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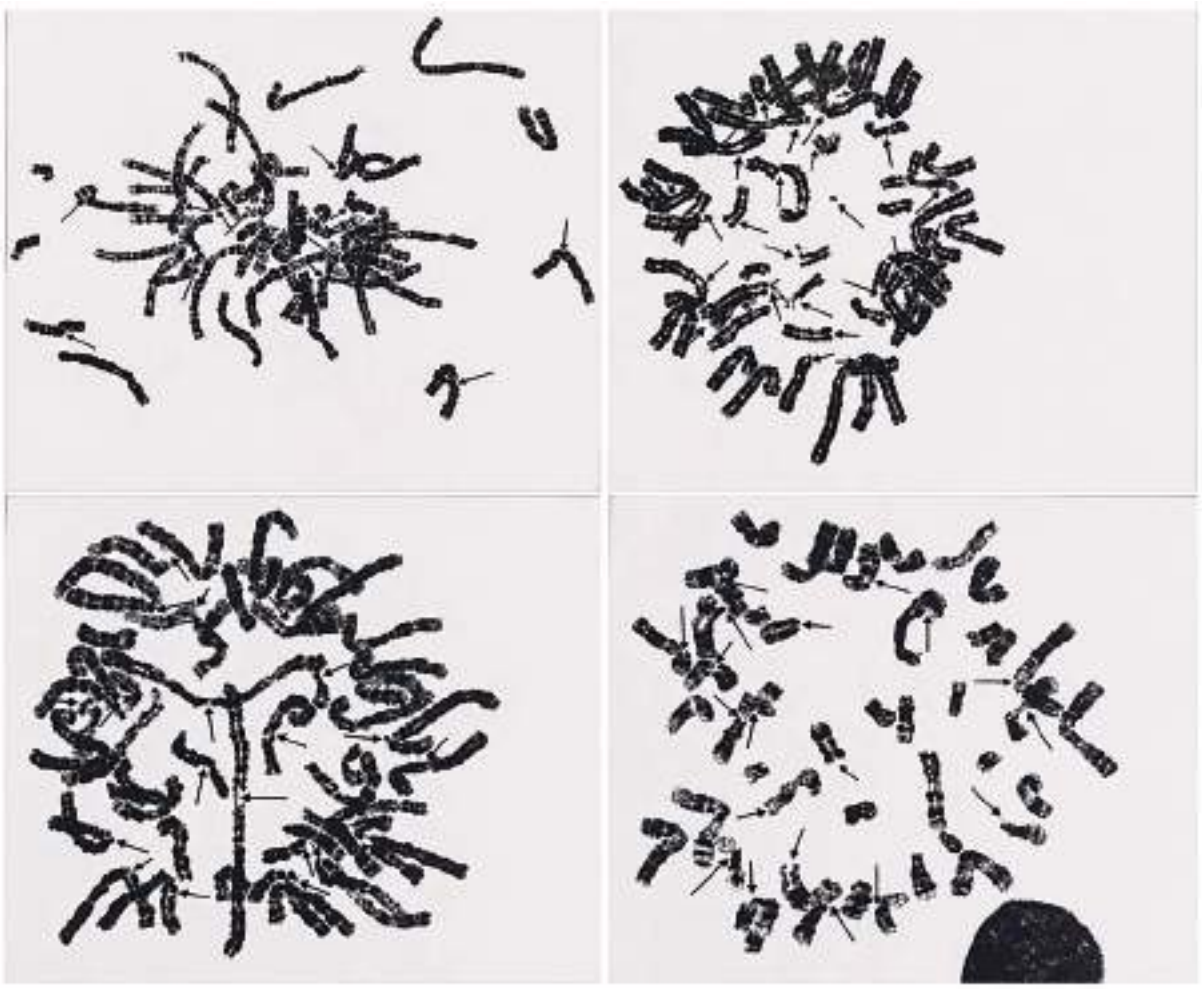
ISSN 0185-3252
e-ISSN: 3082-124X

# Anales Médicos

**Volumen 71, Número 3 / Julio - Septiembre 2026**
**Fundada en 1955**



## Gastric carcinoma in a 25 year old man with Fanconi anemia: case report and literature review

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**Volumen 71, Número 3 / Julio - Septiembre 2026**

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ORIGINAL ARTICLE

# Immediate complications after thrombolysis for acute myocardial infarction: a prospective study

## *Complicaciones inmediatas postrombólisis por infarto agudo al miocardio: estudio prospectivo*

*Sergio G. García-Quiterio[1]*, Jorge Ayón-Aguilar[2], and Israel Aguilar-Cózatl[3]*

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## Abstract

**Background:** *Acute myocardial infarction (AMI) is the leading cause of death worldwide; fibrinolytic therapy is a fundamental part of its treatment, which is why identifying its possible immediate complications has become extremely important.* **Objective:** *Determine the immediate complications following fibrinolytic treatment for acute myocardial infarction.* **Material and methods:** *Descriptive, longitudinal, prospective study in a second-level IMSS hospital in Puebla. Sixty patients over 18 years of age with ST-segment elevation acute myocardial infarction who received fibrinolytic therapy were included. Data analysis was performed using descriptive statistics, and a correlation was performed using Spearman's Rho.* **Results:** *65% of the population was male, with a mean age of 66 years; the predominant associated comorbidity was systemic arterial hypertension. The most frequent complication was arrhythmias in 58.8%, and the correlation between sex and the presence of complications obtained a p = 0.017.* **Conclusions:** *ST-segment elevation acute myocardial infarction is more common in men between the ages of 50 and 60. Complications associated with fibrinolytic therapy are frequent, so identifying this condition is essential when treating this pathology.*

***Keywords:*** *Acute coronary syndrome. ST elevation myocardial infarction. Fibrinolysis.*

## Resumen

**Antecedentes:** *El infarto agudo al miocardio (IAM) es la principal causa de mortalidad en todo el mundo. La terapia fibrinolítica constituye una parte fundamental para su tratamiento, por lo que la identificación de sus posibles complicaciones inmediatas ha tomado gran relevancia.* **Objetivo:** *Determinar las complicaciones inmediatas posterior al tratamiento fibrinolítico por IAM.* **Material y métodos:** *Estudio descriptivo, longitudinal y prospectivo en un hospital de segundo nivel del Instituto Mexicano del Seguro Social en Puebla. Se incluyeron 60 pacientes mayores de 18 años con IAM con elevación del segmento ST y que recibieron terapia fibrinolítica. El análisis de los datos se hizo con estadística descriptiva y se realizó una correlación con rho de Spearman.* **Resultados:** *El 65% de la población fue de sexo masculino, con una edad media de 66 años. La comorbilidad asociada predominante fue hipertensión arterial sistémica. La complicación más frecuente fueron las arritmias en el 58.8%, y la correlación entre el sexo y la presencia de complicaciones obtuvo p = 0.017.* **Conclusiones:** *El IAM con elevación del segmento ST es más frecuente en los hombres entre la quinta y la sexta décadas de la vida, y las complicaciones asociadas a la terapia fibrinolítica son frecuentes, por lo que su identificación es fundamental durante el abordaje de esta patología.*

***Palabras clave:*** *Síndrome coronario agudo. Infarto del miocardio con elevación del ST. Fibrinólisis.*

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Date of reception: 26-11-2025
Date of acceptance: 22-01-2026
DOI: 10.24875/AMH.25000040

Available online: 24-07-2026
An Med ABC. 2026;71(3):173-178
www.analesmedicosabc.com

## Introduction

Cardiovascular diseases have increased their relevance in recent decades and have become one of the main causes of mortality worldwide, also generating a significant economic impact on public and private health systems. Within this group, acute myocardial infarction (AMI) represents the most frequent entity and of greatest clinical relevance[1,2].

AMI is defined as evidence of myocardial necrosis in a clinical context compatible with acute myocardial ischemia, identified by an increase in cardiac biomarkers, particularly troponins, above the 99$^{th}$ percentile, associated with characteristic electrocardiographic findings such as ST-segment elevation or depression, left bundle branch block, and the appearance of pathological Q waves; findings in imaging studies with myocardial loss or wall motion abnormality and identification of coronary thrombus through angiography and/or autopsy are also very useful[3].

Globally, AMI has a higher prevalence in people over 60 years of age, with an approximate incidence of 9.5%, with males being the most affected with a mean age of presentation of 65 years[4,5]. In Mexico, this pathology constitutes the first cause of mortality in men over 45 years of age, with a mean age of presentation of 63.3 years[6,7].

From a pathophysiological point of view, AMI originates mainly from the rupture of an atheromatous plaque in the coronary arteries, which triggers a local inflammatory response mediated by macrophages and monocytes, favoring platelet activation and thrombus formation. This process leads to partial or total obstruction of coronary blood flow, generating myocardial ischemia and, if the occlusion persists, irreversible necrosis of the affected tissue[8,9]. The sudden interruption of blood flow causes structural and functional injury to myocardial cells, culminating in ischemic necrosis due to lack of oxygen and essential nutrients[10,11]. Less common mechanisms include coronary vasospasm, congenital or acquired anatomical abnormalities, spontaneous coronary dissection, and coronary embolisms[12,13].

Risk factors associated with AMI are classified as modifiable and non-modifiable. In young patients (< 45 years), the main non-modifiable factors include male sex, systemic arterial hypertension, type 2 diabetes mellitus, and hereditary family history of myocardial infarction. Among modifiable factors, smoking, obesity, dyslipidemia, and drug use stand out[14,15]. In elderly patients, the predominant sex continues to be male; however, the female sex is related to greater hemodynamic involvement and the appearance of complications, and after menopause the incidence equals that of the male sex[16,17].

The diagnosis is made through typical clinical manifestations (precordial pain, of retrosternal location, with increased intensity, oppressive, burning, which may radiate and does not subside with rest) or atypical (in special groups such as diabetic patients or elderly adults)[18,19], electrocardiogram (elevation or non-elevation of the ST segment in 2 contiguous leads and amplitude according to sex, new appearance of left or right bundle branch block), and elevated troponins (above the 99$^{th}$ percentile)[20,21].

The treatment of choice for this pathology is early reperfusion, which is a fundamental strategy to reduce associated morbidity and mortality. This can be performed through percutaneous coronary intervention (PCI) or fibrinolytic therapy (alteplase or tenecteplase)[22,23].

Regarding fibrinolytic therapy, post-thrombolysis complications have been documented immediately (< 6 hours) or in a delayed manner (6-24 hours); among the most frequent are hemorrhage, cardiogenic shock, acute pulmonary edema, atrial fibrillation, angina, hypotension, nausea, vomiting, and allergic reactions[24,25].

The objective of the present study was to determine the immediate complications following fibrinolytic treatment for AMI.

## Material and methods

An observational, descriptive, impact, longitudinal, unicentric, homodemic, and prospective study was conducted in a second-level hospital of the Mexican Social Security Institute in Puebla, Mexico, during the period from January to June 2024. Patients over 18 years of age with a diagnosis of ST-segment elevation acute myocardial infarction, established through clinical, laboratory (troponin determination), and electrocardiographic criteria, who came to the emergency department within a therapeutic window of less than 12 hours from symptom onset and who were treated with tenecteplase, were included. Those with non-ST-segment elevation AMI and those with absolute and relative contraindications for thrombolysis were excluded. Patients who requested to leave the study for any reason were eliminated.

The variables analyzed included sociodemographic data (age, sex, and occupation), cardiovascular and metabolic comorbidities, clinical characteristics, and the presence of immediate complications following

fibrinolytic therapy, defined as those that occurred within the first 6 hours after tenecteplase administration; these include the presence of arrhythmias, hypotension, reperfusion failure, cardiogenic shock, acute pulmonary edema, or hemorrhagic events.

Statistical analysis was performed using the Statistical Package for the Social Sciences software (SPSS v25.0). Descriptive statistics were used to analyze the frequencies and percentages of the evaluated population, using measures of central tendency and dispersion. The normality of quantitative variables was evaluated using the Kolmogorov-Smirnov test. The correlation between sex and the presentation of complications was analyzed using Spearman's Rho test, considering $p < 0.05$ as statistically significant.

## Results

A total of 60 patients who met the inclusion criteria were recruited; there was a predominance of males, with 39 (65.0%) patients, while 21 (35.0%) were female; the mean age was 66 years (SD + 13), with a minimum of 35 and a maximum of 88 years.

Regarding occupation, the most frequent was retired in 29 (48.3%) patients, while the least frequent was housewife in 2 (3.3%). The remaining results are shown in table 1.

Regarding comorbidities, systemic arterial hypertension was the most frequent, occurring in 57 (95%) patients, followed by type 2 diabetes in 39 (65%), obesity in 30 (50%), and sedentary lifestyle in 26 (43.3%); the least frequent comorbidities were chronic kidney disease in 5 (8.3%) patients and previous ischemic heart disease together with family history of acute myocardial infarction in 12 (20%) patients each. Details are shown in table 2.

Regarding the clinical manifestations associated with acute myocardial infarction in our population, the predominant symptom was retrosternal pain, reported in 55 (91.7%) patients, while 5 (8.3%) presented epigastric pain. Pain radiation to the jaw was observed in 31 (51.7%) patients; 39 (65%) patients presented pain in the left arm, 36 (60%) had dyspnea, 47 (78.3%) had diaphoresis, and 19 (31.7%) reported vertigo (Table 3).

All patients were treated with tenecteplase, and a total of 17 (28.3%) patients presented immediate complications, of which the most frequent were arrhythmias in 10 (58.8%) patients, followed by hypotension (23.5%) and reperfusion failure (17.6%); it is important to mention that none of the patients presented hemorrhage as a complication. The distribution of complications is shown in table 4.

