrhythmics. (image 5).

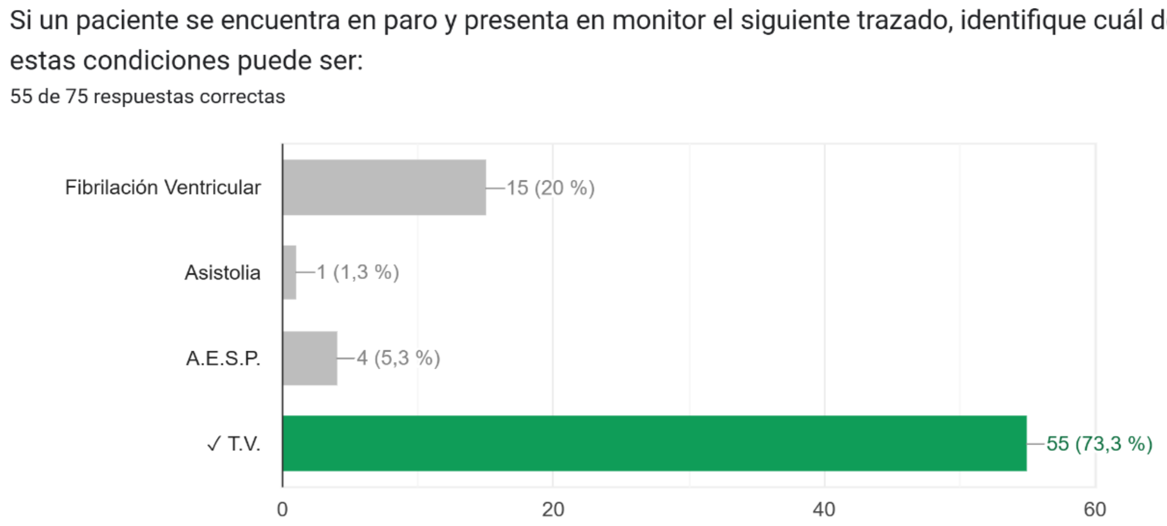


Image 5: Screenshot of pretest responses

- **Question 3 (Ventricular Fibrillation - VF)**
  - Total responses: 75 participants.
  - Correct answers (VF): 66 responses (88%).
  - Main errors: VT: 9 responses (12%). PEA: No participant confused VF with Pulseless Electrical Activity.
  - Interpretation: High recognition of VF, but 12% misclassified it as VT, indicating possible failures in differentiating chaotic rhythms (VF) from fast, organized shockable rhythms (VT). This would not have major clinical repercussions, as both rhythms are managed with defibrillation and antiarrhythmics in the context of cardiopulmonary arrest (pulseless patient). (image 6).

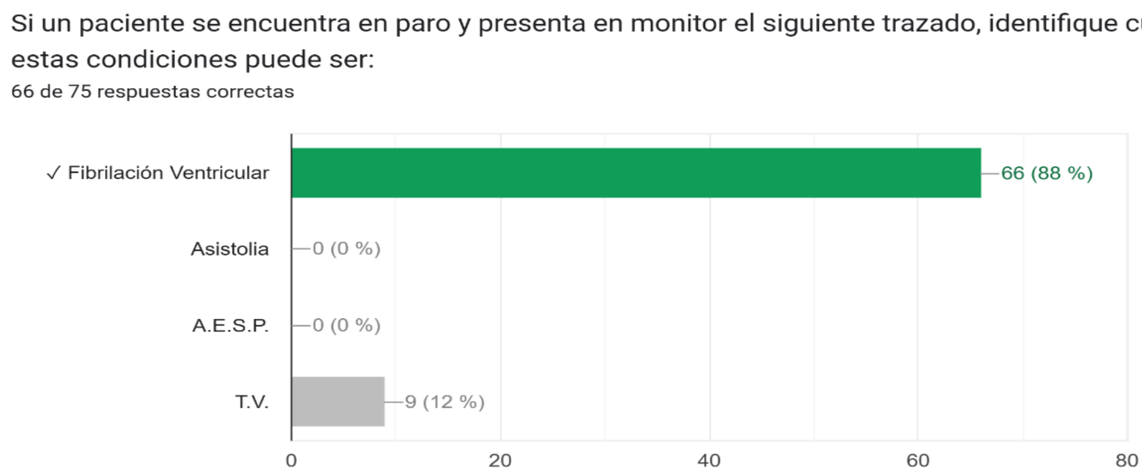


Image 6: Screenshot of pretest responses

The pre-test results, based on responses from 75 participants, reveal a generally high level of recognition of shockable and non-shockable cardiac arrest rhythms. However, specific patterns of confusion between rhythms were also identified, which, while not always having critical implications for initial arrest management, suggest areas for reinforcing knowledge. The main confusions occurred between pairs of rhythms with visual or management similarities: Confusion PEA vs. Asystole (13.3%); Confusion VT vs. VF and VF vs. VT (20% and 12% respectively).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS |Volume IX Issue XXVI December 2025 | Special Issue on Education