When analyzing the relationship between sex and the presence of immediate complications, it was observed

**Table 1.** Occupation

| Activity | (n = 60) | % |
|---|---|---|
| Retired | 29 | 48.3 |
| Employed | 25 | 41.7 |
| Housewife | 2 | 3.3 |
| Unemployed | 4 | 6.7 |

**Table 2.** Comorbidities

| Disease or condition | Yes | | No | |
|---|---|---|---|---|
| | (n = 60) | % | (n = 60) | % |
| Smoking | 15 | 25.0 | 45 | 75.0 |
| Sedentary lifestyle | 26 | 43.3 | 34 | 56.7 |
| Obesity | 30 | 50.0 | 30 | 50.0 |
| Systemic arterial hypertension | 57 | 95.0 | 3 | 5.0 |
| Type 2 diabetes | 39 | 65.0 | 21 | 35.0 |
| Previous ischemic heart disease | 12 | 20.0 | 48 | 80.0 |
| Dyslipidemia | 18 | 30.0 | 42 | 70.0 |
| Chronic kidney disease | 5 | 8.3 | 55 | 91.7 |
| Family history of AMI | 12 | 20.0 | 48 | 80.0 |

AMI: acute myocardial infarction.

**Table 3.** Clinical characteristics

| Variables | Yes | | No | |
|---|---|---|---|---|
| | (n = 60) | % | (n = 60) | % |
| Thoracic pain | 55 | 91.7 | 5 | 8.3 |
| Epigastric pain | 5 | 8.3 | 55 | 91.7 |
| Pain radiating to jaw | 31 | 51.7 | 29 | 48.3 |
| Left arm pain | 39 | 65.0 | 21 | 35.0 |
| Dyspnea | 36 | 60.0 | 24 | 40.0 |
| Diaphoresis | 47 | 78.3 | 13 | 21.7 |
| Vertigo | 19 | 31.7 | 41 | 68.3 |

that 38.5% of male patients presented some type of complication, compared to 9.5% of the female sex. Analysis using Spearman's Rho correlation test showed a coefficient of 0.336, with a p = 0.017. The remaining results are shown in table 5.

**Table 4.** Complications

| Distribution of complications | n | % |
|---|---|---|
| Presentation of complications (n = 60) | | |
| Yes | 17 | 28.3 |
| No | 43 | 71.7 |
| Type of complications (n = 17) | | |
| Hemorrhage | 0 | 0.0 |
| Arrhythmias | 10 | 58.8 |
| Hypotension | 4 | 23.5 |
| Reperfusion failure | 3 | 17.6 |
| Allergy | 0 | 0.0 |
| Mechanical | 0 | 0.0 |

**Table 5.** Complications in relation to sex

| Complications | Male (n = 39) | | Female (n = 21) | | Spearman's Rho (p) |
|---|---|---|---|---|---|
| | n | % | n | % | |
| Yes | 15 | 38.5 | 2 | 9.5 | 0.017 |
| No | 24 | 61.5 | 19 | 90.5 | |

## Discussion

In this study, 60 patients with ST-segment elevation AMI who were treated with thrombolytic therapy were included; a clear predominance of the male sex was observed at 65%, which is consistent with that reported by Martínez et al. and Pérez et al.,[26,27] who obtained a predominance of the male sex at 75% and 73.2%, respectively. This marked predominance in the male sex is explained by a combination of biological mechanisms (lower estrogen levels), the presence of risk factors (they tend to exhibit it in a higher proportion compared to women) and behavioral factors[28,29].

The mean age of presentation reported in national and international literature varies from approximately 62-64 years[26,27], similar to what was found in our study, with a mean age of 66 years.

AMI is associated with cardiovascular risk factors such as dyslipidemia, systemic arterial hypertension, metabolic syndrome, diabetes mellitus, smoking, sedentary lifestyle, and obesity[2]. In this study, it was found that the predominant comorbidity was systemic arterial hypertension at 95%, followed by type 2 diabetes at 65% and obesity at 50%, which is consistent with that reported by Sánchez et al., in which arterial hypertension predominated at 30%, followed by a history of cardiovascular disease at 24% and diabetes mellitus at 23%[30]. However, Mora et al.[31] reported that the most frequent cardiovascular factor was smoking at 68.4%, followed by sedentary lifestyle at 59.6% and, in third place, systemic arterial hypertension at 56.1%.

Regarding clinical presentation, Castro et al.,[19] in their study conducted in Cuba, found that the majority of their study population presented retrosternal pain in 81.3%, with a sensation of oppression in 76% and with radiation to the left shoulder and arm in 92%; which is consistent with what was obtained in this work with a predominance of retrosternal pain in 91.7%, with radiation to the jaw in 65% and to the left arm in 60%.

Of our study population, 28.3% presented complications following fibrinolytic treatment with tenecteplase, the most frequent being arrhythmias at 58.8%, followed by hypotension at 23.5% and reperfusion failure at 17.6%; it is worth mentioning that none of our patients presented hemorrhage. The absence of hemorrhagic events in our population is relevant, since in contrast to what is reported in other studies such as that of Rego et al., in which 18% presented complications, the most frequent being hypotension at 19.34%, followed by nausea at 5.27%[32]; and that of Mora et al.,[31] who reported in their population 10.5% with complications associated with fibrinolysis, and of these, hemorrhage predominated in 100% of patients. This finding can be explained by adequate patient selection, adherence to established contraindications, and the use of tenecteplase, which has demonstrated a favorable safety profile compared to other fibrinolytic agents.

Regarding the relationship between sex and the presence of complications, 38.5% of the male patients in our study presented complications compared to only 9.5% of female patients, with a p = 0.017, which is statistically significant. This result has been reported variably in the literature; some studies suggest a higher incidence of complications in men, while others describe greater severity and worse prognosis in women. These differences could be related to hormonal factors, different risk profiles, or variations in response to treatment, which underscores the need for additional research to clarify the impact of sex on early evolution following fibrinolysis.

The main limitations of the study include its observational design, the relatively small sample size, and the follow-up period restricted to the first hours following fibrinolytic treatment. This study is among the few conducted in our country on this subject and contributes significantly to information on thrombolytic treatment and its associated complications. However, it is a starting point for future research with the areas of opportunity already mentioned for better comparison of results.

## Conclusion

In this study, it was observed that ST-segment elevation acute myocardial infarction was more frequent in males, with an average age in the sixth decade of life. The predominant comorbidities were systemic arterial hypertension, type 2 diabetes mellitus, and obesity.

Approximately one-third of patients presented immediate complications following fibrinolytic therapy with tenecteplase, with arrhythmias being the most frequent complication, followed by hypotension and reperfusion failure. No hemorrhagic events were documented during the observation period.

## Funding

The authors declare they have received no funding for this study.

## Conflicts of interest

The authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** The authors have followed their institution's confidentiality protocols. This study was approved by the Local Health Research Committee No. 2108 of the *Instituto Mexicano del Seguro Social*, with registration number R-2024-2108-003. Informed consent was obtained from the patients, and approval from the Ethics Committee is available. Information was handled with strict confidentiality criteria between the physician and the participant and was used exclusively for research purposes. SAGER guidelines have been followed as applicable to the nature of the study.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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ORIGINAL ARTICLE

# Pedicle morphometry of the lumbar spine in a sample of the Mexican population, measured by computed tomography

## *Morfometría pedicular de columna lumbar en una muestra de población mexicana, medida por tomografía computarizada*

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## Abstract

**Background:** *The greatest purchase of a screw in the lumbar spine occurs in the pedicle. This makes it important to have the largest diameter possible without damaging its walls.* **Objective:** *The aim of the study was to determine lumbar pedicle parameters in a population sample from Mexico City, to properly select the screw for use in lumbar spine surgery.* **Material and methods:** *Sixty patients, aged 20-70 years, were evaluated. Computed tomography (CT) scans measured the internal and external cortical pedicle height, internal and external cortical pedicle width, and the convergence angle in each lumbar pedicle. Descriptive statistics and the Mann-Whitney U test were used to determine the difference between means by sex and segment.* **Results:** *The mean age was 51.7 and 49.7 years in men and women, respectively. In women, the internal cortical pedicle width was smaller from L1 to L4, and the internal cortical pedicle height was smaller at L5. In men, the inner cortical pedicle width was narrower from L1 to L3, and the inner cortical pedicle height was narrower at L4 and L5. The angle of convergence was narrower at L1 and gradually increased up to L5 in both men and women.* **Conclusions:** *In women, 5.0 mm screws are safe for L4 and L5, and 4.0 mm screws are safe for L1-L3. In men, 5.0 mm screws are safe for L1 and L2, and 5.5 mm screws are safe for L3. At L4 and L5, 5.5 mm screws are safe.*

***Keywords:*** *Pedicle. Screw. Lumbar spine.*

## Resumen

**Antecedentes:** *El mayor agarre del tornillo en columna lumbar se da en el pedículo. De ahí la importancia de que el diámetro de este tornillo sea el mayor posible que pueda soportar sin llegar a dañar sus paredes.* **Objetivo:** *Conocer los parámetros pediculares lumbares en una muestra poblacional de la Ciudad de México, para seleccionar adecuadamente el tornillo a utilizar en cirugía de columna lumbar.* **Material y métodos:** *Se evaluaron 60 pacientes, de 20 a 70 años. En tomografía se midieron en cada pedículo lumbar la altura pedicular cortical interna y externa, anchura pedicular cortical interna y externa, y el ángulo de convergencia. Se utilizó estadística descriptiva y U de Mann-Whitnney para diferencia entre medias por sexo y segmento.* **Resultados:** *La edad media fue 51.7 y 49.7 años en hombres y mujeres, respectivamente.*

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Date of reception: 27-06-2025
Date of acceptance: 01-05-2026
DOI: 10.24875/AMH.M26000158

Available online: 24-07-2026
An Med ABC. 2026;71(3):179-187
www.analesmedicosabc.com

*En mujeres, la anchura pedicular cortical interna fue menor de L1 a L4, en L5 fue la altura pedicular cortical interna. En hombres, la anchura pedicular cortical interna fue menor de L1 a L3, en L4 y L5 fue la altura pedicular cortical interna. El ángulo de convergencia fue menor en L1 e incrementó gradualmente hasta L5 en hombres y mujeres.* **Conclusiones:** *En mujeres, tornillos de 5.0 mm son seguros para L4 y L5, para L1 a L3 serían los tornillos de 4.0 mm. En hombres, tornillos de 5.0 mm serían seguros para L1 y L2, en L3 los tornillos de diámetro 5.5 mm. En L4 y L5, son seguros tornillos de 5.5.*

***Palabras clave:*** *Pedículo. Tornillo. Columna lumbar.*

## Introduction

Transpedicular screws have been widely used in pathologies requiring alignment correction to maintain stability and promote adequate fusion in patients with fractures, spondylolisthesis, tumors, or scoliosis.

The most important factors affecting screw stability are: screw size, insertion depth, orientation, insertion technique, and bone mineral density[1].

With the increased use of these screws, potential complications may increase, including screw malposition, infection, pseudoarthrosis, nerve irritation, and screw or rod breakage[2].The presence of these complications plays an important role since, apart from poor clinical outcomes, they increase the cost related to medical care and the patient's loss of productivity[3].To minimize the risks of complications and costs derived from them, adequate pre-operative planning is essential.

The pedicle is a cylinder of bone located between the lamina and the vertebral body and has an outstanding function in the stability of these screws.

Biomechanical studies recommend that a screw should be chosen that has a diameter close to the internal pedicle diameter to achieve a good interface, a recommendation valid for vertebrae with normal bone quality[4].

In studies of screw pullout resistance, the pedicle provides 60% axial resistance and 80% stiffness, which suggests that the pedicle plays an important role in vertebral biomechanics and postoperative recovery. Many academics agree that pedicle width and height are the most important anatomical parameters of this structure[5].

The inner pedicle diameter is very important in screw placement to achieve safe placement and strong stabilization[6]. It has been observed that screw pullout forces are greater when the screw diameter fills more than 80% of the pedicle and lower when this percentage is < 80%[7].

Cadaver studies have reported that plastic deformity occurs in the pedicle, and this precedes fracture when the threads are larger than the endosteal diameter or when the screw diameter is > 80% of the external cortical diameter[8].

The importance of the pedicle for lumbar fixations is such that multiple studies of pedicle morphometry have been conducted in various populations to determine the appropriate diameter and angulation of screws in the lumbar region. In our country, there is only one registered study conducted on cadavers regarding pedicle morphometry.

The objective of this study is to create a database focused on the Mexican population regarding pedicle morphometry and to determine if there are differences between males and females.

## Materials and methods

Retrospective study of pedicle morphometry of 60 patients, performing measurements on computed tomography (CT) scans taken between January and December 2022 were done. CT scans taken of the lumbar spine with 3 mm cuts were reviewed, using a Siemens Somatom Perspective scanner at a tertiary care hospital.

### *Study population*

The CT scans of 60 patients were evaluated, 30 men and 30 women, aged between 20 and 70 years, who attended the outpatient clinic for lumbar pain and to whom non-surgical treatment was provided.

Patients younger than 20 years and older than 70 years, patients presenting fractures of the lumbar spine, tumors, spondylolisthesis, previous lumbar spine surgery, and vertebral deformities were excluded from this study.

### *Measurements*

The internal and external cortical pedicle width was measured; these measurements were performed on an axial projection for both the left and right pedicles at the level of the pedicle isthmus, and the values were recorded in millimeters (Fig. 1).

The pedicle convergence angle was measured in degrees for each pedicle from L1 to L5 (Fig. 2).

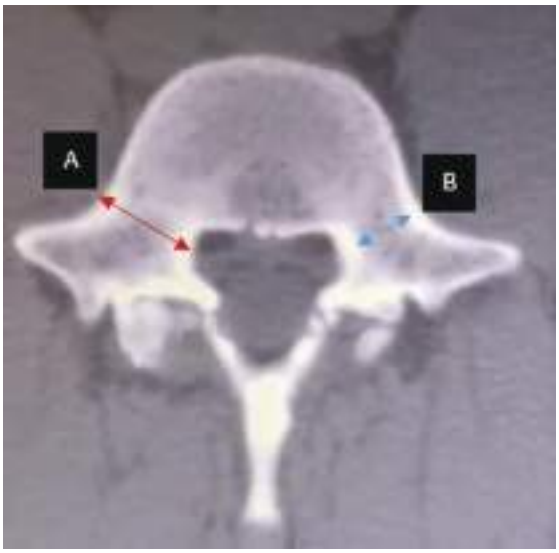


**Figure 1.** Simple computed tomography scan showing an axial cut of L5. **A:** external cortical width and **B:** internal cortical width.

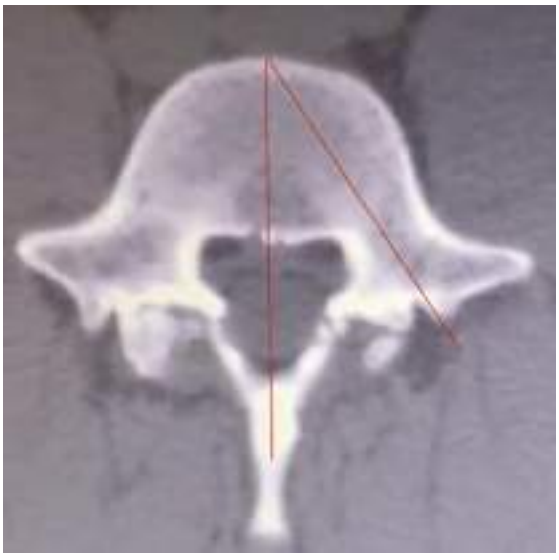

**Figure 2.** Simple computed tomography scan showing an axial cut of L5. The pedicle convergence angle is shown.

The internal and external cortical pedicle height was measured in a parasagittal projection for both the left and right pedicle at the level of the pedicle isthmus, and the values were recorded in millimeters (Figs. 3 and 4).

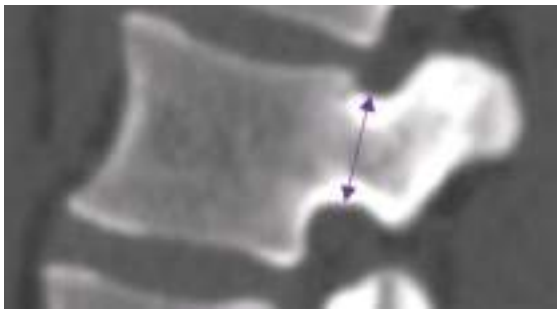

**Figure 3.** Simple computed tomography scan showing a parasagittal cut of L2. The arrow schematizes the external cortical height.

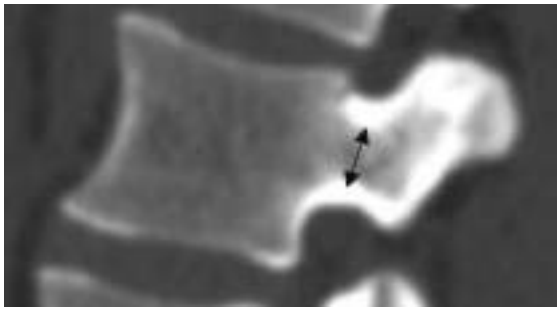

**Figure 4.** Simple computed tomography scan showing a parasagittal cut of L2. The arrow schematizes the internal cortical pedicle height.

### *Statistical analysis*

The differences in these parameters in women and men were evaluated using the Mann-Whitney U statistical test, and $p < 0.05$ was accepted as an indication of statistical significance.

This research work complies with the ethical aspects in research matters, respects the principles of privacy, dignity, and well-being of the participants, and the anonymity of the participants was maintained at all times.

## Results

The mean age was 51.7 ± 13 and 49.7 ± 12.6 years, for men and women, respectively.

At L1, the smallest parameter found in men was the internal cortical pedicle width, and the mean was 4.8 ± 2.7 and 3.67 ± 2.87 mm for right and left pedicles, respectively. The right and left pedicle convergence

**Table 1.** Pedicle parameters of L1 vertebra

| Variables | Sex | Mean | SD | Mean difference | p |
|---|---|---|---|---|---|
| Internal cortical pedicle height_r | Men | 7.83 | 4.28 | 1.05 | 0.328 |
| | Women | 6.77 | 3.27 | | |
| Internal cortical pedicle height_l | Men | 5.78 | 4.99 | 0.31 | 0.882 |
| | Women | 5.47 | 3.79 | | |
| External cortical pedicle height_r | Men | 12.61 | 5.52 | 3.04 | 0.219 |
| | Women | 9.56 | 5.93 | | |
| External cortical pedicle height_l | Men | 8.81 | 7.52 | –0.31 | 0.175 |
| | Women | 9.12 | 5.58 | | |
| Internal cortical pedicle width_r | Men | 4.8 | 2.69 | 1.49 | 0.946 |
| | Women | 3.31 | 1.86 | | |
| Internal cortical pedicle width_l | Men | 3.67 | 2.87 | 0.29 | 0.894 |
| | Women | 3.38 | 1.8 | | |
| External cortical pedicle width_r | Men | 6.95 | 3.92 | 1.89 | 0.629 |
| | Women | 5.05 | 2.73 | | |
| External cortical pedicle width_l | Men | 5.36 | 4.01 | –0.035 | 0.152 |
| | Women | 5.4 | 2.65 | | |
| Convergence angle_r | Men | 14.1 | 10.1 | 2.6 | 0.488 |
| | Women | 11.5 | 10.1 | | |
| Convergence angle_l | Men | 17.4 | 8.7 | –5.3 | 0.111 |
| | Women | 12.7 | 40.1 | | |

A $p < 0.05$ was considered statistically significant.
r: right; l: left; SD: standard deviation; p: probability.

angles were 14.1 ± 1 and 17.4 ± 0.9°, respectively. In women, the internal cortical pedicle width was the smallest parameter found; the mean was 3.3 ± 1.8 mm for both pedicles, with a convergence angle of 11.5 ± 1 and 12.7 ± 4° for right and left pedicles, respectively. In all parameters evaluated for L1, there were no statistically significant differences (Table 1).

At L2, the smallest parameter found in men was the internal cortical pedicle width, and the mean was 4.9 ± 2.2 and 3.8 ± 2.7 mm in right and left pedicles, respectively. The right and left pedicle convergence angles were 15 ± 1 and 18.4 ± 0.8°, respectively. In women, the internal cortical pedicle width was the smallest parameter found; the mean was 3.1 ± 1.9 and 3.4 ± 1.8 mm in right and left pedicles, respectively, with a convergence angle of 16.9 ± 0.9 and 18.4 ± 0.8° for right and left pedicles, respectively. In all parameters evaluated for L2, there were no statistically significant differences (Table 2).

At L3, the smallest parameter found in men was the internal cortical pedicle width, and the mean was 5.47 ± 2.98 and 5.5 ± 3.06 mm in right and left pedicles, respectively. The right and left pedicle convergence angles were 16.5 ± 1.09 and 19.5 ± 0.97°, respectively. In women, the internal cortical pedicle width was the smallest parameter found, the mean was 4.1 ± 2 and 4.03 ± 2.38 mm in right and left pedicles, respectively, with a convergence angle of 16.5 ± 1 and 19.5 ± 0.9° for right and left pedicles, respectively. In all parameters evaluated for L3, there were no statistically significant differences (Table 3).

At L4, the smallest parameter found in men was the internal cortical pedicle height, and the mean was 7.11 ± 3.77 and 3.66 ± 4.07 mm in right and left pedicles,

**Table 2.** Pedicle parameters of L2 vertebra

| Variables | Sex | Mean | SD | Mean difference | p |
|---|---|---|---|---|---|
| Internal cortical pedicle height_r | Men | 7.29 | 3.52 | 2.36 | 0.372 |
| | Women | 4.93 | 3.42 | | |
| Internal cortical pedicle height_l | Men | 5.04 | 4.15 | 0.69 | 0.174 |
| | Women | 4.34 | 3.73 | | |
| External cortical pedicle height_r | Men | 11.58 | 5.99 | 2.07 | 0.25 |
| | Women | 9.5 | 4.92 | | |
| External cortical pedicle height_l | Men | 11.61 | 6.18 | 3.45 | 0.96 |
| | Women | 8.15 | 5.69 | | |
| Internal cortical pedicle width_r | Men | 4.92 | 2.19 | 1.82 | 0.249 |
| | Women | 3.09 | 1.98 | | |
| Internal cortical pedicle width_l | Men | 3.78 | 2.69 | 0.4 | 0.735 |
| | Women | 3.38 | 1.77 | | |
| External cortical pedicle width_r | Men | 7.77 | 2.66 | 2.66 | 0.166 |
| | Women | 5.11 | 2.74 | | |
| External cortical pedicle width_l | Men | 6.78 | 3.29 | 1.71 | 0.213 |
| | Women | 5.07 | 2.76 | | |
| Convergence angle_r | Men | 15 | 1 | –1.9 | 0.274 |
| | Women | 16.9 | 9.1 | | |
| Convergence angle_l | Men | 18.8 | 7.7 | 0.43 | 0.788 |
| | Women | 18.4 | 8.2 | | |

A $p < 0.05$ was considered statistically significant.
r: right; l: left; SD: standard deviation; p: probability.

respectively. The right and left pedicle convergence angles were 17.5 ± 1.25 and 20.8 ± 1.12°, respectively. In women, the internal cortical pedicle width was the smallest parameter found; the mean was 4.59 ± 2.52 and 4.55 ± 2.84 mm in right and left pedicles, respectively, with a convergence angle of 21.4 ± 1.15 and 16.2 ± 1.28° for right and left pedicles, respectively. There were statistically significant differences for the internal cortical pedicle height; in the rest of the evaluated parameters, there were no significant differences (Table 4).

At L5, the smallest parameter found in men was the internal cortical pedicle height, and the mean was 6.52 ± 4.21 and 6.65 ± 5.03 mm in right and left pedicles, respectively. The right and left pedicle convergence angles were 17.7 ± 1.49 and 19 ± 1.53°, respectively. In women, the internal cortical pedicle height was the smallest parameter found, the mean was 5.22 ± 3.04 and 4.76 ± 3.27 mm in right and left pedicles, respectively, with a convergence angle of 30.6 ± 5.7 and 28.5 ± 1.31° for right and left pedicles, respectively. There were statistically significant differences for the internal cortical pedicle width; in the rest of the evaluated parameters, there were no significant differences (Table 5).

The mean of the internal and external pedicle width and the convergence angle gradually increased from L1 to L5 in both men and women.

## Discussion

In the present study, emphasis was placed on the internal and external cortical diameters of the pedicle isthmus and on the pedicle convergence angle.

Based on the results obtained regarding the internal cortical pedicle width for L1 and L2 in males, it is possible to safely place screws with a diameter of 5.0 mm,

**Table 3.** Pedicle parameters of L3 vertebra

| Variables | Sex | Mean | SD | Mean difference | p |
|---|---|---|---|---|---|
| Internal cortical pedicle height_r | Men | 7.7 | 3.47 | 1.68 | 0.241 |
| | Women | 6.02 | 3.29 | | |
| Internal cortical pedicle height_l | Men | 4.94 | 4.19 | 0.23 | 0.785 |
| | Women | 4.71 | 3.57 | | |
| External cortical pedicle height_r | Men | 9.87 | 6.41 | –0.57 | 0.257 |
| | Women | 10.45 | 4.33 | | |
| External cortical pedicle height_l | Men | 7.61 | 7.07 | –3.16 | 0.517 |
| | Women | 10.78 | 4.11 | | |
| Internal cortical pedicle width_r | Men | 5.47 | 2.98 | 1.36 | 0.528 |
| | Women | 4.1 | 2 | | |
| Internal cortical pedicle width_l | Men | 5.5 | 3.06 | 1.47 | 0.668 |
| | Women | 4.03 | 2.38 | | |
| External cortical pedicle width_r | Men | 7.89 | 4.14 | 0.98 | 0.08 |
| | Women | 6.91 | 1.88 | | |
| External cortical pedicle width_l | Men | 8.13 | 4.36 | 1.21 | 0.834 |
| | Women | 6.92 | 2.44 | | |
| Convergence angle_r | Men | 16.5 | 1.09 | 0 | 0.436 |
| | Women | 16.5 | 1.09 | | |
| Convergence angle_l | Men | 19.5 | 0.97 | 0 | 0.199 |
| | Women | 19.5 | 0.95 | | |

A $p < 0.05$ was considered statistically significant.
r: right; l: left; SD: standard deviation; p: probability.

and in the pedicles of L3, the use of 5.5 mm screws would be allowed; in pedicles of L4 and L5, the placement of screws with a diameter of 5.5 mm would be safe and up to 6.5 mm with a higher risk of plastic deformity of the pedicle.

In women, regarding the internal pedicle width, it is observed that the placement of screws with a diameter of 4.0 mm is safe from L1 to L3, with a risk of presenting plastic deformity in L1 and L2 despite the small diameter of the screw; for vertebrae L4 and L5, the safe screw diameter would be 5.0 mm.

With the safe measurements found for the Mexican population, the recommendation of Acharya et al.[9] is agreed upon, who in their study concluded that the use of 7 mm diameter screws in upper lumbar levels is not justified because it can generate violation of the pedicle isthmus and lead to neurological complications.

Regarding the internal cortical pedicle width, values lower than those reported by Olmos-Alfonso et al.[10] in the Spanish population were found. While the values reported by Li et al. were similar compared to this study, as were those reported by Zhe-Heng et al.[11,12] The results obtained for external pedicle width by Urrutia-Vega et al.[13] in their study conducted on 60 cadavers are similar to the values found in men; the results of this study in women were lower.

The measurements of the internal and external pedicle width showed a gradual increase from L1, with the values obtained at L5 being higher for women and men; this trend was similar to that found by Sugisaki et al[14].