B. The results obtained in the post-test were as follows:

- **Question 1 (Pulseless Electrical Activity - PEA)**
  - Total responses: 53 participants.
  - Correct answers (PEA): 42 responses (79.2%).
  - Main errors: Asystole: 11 responses (20.8%). No participant confused PEA with VF or VT.
  - Interpretation: Although 79.2% correctly identified PEA, a significant confusion (20.8%) with asystole persists. The elimination of confusion between PEA and shockable rhythms (VF/VT) is a positive outcome, as patient management in arrest is the same for both asystole and PEA. (image 7).
- **Question 2 (Pulseless Ventricular Tachycardia - VT)**
  - Total responses: 53 participants.
  - Correct answers (VT): 36 responses (67.9%).
  - Main errors: VF: 15 responses (28.3%). PEA: 2 responses (3.8%). Asystole: No participant confused VT with Asystole.
  - Interpretation: The identification of VT was (67.9%), with a 28.3% confusion with Ventricular Fibrillation. The lack of confusion with Asystole and the decrease in confusion with PEA suggests improved discrimination between shockable and non-shockable rhythms. (image 8).
- **Question 3 (Ventricular Fibrillation - VF)**
  - Total responses: 53 participants.
  - Correct answers (VF): 40 responses (75.5%).
  - Main errors: VT: 12 responses (22.6%). PEA: 1 response (1.9%). Asystole: No participant confused VF with asystole.
  - Interpretation: The recognition of VF decreased compared to the pre-test by 12.5%. The confusion with VT increased to 22.6%. Critically, a small (1.9%) but clinically dangerous confusion with PEA appeared, which was not present in the pre-test. (image 9).

The post-test reveals a general decline in the accuracy of arrest rhythm recognition compared to the pre-test, especially notable in the identification of VF. This suggests that the educational intervention did not succeed in consolidating, or may have even diluted, prior knowledge or the capacity for fine discrimination.

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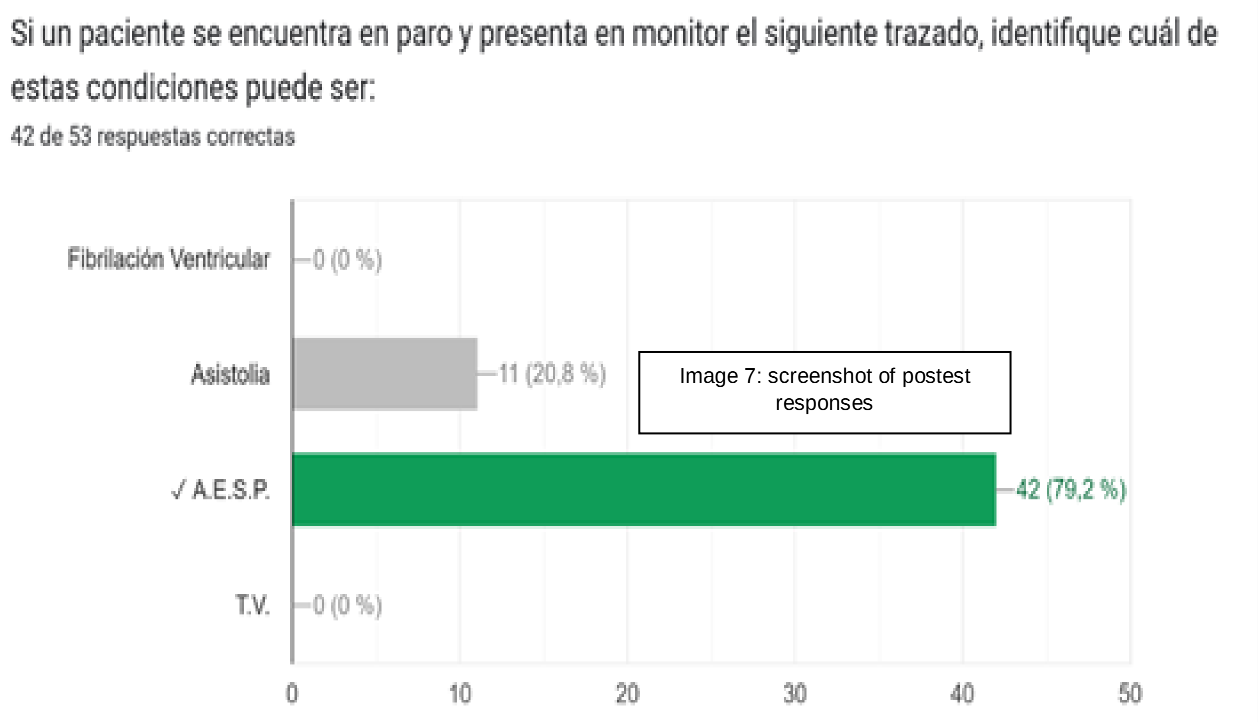