In the results obtained for the internal and external pedicle height, a gradual decrease was found, being higher at L1 and lower at L5, in both men and women. These results contrast with those found by Torun et al.[15], who reported that these values practically

**Table 4.** Pedicle parameters of L4 vertebra

| Variables | Sex | Mean | SD | Mean difference | p |
|---|---|---|---|---|---|
| Internal cortical pedicle height_r | Men | 7.11 | 3.77 | 0.91 | 0.635 |
| | Women | 6.19 | 2.48 | | |
| Internal cortical pedicle height_l | Men | 3.66 | 4.07 | –1.13 | 0.018 |
| | Women | 4.79 | 3.28 | | |
| External cortical pedicle height_r | Men | 9.94 | 5.48 | 0.9 | 0.331 |
| | Women | 9.04 | 4.21 | | |
| External cortical pedicle height_l | Men | 8.45 | 6.18 | –0.21 | 0.953 |
| | Women | 8.67 | 4.59 | | |
| Internal cortical pedicle width_r | Men | 6.39 | 2.99 | 1.8 | 0.141 |
| | Women | 4.59 | 2.52 | | |
| Internal cortical pedicle width_l | Men | 4.98 | 3.92 | 0.42 | 0.435 |
| | Women | 4.55 | 2.84 | | |
| External cortical pedicle width_r | Men | 9.22 | 4.06 | 2.93 | 0.084 |
| | Women | 6.28 | 4.01 | | |
| External cortical pedicle width_l | Men | 9.69 | 3.67 | 2.2 | 0.679 |
| | Women | 7.48 | 3.45 | | |
| Convergence angle_r | Men | 17.5 | 1.25 | –3.8 | 0.825 |
| | Women | 21.4 | 1.15 | | |
| Convergence angle_l | Men | 20.8 | 1.12 | 4.5 | 0.764 |
| | Women | 16.2 | 1.28 | | |

A $p < 0.05$ was considered statistically significant.
r: right; l: left; SD: standard deviation; p: probability.

remain constant in all lumbar vertebrae in men and women. The results in these parameters were similar to those reported by Cook and Baker[16] in a Maori population, where pedicle height values decreased gradually, being higher at L1 and lower at L5.

The measurements obtained for the external cortical pedicle height in males were similar to those reported by Singel et al. in Gujarat, India. The results in women for this same parameter were similar to those reported by Verma and Agrawal in their study on dry lumbar specimens[17].

Regarding the pedicle convergence angle, a gradual increase was found; the angle was smaller at L1 and larger at L5; this was true for both women and men. This trend was similar to that reported by Chen et al.[18] and by Zindrick et al.[19], in Chinese volunteers and in their cadaver study, respectively.

In this population sample, the pedicle convergence angle was greater at L5, but these values were lower than those reported by Grivas et al.[20] in a Greek population.

## Conclusion

This study provides a database on pedicle morphometry specific to the Mexican population sample. The mean values obtained will help us to adequately select the diameter of the transpedicular screw required to be applied for each lumbar vertebra. In the population studied, 5.0 mm diameter screws are safe for pedicles of vertebrae L1 and L2, and 5.5 mm screws are safe for placement from L3 to L5 in men. In women, it is safe to use screws with a diameter of 5.0 mm at L4 and L5; while from L1 to L3, the safe diameter is 4.0 mm, with an increase in plastic deformity in these vertebrae.

**Table 5.** Pedicle parameters of L5 vertebra

| Variables | Sex | Mean | SD | Mean difference | p |
|---|---|---|---|---|---|
| Internal cortical pedicle height_r | Men | 6.52 | 4.21 | 1.29 | 0.361 |
| | Women | 5.22 | 3.04 | | |
| Internal cortical pedicle height_l | Men | 6.65 | 5.03 | 1.89 | 0.386 |
| | Women | 4.76 | 3.27 | | |
| External cortical pedicle height_r | Men | 9.65 | 6.56 | 1.16 | 0.153 |
| | Women | 8.49 | 4.31 | | |
| External cortical pedicle height_l | Men | 8.68 | 7.05 | 0.76 | 0.451 |
| | Women | 7.92 | 4.54 | | |
| Internal cortical pedicle width_r | Men | 6.77 | 4.71 | 0.36 | 0.453 |
| | Women | 6.4 | 3.45 | | |
| Internal cortical pedicle width_l | Men | 8.78 | 2.92 | 2.4 | 0.011 |
| | Women | 6.38 | 3.75 | | |
| External cortical pedicle width_r | Men | 10.06 | 5.53 | 0.71 | 0.861 |
| | Women | 9.34 | 5.09 | | |
| External cortical pedicle width_l | Men | 10.02 | 6.01 | –0.07 | 0.524 |
| | Women | 10.1 | 4.38 | | |
| Convergence angle_r | Men | 17.7 | 1.49 | –12.8 | 0.431 |
| | Women | 30.6 | 5.7 | | |
| Convergence angle_l | Men | 19 | 1.53 | –9.5 | 0.706 |
| | Women | 28.5 | 1.31 | | |

A $p < 0.05$ was considered statistically significant.
r: right; l: left; SD: standard deviation; p: probability.

## Funding

The authors declare that they have not received funding.

## Conflicts of interest

J. Loría-Castellanos is a member of the editorial committee of the journal *Anales Médicos*. The other authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** The authors have obtained approval from the Ethics Committee for the analysis of routinely collected and anonymized clinical data; therefore, individual informed consent was not required. Relevant ethical recommendations have been followed.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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# Asociación entre la posición de las glándulas paratiroides y el riesgo de hipocalcemia e hipoparatiroidismo posoperatorios tras la tiroidectomía

## *Association between the location of the parathyroid glands and the risk of postoperative hypocalcemia and hypoparathyroidism following thyroidectomy*

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## Resumen

**Antecedentes:** *La hipocalcemia posoperatoria tras tiroidectomía total se relaciona con lesión, resección inadvertida o desvascularización de las glándulas paratiroides, pero el papel de su posición anatómica respecto a la cápsula tiroidea ha sido poco caracterizado.* **Objetivo:** *Evaluar la asociación entre la posición anatómica de las glándulas paratiroides (intracapsular o extracapsular) y el riesgo de hipocalcemia e hipoparatiroidismo tras la tiroidectomía total.* **Material y métodos:** *Estudio retrospectivo unicéntrico en pacientes sometidos a tiroidectomía total entre 2013 y 2017. Se clasificó a los pacientes según la localización de al menos dos glándulas paratiroides (intracapsular si ≥ 50% de la superficie en contacto con la cápsula tiroidea). Se analizaron las tasas de hipocalcemia e hipoparatiroidismo transitorio, prolongado y permanente. Se usaron OR con IC 95% y un valor de p < 0.05 para la significancia.* **Resultados:** *Se incluyeron 68 pacientes, el 11.8% con glándulas en posición intracapsular. La hipocalcemia fue más frecuente en este grupo (62.5% vs. 16.7%; OR: 4.4; p = 0.009), así como el hipoparatiroidismo transitorio (37.5% vs. 8.3%; OR: 42.7; p < 0.001). No hubo diferencias significativas en hipoparatiroidismo prolongado o permanente.* **Conclusiones:** *La posición intracapsular de las glándulas paratiroides se asocia con mayor riesgo de hipocalcemia e hipoparatiroidismo transitorio posoperatorios. Se sugiere considerar la suplementación profiláctica en estos pacientes.*

***Palabras clave:*** *Hipoparatiroidismo. Tiroidectomía total. Glándulas paratiroides. Hipocalcemia posoperatoria.*

## Abstrac

**Background:** *Postoperative hypocalcemia after total thyroidectomy is associated with injury, inadvertent removal, or devascularization of the parathyroid glands; however, the role of their anatomical position relative to the thyroid capsule remains poorly characterized.* **Objective:** *To evaluate the association between the anatomical position of the parathyroid glands (intracapsular or extracapsular) and the risk of postoperative hypocalcemia and hypoparathyroidism after total thyroidectomy.* **Material and methods:** *A single-center retrospective study including patients who underwent total thyroidectomy between 2013 and 2017. Patients were classified based on the anatomical location of at least two parathyroid glands (intracapsular defined as ≥ 50% of the gland surface in contact with the thyroid capsule). Rates of transient, prolonged, and permanent hypocalcemia and hypoparathyroidism were analyzed. OR with 95% CI were calculated, and p < 0.05 was considered significant.*

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Fecha de recepción: 09-02-2026
Fecha de aceptación: 17-03-2026
DOI: 10.24875/AMH.26000007

Disponible en internet: 24-07-2026
An Med ABC. 2026;71(3):188-195
www.analesmedicosabc.com

**Results:** *A total of 68 patients were included, with 11.8% having glands in an intracapsular position. Hypocalcemia was more frequent in this group (62.5% vs. 16.7%; OR: 4.4; p = 0.009), as was transient hypoparathyroidism (37.5% vs. 8.3%; OR: 42.7; p < 0.001). No significant differences were observed in prolonged or permanent hypoparathyroidism.* **Conclusions:** *Intracapsular location of the parathyroid glands is associated with an increased risk of postoperative hypocalcemia and transient hypoparathyroidism. Prophylactic supplementation should be considered in these patients.*

***Keywords:*** *Hypoparathyroidism. Total thyroidectomy. Parathyroid glands. Postoperative hypocalcemia.*

## Introducción

El hipoparatiroidismo posoperatorio es una de las complicaciones más relevantes tras la tiroidectomía total, con implicaciones clínicas que incluyen hipocalcemia sintomática, requerimientos prolongados de suplementación y, en casos graves, alteraciones neuromusculares crónicas. Su aparición se asocia principalmente con la resección inadvertida, la lesión térmica o la desvascularización de las glándulas paratiroides durante la disección quirúrgica[1,2].

Desde las primeras observaciones anatómicas de Halsted en 1907 se reconoció la importancia de preservar la irrigación paratiroidea mediante la conservación de las ramas terciarias de la arteria tiroidea inferior, íntimamente relacionadas con la cápsula tiroidea[3]. Desde entonces, varios autores han descrito técnicas de disección capsular cuidadosa orientadas a preservar la integridad vascular del tejido paratiroideo y reducir la incidencia de hipoparatiroidismo permanente[4-6]. En este contexto, el uso de magnificación óptica y técnicas microquirúrgicas ha demostrado ser útil para disminuir las tasas de hipocalcemia, paratiroidectomía incidental y lesión del nervio laríngeo recurrente[7-10].

Se ha postulado que la relación anatómica de las glándulas paratiroides con la cápsula tiroidea puede representar un factor de riesgo independiente para el desarrollo de hipoparatiroidismo. En particular, cuando las glándulas se encuentran en parte o totalmente incluidas en la cápsula, su identificación y preservación se ve comprometida, lo cual incrementa el riesgo de daño intraoperatorio[11-13].

El objetivo de este estudio fue analizar la asociación entre la posición anatómica de las glándulas paratiroides respecto a la cápsula tiroidea (posición intracapsular o extracapsular) y la incidencia de hipoparatiroidismo e hipocalcemia posoperatorios en pacientes sometidos a tiroidectomía total.

## Material y métodos

Se llevó a cabo un estudio observacional y retrospectivo utilizando una base de datos elaborada prospectivamente en el servicio de cirugía endocrina del Hospital General de Puebla Eduardo Vázquez Navarro. Se incluyeron pacientes consecutivos sometidos a tiroidectomía total primaria entre enero de 2013 y diciembre de 2017. El protocolo fue aprobado por el Comité de Ética en Investigación institucional.

De un total de 72 pacientes inicialmente identificados, se excluyeron aquellos con disección ganglionar cervical concomitante, antecedentes de hiperparatiroidismo (primario, secundario o terciario), paratiroidectomía incidental o expediente clínico incompleto. La cohorte final estuvo conformada por 68 pacientes.

Durante el procedimiento quirúrgico se documentó la relación anatómica de las glándulas paratiroides con la cápsula tiroidea. Según esta observación, los pacientes fueron clasificados en dos grupos:

- Grupo extracapsular: al menos dos glándulas paratiroides sin contacto aparente con la cápsula tiroidea.
- Grupo intracapsular: al menos dos glándulas con ≥ 50% de su superficie en contacto con la cápsula tiroidea.

Se recolectaron variables demográficas (edad, sexo), clínicas (indicación quirúrgica) y bioquímicas. El seguimiento posoperatorio incluyó la medición de hormona paratiroidea intacta (PTHi) a las 6 horas y de calcio sérico ajustado por albúmina a las 24 horas, 1 mes, 3 meses y 12 meses. También se evaluaron los síntomas clínicos de hipocalcemia y el requerimiento de tratamiento sustitutivo.

Las definiciones operativas fueron:

- Hipocalcemia posoperatoria: calcio ajustado < 8.0 mg/dl.
- Hipoparatiroidismo transitorio: calcio < 8.0 mg/dl y PTHi < 13 pg/ml dentro de las primeras 24 horas.
- Hipoparatiroidismo prolongado: persistencia de PTHi < 13 pg/ml o necesidad de suplementación entre el primer y el duodécimo meses tras la operación.
- Hipoparatiroidismo permanente: PTHi < 13 pg/ml o necesidad de suplemento a los 12 meses.

Todos los pacientes recibieron suplementación profiláctica desde las primeras 12 horas posoperatorias. En el grupo intracapsular se administraron carbonato de calcio (2.0-3.0 g/día) y calcitriol (0.75 μg/día), mientras

que en el grupo extracapsular solo se indicó carbonato de calcio (500 mg/día a 1.5 g/día).

El análisis estadístico se realizó principalmente con R (versión 4.3.1, R Core Team), utilizando RStudio como entorno de desarrollo y los paquetes tidyverse, ggplot2, dplyr, stats y finalfit. Se aplicaron pruebas de normalidad (Shapiro-Wilk), análisis de asimetría y curtosis para evaluar la distribución de las variables continuas. Las comparaciones entre grupos se realizaron mediante la prueba t de Student o la prueba U de Mann-Whitney, según correspondiera. Las variables categóricas se analizaron con la prueba $\chi^2$ de Pearson o la prueba exacta de Fisher.

Se calcularon las razones de momios (OR, *odds ratio*) con intervalos de confianza del 95% (IC 95%) para estimar la fuerza de la asociación entre la localización paratiroidea y las complicaciones posoperatorias. Se consideró significancia estadística un valor de $p \leq 0.05$ (bilateral). Para algunas visualizaciones complementarias y validación cruzada se emplearon SPSS versión 24.0 y Python 3.11.