Image 7: screenshot of postest responses

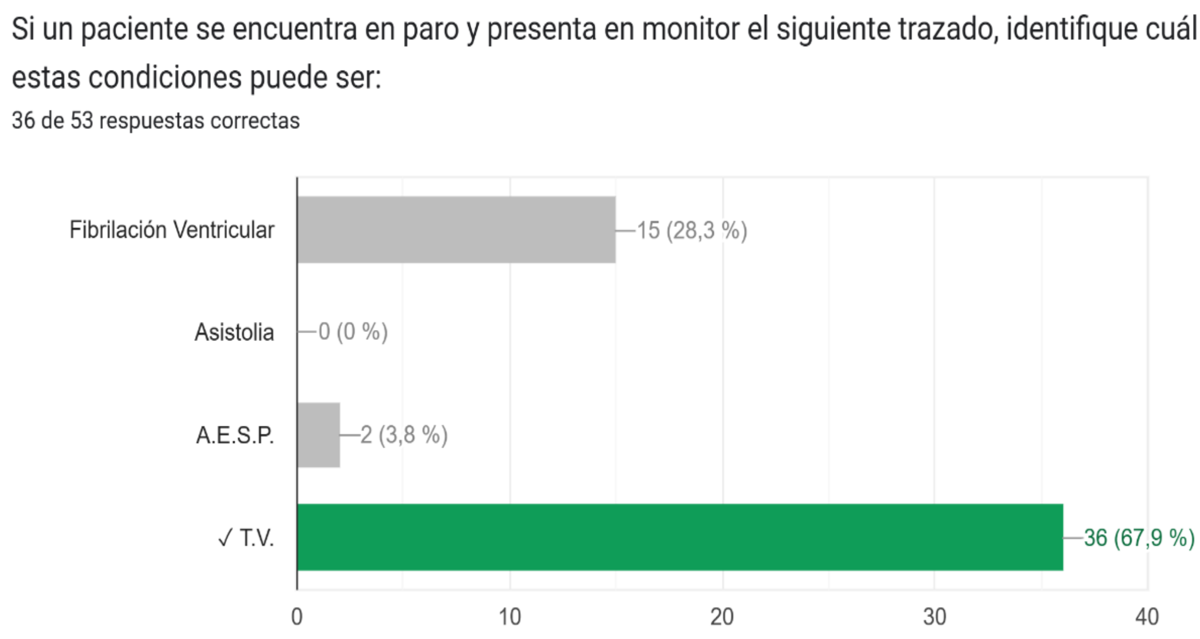

Image 8: screenshot of postest responses

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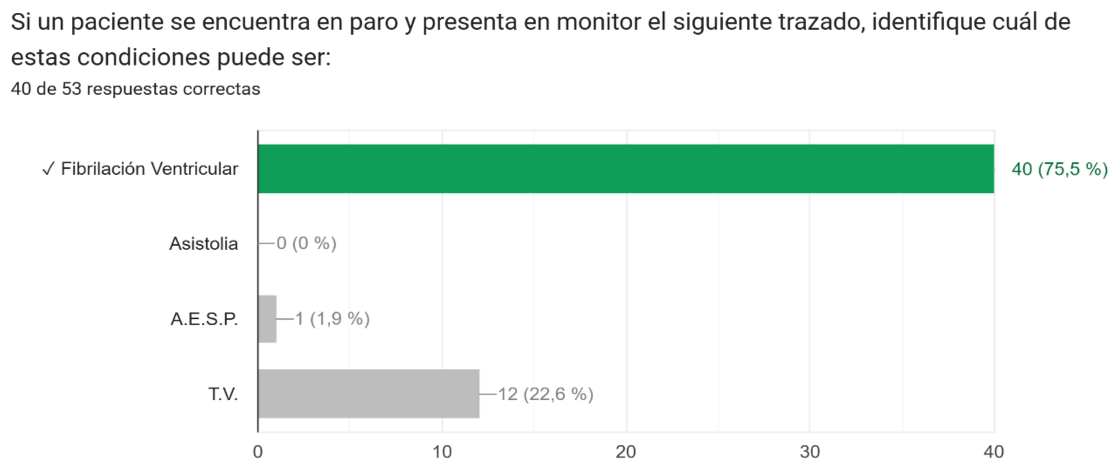