## Resultados

### Características generales de la cohorte

Se analizaron 68 pacientes sometidos a tiroidectomía total, con una edad mediana de 43 años (rango intercuartílico: 33-57). La cohorte estuvo compuesta por 67 mujeres (98.5%) y 1 hombre (1.5%). Las indicaciones quirúrgicas más frecuentes fueron bocio o hiperplasia tiroidea (n = 36; 52.9%), enfermedad de Hashimoto (n = 7; 10.3%), carcinoma papilar clásico (n = 6; 8.8%), carcinoma papilar mixto (n = 4; 5.9%) y otros diagnósticos menos frecuentes. En 9 casos (13.2%) no se documentó el diagnóstico definitivo.

Tras excluir a 4 pacientes con datos faltantes o no aplicables sobre la posición anatómica de las glándulas paratiroides, se analizaron únicamente aquellos con información válida. La ubicación fue extracapsular en 44 casos (64.7%), mixta en 16 (23.5%) e intracapsular en 8 (11.8%); para el análisis comparativo, los casos con localización mixta se agruparon con los extracapsulares. Las características clínicas y demográficas se presentan en la tabla 1.

**Tabla 1.** Características clínicas y demográficas de los pacientes sometidos a tiroidectomía total

| Variable | n (%) |
|---|---|
| Edad (años), mediana | 43 (RIC: 33-57) |
| Sexo femenino | 67 (98.5%) |
| Sexo masculino | 1 (1.5%) |
| Bocio/hiperplasia tiroidea | 36 (52.9%) |
| Hashimoto | 7 (10.3%) |
| Carcinoma papilar clásico | 6 (8.8%) |
| Carcinoma papilar mixto | 4 (5.9%) |
| No especificado | 9 (13.2%) |
| Grupo extracapsular (incluye mixto) | 60 (88.2%) |
| Grupo intracapsular | 8 (11.8%) |

RIC: rango intercuartílico.

### Incidencia de complicaciones posoperatorias

Se identificó hipocalcemia posoperatoria en 15 pacientes (22.1%), siendo más frecuente en el grupo intracapsular (62.5%) que en el extracapsular (16.7%). El hipoparatiroidismo transitorio se presentó en 8 pacientes (11.8%), con mayor incidencia en el grupo intracapsular (37.5% vs. 8.3%). El hipoparatiroidismo prolongado se observó en 7 casos (10.3%), predominando también en el grupo intracapsular (25.0% vs. 8.3%). Finalmente, dos pacientes desarrollaron hipoparatiroidismo permanente (2.9%), uno en cada grupo (12.5% intracapsular y 1.7% extracapsular). Estos resultados se detallan en la tabla 2, que muestra las frecuencias absoluta y relativa de cada complicación según la localización paratiroidea.

### Comparación de parámetros bioquímicos posoperatorios

Con el objetivo de evaluar si la posición anatómica de las glándulas paratiroides influye en la función paratiroidea y en los niveles de calcio posoperatorios, se compararon los desenlaces bioquímicos entre pacientes con glándulas predominantemente extracapsulares o intracapsulares.

Se analizaron los niveles de calcio ajustado por albúmina y PTHi en distintos momentos del seguimiento posoperatorio. Previamente, se evaluó la normalidad de la distribución mediante la prueba de Shapiro-Wilk, la cual mostró que la mayoría de las variables tenían una distribución normal, excepto el calcio a 1 mes, para el que se identificó una distribución no normal ($p < 0.05$). En función de estos hallazgos, se aplicó la prueba t de Student o la prueba U de Mann-Whitney, según correspondiera.

**Tabla 2.** Frecuencia de complicaciones hipocalcémicas posoperatorias según la localización anatómica de las glándulas paratiroides

| Desenlace | Extracapsular, n (%) | Intracapsular, n (%) |
|---|---|---|
| Hipocalcemia 24 horas | 10 (16.7) | 5 (62.5) |
| Hipoparatiroidismo transitorio | 5 (8.3) | 3 (37.5) |
| Hipoparatiroidismo prolongado | 5 (8.3) | 2 (25.0) |
| Hipoparatiroidismo permanente | 1 (1.7) | 1 (12.5) |

A las 24 horas, el calcio ajustado fue significativamente mayor en el grupo extracapsular (8.36 ± 0.51 mg/dl) que en el intracapsular (7.60 ± 0.69 mg/dl; p = 0.0265). La PTHi a las 6 horas también fue más alta en el grupo extracapsular (30.2 ± 19.6 vs. 8.8 ± 7.1 pg/ml; p = 0.0001).

Durante el seguimiento no se observaron diferencias significativas en el calcio a 1 y 3 meses; a los 12 meses se encontró una diferencia a favor del grupo intracapsular (p = 0.0453). En la PTHi no hubo diferencias a 1 mes (p = 0.0822), pero sí a los 3 meses (p < 0.0001), con valores superiores en el grupo extracapsular; la comparación a 12 meses no fue posible por datos incompletos del grupo intracapsular. Los detalles se presentan en la tabla 3.

Estos hallazgos se visualizan en la evolución longitudinal de los niveles de calcio y PTHi en las figuras 1 y 2, respectivamente.

## *Análisis de asociaciones y regresión logística*

Con el objetivo de identificar asociaciones entre la localización anatómica de las glándulas paratiroides y el desarrollo de complicaciones posoperatorias se calcularon las OR para los principales desenlaces clínicos. La hipocalcemia fue significativamente más frecuente en el grupo intracapsular (OR: 4.40; IC 95%: 1.38-13.96; p = 0.009), al igual que el hipoparatiroidismo transitorio (OR: 42.67; IC 95%: 4.80-373.63; p < 0.001). Aunque se observaron tendencias hacia un mayor riesgo de hipoparatiroidismo prolongado y permanente, estas no alcanzaron significancia estadística (OR: 6.33 y ∞; p = 0.159 y 0.355, respectivamente). Para facilitar la interpretación visual de estas asociaciones se realizó un *forest plot* que resume gráficamente las OR y los IC 95% para cada desenlace (Fig. 3). Además, se llevó a cabo un análisis de regresión logística binaria para evaluar específicamente la asociación entre la localización paratiroidea y el riesgo de hipoparatiroidismo transitorio. La localización intracapsular se asoció significativamente con un mayor riesgo de hipoparatiroidismo transitorio (OR: 6.6; IC 95%: 1.21-36.11; p = 0.029), incluso tras ajustar por el resto de la cohorte. Los hallazgos se resumen en la tabla 4.

**Tabla 3.** Comparación de los parámetros bioquímicos posoperatorios de los pacientes con glándulas paratiroides en localización extracapsular e intracapsular

| Variable | Extracapsular, media ± DE | Intracapsular, media ± DE | p |
|---|---|---|---|
| Calcio ajustado 24 horas | 8.36 ± 0.51 | 7.60 ± 0.69 | 0.0265 |
| PTHi 6 horas | 30.20 ± 19.63 | 8.78 ± 7.11 | 0.0001 |
| Calcio ajustado 1 mes | 9.19 ± 0.51 | 10.38 ± 3.09 | 0.4991 |
| Calcio ajustado 3 meses | 9.08 ± 0.63 | 8.84 ± 0.51 | 0.5127 |
| Calcio ajustado 12 meses | 9.08 ± 0.53 | 9.45 ± 0.08 | 0.0453 |
| PTHi 1 mes | 35.36 ± 19.52 | 22.10 ± 23.42 | 0.3447 |
| PTHi 3 meses | 36.73 ± 19.55 | 12.60 ± 5.00 | 0.0000 |

DE: desviación estándar; PTHi: hormona paratiroidea intacta.

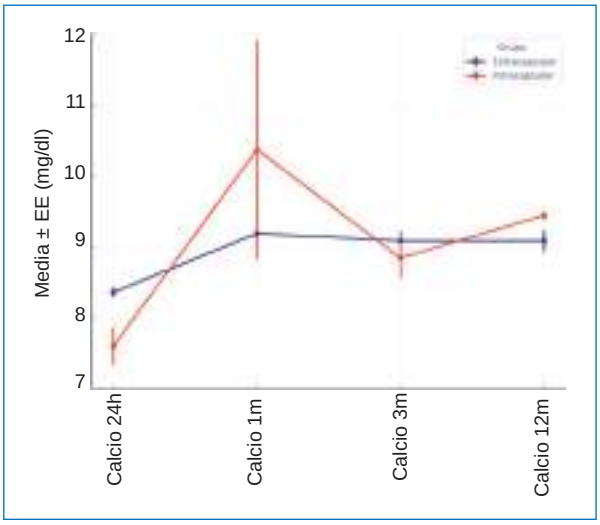


**Figura 1.** Evolución del calcio sérico ajustado (media ± error estándar [EE]) en pacientes sometidos a tiroidectomía total, comparando los grupos con glándulas paratiroideas extracapsulares e intracapsulares en cuatro momentos posoperatorios: 24 horas, 1 mes, 3 meses y 12 meses. Se observa un patrón de recuperación más sostenido en el grupo extracapsular.

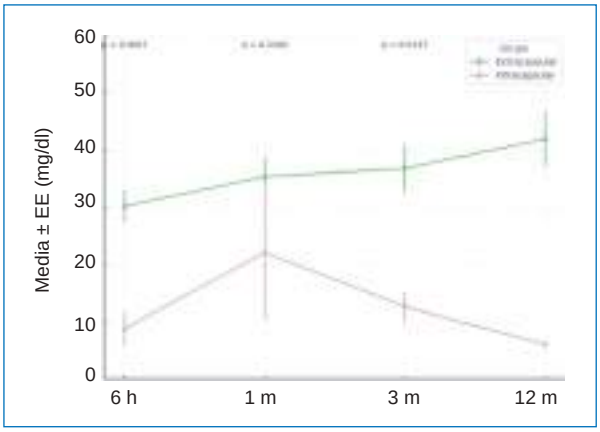


**Figura 2.** Evolución de los niveles de hormona paratiroidea intacta (media ± error estándar [EE]) en pacientes sometidos a tiroidectomía total. Se comparan los grupos según la localización anatómica de las glándulas paratiroides: extracapsular o intracapsular. Los valores de p corresponden a la comparación entre grupos en cada momento mediante la prueba U de Mann-Whitney.

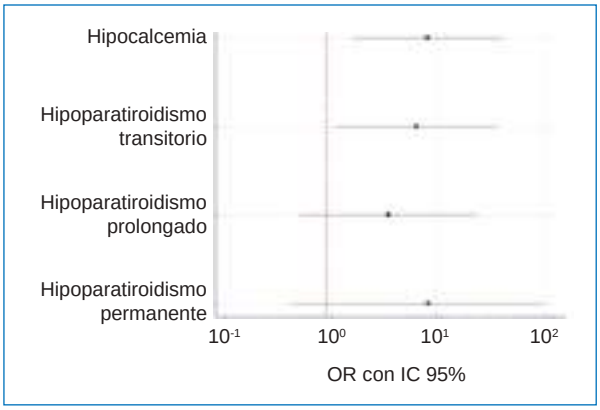


**Figura 3.** *Forest plot* que representa la asociación entre la localización anatómica de las glándulas paratiroides (intracapsular o extracapsular) y la aparición de complicaciones posoperatorias tras la tiroidectomía total. Se muestran las *odds ratios* (OR) con sus intervalos de confianza al 95% (IC 95%) para hipocalcemia e hipoparatiroidismo transitorio, prolongado y permanente. La línea roja vertical indica el valor nulo (OR: 1). Una OR > 1 sugiere mayor riesgo asociado a la localización intracapsular.

### *Subanálisis por diagnóstico histopatológico*

En el subanálisis según el diagnóstico definitivo no se encontró una asociación significativa entre la presencia de enfermedad tiroidea maligna y el desarrollo de hipoparatiroidismo transitorio (OR: 1.0; p = 1.00). Tampoco se observó una relación estadísticamente significativa con la presencia de tiroiditis de Hashimoto (OR: ≈ 2.17; p = 0.33). Estos resultados sugieren que la etiología tiroidea no fue un factor determinante en la aparición de disfunción paratiroidea transitoria.

**Tabla 4.** Asociación entre la localización anatómica de las glándulas paratiroides y las complicaciones posoperatorias

| Complicación | OR | IC 95% | p |
|---|---|---|---|
| Hipocalcemia | 4.4 | 1.38-13.96 | 0.009 |
| Hipoparatiroidismo transitorio | 42.67 | 4.80-373.63 | < 0.001 |
| Hipoparatiroidismo prolongado | 6.33 | 0.49-82.51 | 0.159 |
| Hipoparatiroidismo permanente | ∞ | 0.17-∞ | 0.355 |

IC 95%: intervalo de confianza del 95%; OR: *odds ratio.*

## Discusión

La hipocalcemia y el hipoparatiroidismo posoperatorios siguen siendo las complicaciones más frecuentes tras la tiroidectomía total y representan una carga clínica relevante por síntomas, reingresos, prolongación de la estancia y seguimiento bioquímico, con una variabilidad importante entre centros aun en la era de la estandarización perioperatoria[13]. Para la comunidad de cirujanos endocrinos, el problema resulta especialmente sensible porque el desenlace no depende solo de identificar las paratiroides, sino de preservar su perfusión: pequeñas diferencias anatómicas y la fragilidad del patrón vascular paratiroideo durante la disección pueden traducirse en disfunción bioquímica y clínica incluso si la glándula se conserva de forma macroscópica[14]. Además, la evolución de los cuadros prolongados tiene impacto clínico sostenido y refuerza la necesidad de prevención y seguimiento estructurado[15]. La evidencia sobre predictores de hipocalcemia postiroidectomía apoya un modelo multifactorial en el que convergen técnica, anatomía y riesgo basal[16]. En paralelo, las estrategias farmacológicas, como el calcitriol, pueden reducir la hipocalcemia sintomática en pacientes seleccionados, aunque no sustituyen la preservación vascular como determinante primario del desenlace[17].

La evidencia contemporánea coincide en que las estrategias orientadas a la preservación vascular, incluida la disección capsular cuidadosa con respeto

de ramas terciarias, son cruciales para reducir el riesgo, pero su efectividad puede depender de la relación cápsula-paratiroides y del fenotipo anatómico de la glándula[14]. En paralelo, los estudios prospectivos en escenarios de alto riesgo, como la disección central, han mostrado que una estrategia activa de identificación y preservación vascular reduce de manera sustancial el hipoparatiroidismo transitorio, y en menor magnitud el permanente, lo que apoya que el determinante clave es la integridad del pedículo vascular más que la mera visualización de la glándula[18]. En este contexto, nuestros hallazgos aportan valor práctico al proponer que la localización intracapsular es un marcador anatómico simple de mayor vulnerabilidad, útil para anticipar el riesgo y ajustar la estrategia quirúrgica y la vigilancia posoperatoria.