Imagen 9: screenshot of postest responses

C. Interpretation of comparative results between pre and postest:

Despite the strengths, the study also evidenced significant areas for improvement and concerning trends:

- Statistical Justification of Findings:

The application of the McNemar's Test showed a statistically significant decline in the correct identification of Ventricular Fibrillation (VF) after the intervention ($p < 0.05$). The test confirmed that the observed decrease in accuracy (from 88% to 75.5%) was unlikely due to chance, statistically supporting the finding that the training was ineffective and may have contributed to a regression in the recognition of this critical shockable rhythm. For Pulseless Electrical Activity (PEA) and Ventricular Tachycardia (VT), the changes in overall correct recognition were not statistically significant, confirming the interpretation of limited overall effectiveness.

- The confusion between PEA and asystole not only persisted in the post-test but increased from 13.3% to 20.8%. Although both rhythms share the same management protocol (CPR and drugs), this growing difficulty in visually distinguishing them indicates the need to reinforce their specific characteristics.
- The difficulty in discriminating between Ventricular Tachycardia and Ventricular Fibrillation (both shockable) was the most prominent and persistent confusion, becoming even more pronounced in the post-test (total confusion increased from 32% to 50.9%).
- The post-test revealed a notable decrease in the correct identification of VF, falling from 88% to 75.5% (a regression of 12.5 percentage points). This is a significant regression for a rhythm that demands an immediate and precise response.
- The most concerning finding of the post-test, although in a smaller percentage (1.9%), was the confusion of VF with PEA, which did not exist in the pre-test. This confusion is critical, as VF requires urgent defibrillation, while PEA does not. An error here could lead to a delay or incorrect management that directly impacts patient survival.

The results suggest that while the educational intervention may have improved the general discrimination between shockable and non-shockable rhythms, it was insufficient to consolidate the precise identification of each individual rhythm, and may have even introduced or exacerbated certain confusions.

Final reflections and Future Directions

The findings of this study, derived from the comparison between pre-test and post-test results and supported by McNemar's Test statistics, reveal a complex educational effect in training for cardiac arrest rhythm recognition. Participants entered the program with a relatively solid baseline knowledge of critical rhythms such as ventricular fibrillation (VF) and pulseless electrical activity (PEA). However, the simulation-based intervention proved insufficient to consistently consolidate diagnostic precision and, in some cases, appeared to exacerbate specific rhythm-recognition confusions.

In particular, the persistence—and in some cases increase—of confusion between ventricular tachycardia (VT) and ventricular fibrillation (VF), together with ongoing difficulty distinguishing PEA from asystole, underscores a relevant gap in the visual discrimination of arrest rhythms. Most concerning, however, was the statistically significant decline in correct VF recognition, accompanied by the emergence of confusion between VF and PEA, a pattern not observed in the pre-test. Although infrequent, this type of error is clinically critical, as misclassification of VF may delay urgent defibrillation or lead to inappropriate management, directly compromising patient survival.

Several limitations must be acknowledged. The quasi-experimental design without a control group limits causal attribution, while participant attrition between pre-test and post-test may have introduced selection bias and reduced statistical power. Additionally, the assessment tool was limited to three rhythm-identification items and did not include time-to-decision metrics or evaluation of management choices, which may better reflect real-world clinical performance. Addressing these aspects was beyond the scope of the present study.

Nevertheless, these findings provide valuable guidance for targeted educational improvement. In response to the identified gaps, we propose the incorporation of a dedicated Zone 1 rhythm-recognition station focused exclusively on cardiopulmonary arrest rhythms (PEA, VF, pulseless VT, and asystole), in accordance with the Roussin and Weinstock classification. This station should be supported by spaced repetition, deliberate practice strategies, and structured feedback, emphasizing not only accurate rhythm identification but also the clinical consequences of diagnostic errors. Complementary pre-laboratory interactive activities using ECG images with immediate feedback, as well as enhanced focus on rhythm-related errors during debriefing, may further strengthen skill consolidation.

Such refinements aim to preserve the overall strengths of the existing simulation-based program while addressing its identified limitations, thereby enhancing the reliability of cardiac rhythm recognition during cardiopulmonary arrest and supporting safer, more effective clinical decision-making.

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Ethical Considerations

The research conducted did not involve human subjects (patients) as the object of investigation. The data were collected exclusively through voluntary and anonymous user surveys related to system use and satisfaction, which were approved for administration by the participating institution and users. Formal ethical approval for human subjects research was therefore not required.

Conflict of Interest

The authors declare no conflicts of interest related to the research, the data collection, or the publication of the findings.

Data Availability Statement

All data necessary to support the findings of this study are contained within the article text itself. No additional data are available in external repositories.