En el presente estudio se observó que la localización intracapsular de las glándulas paratiroides se asoció con una mayor incidencia de hipocalcemia e hipoparatiroidismo posoperatorios en comparación con la localización extracapsular. Este hallazgo refuerza la hipótesis de que la relación anatómica entre la cápsula tiroidea y el tejido paratiroideo influye de manera significativa en la preservación funcional de las glándulas durante la tiroidectomía total.

Diversos autores han demostrado que la disección capsular cuidadosa representa una estrategia eficaz para preservar las glándulas paratiroides tanto superiores como inferiores, favoreciendo la conservación de su irrigación a través de las ramas vasculares terciarias de la arteria tiroidea inferior[3,19]. Cuando las glándulas se encuentran parcialmente incluidas en la cápsula tiroidea, en posición intracapsular o intratiroidea, su identificación se ve comprometida, lo cual incrementa el riesgo de paratiroidectomía incidental y disfunción posoperatoria[20,21]. Los estudios retrospectivos de gran tamaño han descrito técnicas quirúrgicas orientadas a la preservación vascular del tejido paratiroideo, logrando una reducción significativa en las tasas de hipocalcemia e hipoparatiroidismo mediante la conservación sistemática de las ramas capsulares posteriores[14,15].

En una cohorte de 1411 pacientes sometidos a tiroidectomía por enfermedades benignas y malignas, la aplicación de una técnica de preservación vascular en bloque permitió reducir de manera significativa las tasas de hipoparatiroidismo transitorio y permanente[22]. De forma similar, un estudio prospectivo realizado en la Universidad Médica de Nanjing reportó que el uso de una estrategia activa de identificación y preservación vascular de glándulas intracapsulares durante la disección central en pacientes con cáncer papilar de tiroides redujo la incidencia de hipoparatiroidismo transitorio del 32.6% al 8.3% ($p < 0.001$), y la de hipoparatiroidismo permanente del 8.8% al 1.0% ($p = 0.017$)[18].

Estos hallazgos, en conjunto con los resultados de nuestra cohorte, sugieren la existencia de variaciones anatómicas en el patrón vascular de las glándulas paratiroides que aún no han sido completamente caracterizadas. En particular, la vascularización de las glándulas intracapsulares parece más vulnerable durante la disección quirúrgica, lo que incrementa el riesgo de lesión inadvertida y disfunción posoperatoria.

La preservación *in situ* del tejido paratiroideo ha sido reconocida desde hace décadas como un factor clave en la prevención de la hipocalcemia posoperatoria[2]. La caída abrupta de los niveles séricos de PTH tras la tiroidectomía refleja una disfunción aguda del tejido paratiroideo, usualmente transitoria, asociada con una manipulación directa o una desvascularización intraoperatoria. Varios estudios han demostrado que la preservación efectiva de las glándulas se correlaciona con menores tasas de hipoparatiroidismo transitorio y permanente[13,15,19]. No obstante, la preservación anatómica no garantiza necesariamente la conservación funcional, y se han documentado casos en los que glándulas con aspecto indemne resultan no funcionales durante el seguimiento[13,20].

Por otro lado, algunos autores han planteado que la identificación sistemática de todas las glándulas puede incrementar el riesgo de daño vascular. Un estudio prospectivo mostró que los pacientes en los que se identificaron menos de tres glándulas presentaron menores tasas de hipocalcemia posoperatoria en comparación con aquellos en los que se identificaron tres o más glándulas (3.2% vs. 17.1%; $p = 0.02$)[23]. En esta línea, Song et al.[24] señalaron que la preservación sistemática de las cuatro glándulas afecta principalmente al riesgo de hipocalcemia transitoria, sin un impacto claro en la incidencia de la forma permanente, salvo en casos en que se realiza autotrasplante.

En nuestra cohorte se empleó sistemáticamente magnificación con lupas binoculares para la identificación intraoperatoria del tejido paratiroideo, junto con disección capsular meticulosa asistida por bisturí bipolar, lo que permitió preservar grandes pedículos vasculares en bloque. A pesar de estas medidas, un paciente del grupo intracapsular con diagnóstico de tiroiditis de Hashimoto desarrolló hipoparatiroidismo prolongado, pero con recuperación funcional completa a los 18 meses.

La estratificación pronóstica del hipoparatiroidismo prolongado puede apoyarse en marcadores bioquímicos tardíos. Sitges-Serra et al.[25] propusieron un nomograma basado en el calcio sérico y la PTHi a 1 mes para estimar la probabilidad de recuperación o de hipoparatiroidismo permanente, con utilidad operativa para orientar la vigilancia y la suplementación en pacientes bajo terapia de reemplazo. A diferencia de ese enfoque, que predice la recuperación una vez establecido el cuadro bioquímico tardío, nuestro trabajo se centra en un marcador anatómico intraoperatorio, la localización intracapsular, como señal temprana de vulnerabilidad que permite anticipar el riesgo y ajustar la técnica quirúrgica y el seguimiento desde el posoperatorio inmediato.

Estos hallazgos refuerzan la relevancia de la anatomía individual en la irrigación del tejido paratiroideo y sugieren que ciertos patrones de crecimiento tiroideo pueden influir en el riesgo de disfunción posquirúrgica. La localización intracapsular, en particular, parece asociarse con mayor riesgo de paratiroidectomía incidental, niveles más bajos de calcio y de PTH posoperatorios, y una recuperación más lenta de la función paratiroidea tras la tiroidectomía total.

Este estudio presenta algunas limitaciones que deben considerarse al interpretar los resultados. En primer lugar, su diseño retrospectivo implica un riesgo inherente de sesgo de selección y dependencia de la calidad del registro clínico. Aunque se utilizó una base de datos elaborada prospectivamente, no fue posible controlar de manera uniforme todas las variables operatorias y de seguimiento. En segundo lugar, el tamaño muestral relativamente pequeño limita la potencia estadística para detectar diferencias en desenlaces menos frecuentes, como el hipoparatiroidismo permanente, y puede haber sobreestimado las OR en algunas comparaciones. Finalmente, la clasificación de la localización paratiroidea se basó en observaciones intraoperatorias del equipo quirúrgico, lo cual introduce un componente subjetivo que podría afectar la consistencia del agrupamiento. A pesar de estas limitaciones, los hallazgos aportan evidencia relevante sobre el papel de la relación anatómica en la función paratiroidea posoperatoria.

## Conclusiones

Este estudio propone una clasificación práctica del riesgo de disfunción paratiroidea basada en la relación anatómica de las glándulas con la cápsula tiroidea, estableciendo al grupo intracapsular como una población con mayor riesgo de hipocalcemia e hipoparatiroidismo transitorio tras la tiroidectomía total. La identificación cuidadosa del tejido paratiroideo y la disección meticulosa asistida por magnificación pueden favorecer la preservación de su irrigación y reducir las complicaciones posoperatorias. Aunque no se observaron diferencias significativas en la incidencia de hipoparatiroidismo prolongado o permanente entre los grupos, recomendamos considerar medidas profilácticas específicas, como la administración temprana de calcio y de vitamina D, en los pacientes con las glándulas paratiroides en posición intracapsular para facilitar la recuperación de la función paratiroidea y prevenir los síntomas clínicos asociados.

## Financiamiento

Los autores declaran no haber recibido financiamiento para este estudio.

## Conflicto de intereses

Los autores declaran no tener conflicto de intereses.

## Consideraciones éticas

**Protección de personas y animales.** Los autores declaran que para esta investigación no se han realizado experimentos en seres humanos ni en animales.

**Confidencialidad, consentimiento informado y aprobación ética.** Los autores han obtenido la aprobación del Comité de Ética para el análisis de datos clínicos obtenidos de forma rutinaria y anonimizados. Debido a la naturaleza del estudio, no fue necesario el consentimiento informado individual. Se han seguido las recomendaciones éticas pertinentes.

**Declaración sobre el uso de inteligencia artificial.** Los autores declaran que no se utilizó ningún tipo de inteligencia artificial generativa para la redacción ni la creación de contenido de este manuscrito.

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ORIGINAL ARTICLE

# Immersive learning in medical education

## *El aprendizaje inmersivo en la formación médica*

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## Abstract

**Background:** *In the past, learning was acquired through direct experience. However, due to a changing world, such learning began to be acquired in increasingly abstract ways. Today, immersive technologies represent the opportunity to reconnect learning with experience through various innovative tools, which have had an impact on health education.* **Objective:** *To conduct a review to identify the most relevant benefits and limitations of immersive technologies in the field of health education, and to provide clear recommendations for their implementation in future academic programs.* **Material and methods:** *A comprehensive search of articles was conducted in PubMed, Cochrane, and Epistemonikos databases. Nine relevant articles were identified and analyzed by the reviewers to determine similarities and differences among them.* **Results:** *Multiple articles highlight immersive technologies' benefits, such as: 40% improvement in the acquisition of surgical skills, improvements in the theoretical teaching of abstract topics, which benefit from the application of 3D technologies, as well as, a positive impact student motivation, confidence, self-satisfaction, in addition to improving the accessibility of education in underserved areas.* **Conclusions:** *Immersive technologies positively impact medical education. Their implementation faces multiple barriers, but formally introducing them into medical education programs represents the first step toward obtaining future benefits for patients.*

***Keywords:*** *Immersive learning. Medical education. Virtual reality. Augmented reality.*

## Resumen

**Antecedentes:** *En el pasado, el aprendizaje se adquiría con la experiencia directa. Sin embargo, un mundo cambiante hizo que el aprendizaje fuera adquirido de manera abstracta. Actualmente, las tecnologías inmersivas representan la oportunidad de reconectar aprendizaje y experiencia mediante herramientas innovadoras que impactan la educación en salud.* **Objetivo:** *Identificar beneficios y limitaciones relevantes de las tecnologías inmersivas en educación en salud, proporcionando recomendaciones para su implementación en futuros programas académicos.* **Material y métodos:** *Se realizó una búsqueda exhaustiva de artículos en bases de datos PubMed, Cochrane y Epistemonikos. Nueve artículos relevantes fueron identificados y analizados por los revisores para determinar similitudes y diferencias entre ellos.* **Resultados:** *Múltiples artículos destacan los beneficios de las tecnologías inmersivas, como: mejora del 40% en la adquisición de habilidades quirúrgicas; mejoras en la enseñanza teórica de temas abstractos, que se benefician de tecnologías 3D; y un impacto positivo en motivación estudiantil, confianza y autosatisfacción, además de mejorar la accesibilidad educativa en áreas desatendidas.* **Conclusiones:** *Las tecnologías inmersivas tienen un impacto positivo en la educación médica. Su implementación enfrenta múltiples barreras, pero su introducción formal en los programas de educación médica representa el primer paso hacia la obtención de beneficios futuros para los pacientes.*

***Palabras clave:*** *Aprendizaje inmersivo. Educación médica. Realidad virtual. Realidad aumentada.*

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Date of reception: 01-02-2026
Date of acceptance: 20-03-2026
DOI: 10.24875/AMH.M26000153

Available online: 24-07-2026
An Med ABC. 2026;71(3):196-201
www.analesmedicosabc.com

## Introduction

Since the beginning of humanity, human learning has been widely related to direct experience, which means knowledge was acquired through observation, imitation, and practice. However, over time, the advancement and development of civilization created the need for knowledge to be distributed more efficiently and, therefore, for learning to be transmitted in a more rapid manner. Thus, learning became detached from its physical context and direct experience, leading to the transmission of knowledge through storytelling, poetry, theatrical works, and later through writing, printed media, and abstract academic formats[1]. These new methods of transmitting knowledge demonstrated several advantages, therefore, learning continued to move away from contextual experience over time. Nevertheless, these new learning methods did not necessarily represent the most effective way to acquire knowledge, especially when seen from the perspective of human nature, which highlights the importance of experiential, contextual, and interactive elements.

In recent decades, significant advances in communication technologies, computing, and artificial intelligence (AI) have created an innovative opportunity for learning to recover what it once lost: experience. These technologies have demonstrated the advantage of reintroducing the experiential dimension into learning without compromising safety, accuracy, or effectiveness. Among the digital tools that stand out most prominently in the field of education are the metaverse, virtual reality (VR), augmented reality (AR), immersive classrooms, holograms, and AI[2]. These concepts are frequently used incorrectly in everyday contexts; therefore, they are defined in this article, emphasizing their similarities and differences.

VR is defined as a technological system based on computer tools capable of generating three-dimensional digital environments that represent real or fictional settings, in which the user can experience varying levels of immersion depending on the sensory stimuli provided and the availability of specialized devices (three-dimensional headsets, headphones, haptic gloves, etc.)[3].

AR is a technological system that integrates digital elements into the physical environment, enabling simultaneous interaction between the real world and computer-generated virtual objects. Similar to VR, this technology depends on the availability of specialized devices such as smartphones, tablets, cameras, or smart glasses that project information or three-dimensional models onto the tangible space. These technologies allow users to visualize, in real time, virtual content superimposed on their immediate surroundings, thereby expanding perception and facilitating new forms of experiential learning[3].

AI is a concept coined by John McCarthy in 1955, who defined it as "the science and engineering of making intelligent machines." With current technological advances, AI is defined as technological systems that employ advanced computational resources to develop methods, algorithms, and applications capable of simulating, extending, enhancing, and optimizing cognitive processes similar to those of human intelligence. These technologies have evolved rapidly and currently play an important role across diverse professional fields[4].

The implementation of these technologies in educational settings has increased in recent years and accelerated following the 2020 pandemic. This has led to the development of immersive classrooms, which are innovative educational spaces that integrate and utilize VR and AR to create digital learning environments that allow students to explore complex concepts in an active and practical manner. These classrooms enhance interaction between educators and students by reconnecting learning with direct experience[5].

## Material and methods

An umbrella review was conducted with the aim of synthesizing the available evidence from systematic reviews and meta-analyses regarding the use of immersive technologies in medical education. A comprehensive search was performed in PubMed, the Cochrane Database of Systematic Reviews, and Epistemonikos. MeSH terms were used, including: ("immersive learning" OR "immersive teaching" OR "immersive classrooms" OR "virtual reality" OR "augmented reality") AND ("medical education"), as well as their English translations. This search yielded a total of 77 articles, which were subsequently screened to include only those focused on the application of immersive technologies in medical education in general. After the screening process was completed, nine relevant articles were identified and comparatively analyzed in order to determine the main similarities and differences regarding the benefits and limitations of these technologies.

## Results

Immersive technologies represent a major innovation in the field of medical education. Although these

technologies have been implemented and their benefits and limitations reported by various authors, it is essential to evaluate their applications in a systematic and comparative manner in order to identify the most consistently reported advantages and drawbacks and subsequently provide relevant recommendations for their implementation in medical education overall. This section outlines the main benefits and limitations reported by the most relevant articles in the field of medical education.

Barteir et al.[6] explore the application of head-mounted devices (HMDs) in medical education. They highlight their capacity to create complex, detailed, and reproducible simulations that positively impact medical training, particularly in surgery and ophthalmology. The authors identify multiple advantages of immersive technologies in medical education, including a reduction in procedural errors and emotional benefits such as decreased stress and increased confidence and motivation. They also mention the positive impact on educational accessibility in low-resource countries. Reported disadvantages include adverse health effects such as nausea, as well as current technical limitations and the oversimplification of immersive technologies in highly complex procedures[6].

Ryan et al.[7] focus on the application of VR, AR, and mixed reality technologies. These technologies are reported to be more effective than traditional education due to their positive impact on knowledge acquisition and retention. Benefits for clinical practice are also emphasized, as these tools allow for increased practice opportunities by creating safe and repeatable scenarios, as well as innovative 3D environments that enhance learning in areas such as anatomy and embryology. In addition, improvements in students' mindset are highlighted, particularly increased self-satisfaction and enhanced educational engagement. However, limitations in current research are noted, including methodological heterogeneity and a lack of validity due to the absence of standardized scales for the objective evaluation of immersive technologies[7].

Tene et al.[8] demonstrate that the application of immersive technologies in the medical field has led to multiple advantages, including hands-on learning through realistic, safe, and flexible scenarios. The authors also note that their effectiveness has been more clearly demonstrated in theoretical areas, particularly anatomy, resulting in increased student motivation. Regarding limitations, the study underscores the importance of designing a solid pedagogical framework and establishing evaluation criteria to ensure the appropriate use of these technologies in medical education. It also highlights the need for further research and consideration of economic and logistical barriers to implementation[8].

Kim and Kim[9] report that VR can enhance both skills and knowledge in educational settings by promoting greater student autonomy and self-directed learning. Furthermore, its use contributes to reducing the anxiety commonly experienced during academic training. However, due to methodological variability and the lack of standardized measurement instruments, the findings are not statistically significant, limiting the strength of the conclusions[9].

Khakpaki[10] evaluated the application of immersive technologies (VR, chatbots, adaptive platforms, etc.) and highlighted positive effects on physicians' technical and cognitive skills, particularly in the surgical field, where a 40% improvement in procedural success was reported. AI also demonstrated benefits, including more objective assessments, rapid feedback, and autonomous learning. Nevertheless, limitations persist, such as high implementation costs and restricted access to the necessary infrastructure and resources[10].

Tudor et al.[11] report that the use of VR, AR, and mixed reality improves practical and clinical skills in 97% and 100% of cases, respectively, as well as theoretical knowledge acquisition in 80% of cases. Additional benefits include increased student engagement and participation, as well as improved objectivity and efficiency in assessments. However, current studies primarily evaluate short-term learning outcomes, present methodological heterogeneity, and lack validation, limiting reproducibility, cross-study comparability, and the credibility of reported findings[11].

Pedram et al.[12] indicate that the use of VR and HMDs enables the creation of virtual scenarios that would be impossible to replicate in real life, which is particularly valuable for emergency training and clinical procedures. These technologies positively impact technical skills, teamwork, leadership, and communication, and contribute to long-term patient safety improvements. Nonetheless, limitations include the absence of long-term studies, insufficient haptic feedback, low visual quality, user health concerns (dizziness and visual fatigue), high implementation costs, lack of specialized technical support, and the absence of curricular standardization in educational institutions[12].

Siddiqui et al.[13] report that VR, AR, and mixed reality increase student motivation and engagement, reduce errors and procedural times in surgical settings, and facilitate the visualization of 3D structures, positively impacting the learning of abstract concepts such as anatomy.

Additional benefits include improved accessibility to education in underserved regions. However, these technologies face limitations such as high hardware and software costs, the need for high-speed internet, adverse physical effects (nausea, headaches, and cognitive overload), and a lack of standardization and global representation in current studies. Therefore, replacing traditional methods exclusively with these technologies does not appear to provide additional benefit in medical education[13].

Kalantari et al.[14] identify that the integration of AI, VR, and AR in medical education enhances practical skill development and knowledge acquisition, reduces errors, improves procedural efficiency, and increases student engagement and motivation. However, the author acknowledges limitations such as an excessive focus on psychomotor skills at the expense of theoretical knowledge acquisition, a lack of evidence regarding skill transfer to real-world settings and patient outcomes, and the need for systemic integration of these technologies into clinical curricula to assess their large-scale impact[14].

## Discussion

After analyzing the nine selected articles, it becomes evident that most authors reach a consensus regarding the benefits of implementing immersive technologies in medical education. Similarly, there is agreement concerning current limitations and areas of opportunity for their practical implementation.

### *Benefits of immersive technologies in medical education*

Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Kim and Kim,[9] Tudor et al.,[11] Pedram et al.,[12] Siddiqui et al.,[13] and Kalantarion et al.[14] agree that the use of immersive technologies is particularly valuable for the development of practical and surgical skills. This is because these technologies enable the creation of immersive scenarios that allow for repetitive, safe, and controlled practice of both basic and complex clinical procedures. Following their implementation in this context, objective benefits have been identified, including a marked reduction in user errors, as well as a significant decrease in the time required to complete practiced procedures. In addition, objective improvements include increased participation, heightened interest, and greater confidence among users when performing procedures and interacting with real patients. Specifically, Tudor et al.[11] report improvements in practical and clinical skills in 97% and 100% of the cases addressed, respectively. Likewise, Khakpaki[10] highlights that VR can increase surgical procedure success rates by 40%.

Similarly, Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Tudor et al.,[11] Siddiqui et al.,[13] and Kalantarion et al.[14] present comparable findings regarding the acquisition and retention of theoretical knowledge. They identify that immersive technologies are not only beneficial for the development of practical skills but also for learning theoretical content, particularly in areas that benefit from 3D visualization, such as anatomy and embryology[1-9]. Specifically, Tudor et al.[11] quantify this improvement, reporting enhanced theoretical knowledge acquisition in 80% of the studied cases.

Another widely recognized benefit is the impact on student motivation and engagement. Additionally, Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Kim and Kim,[9] Tudor et al.,[11] and Siddiqui et al.[13] identify benefits that extend to students' psychological domains. They report that immersive technologies create learning environments that are more interactive, engaging, and dynamic than traditional methods, positively influencing motivation, interest, engagement, and student satisfaction. Furthermore, Khakpaki[10] and Pedram et al.[12] emphasize that such scenarios foster the development of communication, leadership, and teamwork skills, which are essential for physicians. Benefits are also observed in assessment processes, as Khakpaki[10] and Tudor et al.[11] indicate that AI has the potential to enable more objective evaluations and improve grading efficiency.

These technologies also offer benefits beyond the classroom. Tene et al.[8] and Siddiqui et al.[13] highlight their social potential to standardize education and improve accessibility in remote, underserved, and marginalized regions.

### *Limitations and challenges of immersive technologies in medical education*

The primary limitation identified across most articles is the heterogeneity of studies and the lack of standardized measurement instruments and validated indicators. Ryan et al.,[7] Kim and Kim,[9] Tudor et al.,[11] Pedram et al.,[12] and Siddiqui et al.[13] agree that this significantly reduces the credibility and validity of findings, limiting researchers' and educators' ability to objectively compare results across studies.

In addition, Tudor et al.[11] and Pedram et al.[12] note that current studies focus almost exclusively on short-term learning outcomes, largely omitting long-term evaluation.

This represents a significant bias, as demonstrating superiority over traditional learning methods requires long-term studies assessing skill retention and effective transfer to real clinical settings, an area that remains insufficiently explored. Furthermore, Kalantarion et al.[14] indicate that no studies have evaluated the ultimate objective of these technologies, including behavioral changes in real workplace environments or direct improvements in patient health following immersive technology-based education.

From a technological perspective, Pedram et al.[12] identify current technical limitations, including low visual quality and insufficient haptic feedback, which restrict the realism necessary for clinical scenarios. This directly affects the validity of simulations, particularly in surgical settings where realism and immediate feedback are critical for learning[7].

Regarding health considerations, Barteir et al.,[6] Pedram et al.,[12] and Siddiqui et al.[13] report that immersive technologies, especially when using HMDs, are not without risk and may produce adverse effects such as nausea, dizziness, headaches, visual fatigue, and stress.

In economic and logistical terms, Barteir et al.,[6] Tene et al.,[8] Khakpaki,[10] Pedram et al.,[12] and Siddiqui et al.[13] identify major barriers that directly affect accessibility and widespread adoption. These include high hardware and software costs, the need for robust technological infrastructure, and the availability of technical support in simulation centers and institutions, all of which are essential for proper implementation in educational settings. The authors note that populations unable to afford these resources are disproportionately affected, particularly in low- and middle-income countries[1-6,8].

Finally, differing perspectives emerge regarding the limitations and current focus of these technologies. Barteir et al.[6] and Pedram et al.[12] argue that current immersive technologies remain overly simplistic and lack sufficient realism for high-precision procedures, suggesting that future developments should address these shortcomings. In contrast, Kalantarion et al.[14] contend that current technologies disproportionately emphasize psychomotor skill development while neglecting cognitive skill development, which should be a central focus. In this context, Siddiqui et al.[13] note that the complete replacement of traditional teaching methods with immersive technologies has not demonstrated additional benefit. Therefore, immersive technologies should be viewed not as a substitute but rather as a complement, enhancing both practical and cognitive skill development.

## Conclusion

The use of immersive technologies may be considered the next major step in the evolution of medical education. At present, research remains heterogeneous and is still in an early stage, where reported findings may be regarded as having limited validity. Nevertheless, most of the reviewed articles identify several benefits associated with the implementation of these technologies in medical education.

The primary benefits involve improvements in the teaching of practical skills, particularly in the surgical field, where a clear reduction in errors has been demonstrated following the implementation of these technologies, along with a decrease in the time required to perform surgical procedures. In addition, benefits extend to the theoretical domain of medicine, where 3D technologies and HMDs enable the creation of innovative scenarios that enhance students' acquisition of abstract knowledge. Furthermore, immersive technologies provide benefits beyond the classroom, directly influencing students' mindset by increasing motivation, strengthening engagement, and enhancing confidence. Several authors also highlight their potential social impact, noting that although these technologies require considerable investment, such investment may yield substantial benefits, including improved access to education in underserved regions.

The main disadvantages of implementing these technologies at present include the high technological costs of the required equipment, as well as limitations in institutional infrastructure, which necessitate specialized personnel for proper implementation. In addition, current research lacks standardized methods to evaluate the various applications of these technologies under uniform parameters, resulting in studies that are heterogeneous and of limited validity.

In light of these benefits and limitations, it is recommended that standardized evaluation instruments be developed and that these technologies be incorporated into formal educational programs in order to generate valid data that can be systematically compared and analyzed to support more robust recommendations. Based on current evidence, replacement of traditional methods is not advised; rather, the integration of immersive technologies into existing medical education programs is recommended, particularly in practical and abstract areas of training. Further research is also needed to assess the long-term impact of these technologies on learning outcomes and their direct effect on patient health.

## Funding

J. Loría-Castellanos is member of the editorial committee of the journal *Anales Médicos*. The other authors declare that they have not received funding.

## Conflicts of interest

The authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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PERMANYER



ARTÍCULO ORIGINAL

# Control de la presión arterial en pacientes hipertensos de acuerdo con el algoritmo del protocolo de atención integral

## *Blood pressure control in hypertensive patients according to the comprehensive care protocol algorithm*

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## Resumen

**Antecedentes:** *La hipertensión arterial es el principal factor de riesgo cardiovascular modificable con impacto en morbimortalidad. El Protocolo de Atención Integral (PAI) estandariza su prevención, diagnóstico y tratamiento con enfoque multidisciplinario, centrado en el paciente, y evitar complicaciones cardiovasculares.* **Objetivo:** *Analizar el control de la hipertensión utilizando el algoritmo terapéutico del protocolo de atención integral.* **Material y métodos:** *Estudio observacional, descriptivo, en una Unidad de Medicina Familiar en Puebla, México; en pacientes mayor de 18 años, de ambos sexos, con diagnóstico de hipertensión en tratamiento activo; se excluyeron embarazadas y lactantes. Se evaluó apego al algoritmo, y control de hipertensión por revisión del expediente clínico. Se utilizó exacta de Fisher para evaluar asociación apego-control hipertensión; se consideró significativo $p < 0.05$.* **Resultados:** *219 pacientes con hipertensión, predominio femenino (63.9%); prevalencia alta de obesidad (20.1%), diabetes (13.2%) o ambas (16%). El control de hipertensión alcanzó 89%; 83.1% con apego y 16.9% sin apego. El apego al algoritmo se asoció significativamente al control de hipertensión ($p < 0.001$).* **Conclusiones:** *El apego al algoritmo terapéutico del protocolo de atención integral para hipertensión arterial se asocia significativamente con el control adecuado de la presión arterial.*

***Palabras clave:*** *Hipertensión. Presión arterial. Monitorización ambulatoria de la presión arterial. Antihipertensivo. Atención primaria de salud.*

## Abstract

**Background:** *Hypertension is the leading modifiable cardiovascular risk factor with an impact on morbidity and mortality. The Comprehensive Care Protocol (PAI) standardizes its prevention, diagnosis, and treatment through a multidisciplinary, patient-centered approach aimed at preventing cardiovascular complications.* **Objective:** *To analyze the control of hypertension using the therapeutic algorithm of the Comprehensive Care Protocol.* **Material and methods:** *An observational, descriptive study was conducted in a Family Medicine Unit in Puebla, Mexico, involving patients over 18 years of age of both sexes diagnosed with hypertension and undergoing active treatment; pregnant and lactating women were excluded. Adherence to the algorithm and hypertension control were assessed by reviewing medical records. Fisher's exact test was used to evaluate the association between adherence and hypertension control; $p < 0.05$ was considered significant.*

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Fecha de recepción: 30-01-2026
Fecha de aceptación: 09-03-2026
DOI: 10.24875/AMH.M26000148

Disponible en internet: 24-07-2026
An Med ABC. 2026;71(3):202-206
www.analesmedicosabc.com

**Results:** *219 patients with hypertension, predominantly female (63.9%); high prevalence of obesity (20.1%), diabetes (13.2%), or both (16%). Hypertension control reached 89%; 83.1% with adherence and 16.9% without adherence. Adherence to the algorithm was significantly associated with hypertension control (p < 0.001).* **Conclusions:** *Adherence to the therapeutic algorithm of the comprehensive care protocol for hypertension is significantly associated with adequate blood pressure control.*

***Keywords:*** *Hypertension. Blood pressure. Ambulatory blood pressure monitoring. Antihypertensive. Primary health care.*

## Introducción

La hipertensión arterial (HTA) es el principal factor de riesgo cardiovascular modificable y el de mayor impacto por el incremento de morbilidad cardiovascular. Aproximadamente 1.3 billones de personas en el mundo padecen HTA.

La HTA es la principal causa de muerte en todo el mundo y en los últimos 29 años se duplicaron los fallecimientos; en México, la prevalencia estandarizada era de 32.1 para el año 2019[1]. La HTA puede ser asintomática o bien presentar síntomas que se confunden con otras afecciones. En México predomina el diagnóstico tardío, y hasta el 70% de los adultos desconocen tener HTA[1]. Los reportes de incidencia de la HTA están influenciados por factores metodológicos, culturales y de la región de residencia de las personas[2]. Los pacientes con mayor prevalencia comparten características de sexo, edad, falta de conocimiento, factores de riesgo y poca adherencia a los protocolos preventivos y los tratamientos[2]. Además, la pandemia de COVID-19 incrementó la incidencia y las complicaciones de la HTA[3].

Por otro lado, los pacientes con HTA cursan con factores modificables adquiridos como consecuencia de acciones propias, como aquellos relacionados con el peso corporal, el alcoholismo, el tabaquismo y otros factores no modificables[2]. La HTA esencial o primaria corresponde al 90-95% de los casos y la secundaria suele detectarse en el 5-10%[4]. El diagnóstico y el tratamiento de la HTA inician con la búsqueda del control de la presión arterial diastólica[5,6]. La falta de adherencia al tratamiento y sus recomendaciones es un desafío mundial muy relevante; se determina por distintos factores que influyen en el cuidado de las enfermedades crónicas[7,8]. La simplificación del tratamiento con el uso de polipíldoras o la combinación de medicamentos registra mayor adherencia y consigue el control de la HTA en menos tiempo[9,10].

Las variaciones inadecuadas en la técnica de medición de la presión arterial ocasionan que la medición y el monitoreo correctos de la presión sean limitados[11]. El monitoreo domiciliario tiene como objetivo contar con mediciones confiables para la toma de decisiones clínico-terapéuticas adecuadas y así mejorar el control y reducir la mortalidad causada por las enfermedades cardiovasculares[12,13].

El Instituto Mexicano del Seguro Social presentó un protocolo de atención integral (PAI) especial para estos pacientes, que contiene lineamientos para el personal de salud con el objetivo de estandarizar y sistematizar la atención para que sea completa, eficiente y de alta calidad[14,15]. Incluye un algoritmo de tratamiento que establece pautas específicas para el accionar de los profesionales.

Ante esto, surge la importancia de analizar la aplicación del algoritmo de atención del PAI de hipertensión arterial y su relación con el control de la presión arterial.

## Material y métodos

Se realizó un estudio descriptivo, observacional y transversal en una Unidad de Medicina Familiar (UMF) del Instituto Mexicano del Seguro Social en Puebla, México. Se incluyeron pacientes mayores de 18 años, de ambos sexos, con diagnóstico de HTA, en tratamiento en la UMF y que contaran con expediente clínico electrónico. Se excluyeron las mujeres en lactancia o embarazo.

El diagnóstico de HTA se estableció ante una presión arterial > 140/90 mm Hg en un paciente tras 5-10 minutos de reposo[16].

Por revisión de los expedientes se evaluaron la edad, el sexo, la comorbilidad, la evolución, la estrategia terapéutica (monoterapia, doble, triple y triple más otros medicamentos), el apego al algoritmo terapéutico del PAI de hipertensión arterial y el control de la presión arterial.

Se consideró control de la presión arterial cuando se obtuvieron cifras < 130/80 mmHg al mes de inicio del tratamiento en un paciente tras 5-10 minutos de reposo[16].

Se realizó estadística descriptiva y se aplicó la prueba exacta de Fisher para determinar la relación entre el apego al algoritmo y el control de las cifras de presión arterial ($p < 0.05$).

El presente estudio fue aprobado por el Comité de Investigación en Salud No. 2104 del Instituto Mexicano del Seguro Social. La confidencialidad de los datos fue prioridad y los registros se trataron de forma anónima y protegida, y para fines exclusivos de la investigación.

## Resultados

Se incluyeron los expedientes de 219 pacientes con diagnóstico de HTA, de los cuales 140 eran mujeres (64%) y 79 hombres (36%). La edad media fue de 61.5 años (desviación estándar: 11.6).

Se registró una evolución más prevalente en 0-5 años (147 pacientes; 67.1%), seguida de 6-10 años (25 pacientes; 11.4%) y 11-20 años (47 pacientes; 21.5%). La comorbilidad más frecuente fue obesidad (26 pacientes; 20.2%), seguida de diabetes (17 pacientes; 13.2%) y de la combinación de ambas (21 pacientes; 16.3%). Hubo 19 pacientes (14.6%) sin comorbilidad.

La estrategia terapéutica más utilizada fue la terapia doble (93 pacientes; 42.5%), seguida de la monoterapia (86 pacientes; 39.3%) y en menor proporción la triple terapia (38 pacientes; 17.4%). Las polipíldoras y los antagonistas de los receptores de la angiotensina II fueron los medicamentos más prescritos, especialmente en pacientes con control de la presión arterial, lo cual respalda su eficacia clínica.

De la muestra total, 195 pacientes (89%) registraron control de la presión arterial de acuerdo con el PAI; solo 24 (11%) presentaron cifras descontroladas.

En cuanto al apego al algoritmo terapéutico, en 182 pacientes (83.1%) se registró apego, de los cuales 179 (98.3%) mostraron control de la presión arterial. De los 37 pacientes (16.8%) sin apego, 21 (56.7%) registraron descontrol de la presión arterial (Fig. 1). Estas diferencias resultaron significativas ($p < 0.001$).

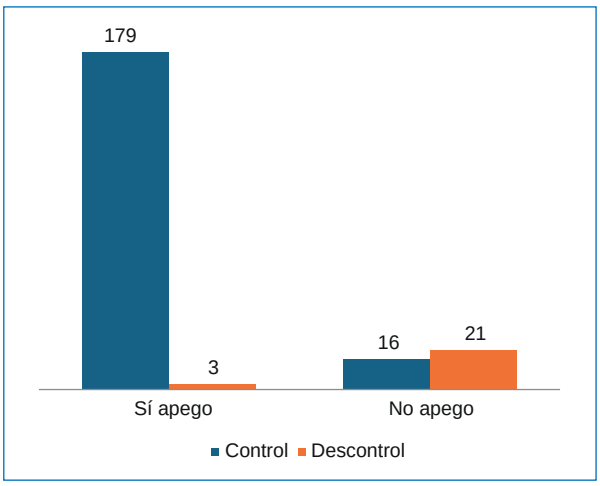


**Figura 1.** Control de la presión arterial en pacientes con y sin apego al algoritmo terapéutico del Protocolo de Atención Integral para hipertensión arterial.

## Discusión

La HTA continúa siendo uno de los principales problemas de salud pública en todo el mundo. Su alta prevalencia y su impacto en la morbimortalidad cardiovascular y renal la convierten en un objetivo prioritario de atención a la salud. El conocimiento de la patología y la prevención, el diagnóstico oportuno y el control efectivo en el primer nivel de atención representan un reto constante pese a los avances terapéuticos y el desarrollo de guías de práctica clínica[17].

La mayoría de los pacientes corresponden a grupos etarios de mediana edad y adultos mayores; población típicamente afectada por HTA, en concordancia con diferentes investigaciones realizadas en Latinoamérica. Se ha descrito una mayor prevalencia en las mujeres a partir de la sexta década de la vida, atribuida en parte a los cambios hormonales posmenopáusicos[1]. Se ha documentado que las mujeres acuden con mayor frecuencia a los servicios de salud y, por ende, presentan mayores oportunidades de tamizaje, diagnóstico y seguimiento[18]. También se reporta mayor prevalencia de control de las cifras de presión arterial en las mujeres en comparación con los hombres, atribuida a un patrón cultural relacionado con la percepción del riesgo y el autocuidado[1].

Más de dos tercios de los pacientes tenían 0-5 años desde el diagnóstico, es decir, una detección relativamente oportuna y una captación activa de casos en el primer nivel de atención[14]. A pesar de la tendencia actual hacia el diagnóstico de HTA en edades más tempranas, incluso entre los 30 y 40 años[18], el riesgo de padecerla se incrementa con la edad. De esta forma, el diagnóstico precoz permite limitar la progresión de la enfermedad y la aparición de complicaciones tardías[14].

En este reporte se identificó una alta frecuencia de obesidad y diabetes, aisladas y combinadas. Estas condiciones metabólicas determinan un mal control de la presión arterial, pues incrementan la resistencia vascular periférica y favorecen procesos inflamatorios y ateroscleróticos, y con ello la progresión del daño cardiovascular[19]. La comorbilidad múltiple en proporción alta subraya la necesidad de un enfoque integral que incluya modificaciones del estilo de vida y manejo de

los factores de riesgo cardiovascular, y no solo limitado al control de las cifras de presión arterial[2,18].

En relación con el tratamiento hipertensivo, la doble terapia fue el esquema más utilizado. Este patrón terapéutico cumple con las recomendaciones del PAI y de las guías internacionales para mejorar la adherencia terapéutica y el control de la presión arterial[4,9].

Uno de los hallazgos más relevantes del estudio fue el alto porcentaje (89%) de pacientes con control de la presión arterial, superior al reportado en los Estados Unidos de América y Canadá, donde el control oscila entre el 40% y el 60%, y donde cuentan con estrategias multinivel consolidadas para el manejo de la HTA[1].

En Latinoamérica existen barreras en el conocimiento, el tratamiento y el control de la hipertensión relacionadas con la falta de participación del paciente y con un sistema de salud fragmentado[20]. En este trabajo, un porcentaje alto de pacientes permanecieron en descontrol, lo que coincide con reportes internacionales que señalan que el control de la HTA sigue siendo insuficiente a pesar de la disponibilidad de tratamientos eficaces[6,17].

El presente estudio aporta evidencia sobre la importancia del apego al algoritmo del PAI como estrategia estructurada. Este prioriza un enfoque escalonado según la respuesta del paciente para lograr un control adecuado en pacientes atendidos en el primer nivel de atención. La asociación significativa entre este apego y el control de la presión arterial constituye el hallazgo central del estudio y confirma que el cumplimiento sistemático de los algoritmos de atención favorece unos resultados clínicos adecuados[7]. El diagnóstico y el seguimiento continúan basándose principalmente en las mediciones de la presión en la consulta. La evidencia actual resalta la necesidad de fortalecer la monitorización ambulatoria y la automedida de la presión arterial para mejorar la precisión diagnóstica, detectar variaciones (como hipertensión enmascarada) y optimizar la adherencia terapéutica[2,13]. También se enfatiza la necesidad de fortalecer estrategias integrales que promuevan estilos de vida saludables, mejoren la adherencia terapéutica y consoliden la implementación de protocolos de atención, para reducir la carga cardiovascular asociada a esta enfermedad en la población mexicana[2,5].

Dentro de las limitaciones del estudio destacan su diseño retrospectivo y el uso de expedientes, lo que puede ocasionar sesgos. Sin embargo, el tamaño de la muestra y la consistencia de los resultados fortalecen la validez interna del estudio y permiten extrapolar sus conclusiones al contexto del primer nivel de atención.

## Conclusión

El apego adecuado al logaritmo terapéutico del PAI para la HTA se asocia significativamente al control de la presión arterial. Los resultados refuerzan que la estandarización de la atención mediante algoritmos clínicos basados en la evidencia mejora de manera significativa los resultados de salud. El PAI no solo facilita la toma de decisiones clínicas, sino que también promueve un manejo homogéneo y sistemático de la HTA.

La alta adherencia observada en la UMF sugiere una adecuada aplicación del PAI, así como un seguimiento continuo y estructurado del paciente hipertenso. Los resultados obtenidos sugieren que la aplicación estructurada del PAI y el seguimiento continuo permiten mejorar la adherencia terapéutica y el control de la presión arterial. Sin embargo, a pesar de los resultados favorables, persisten retos importantes.

En conjunto, los hallazgos de este estudio refuerzan la importancia del diagnóstico temprano, el tratamiento oportuno y el apego a los algoritmos clínicos estandarizados para lograr un adecuado control de la HTA en el primer nivel de atención.

## Financiamiento

J. Loría-Castellanos es miembro del comité editorial de la revista *Anales Médicos*. Los demás autores declaran no haber recibido financiamiento para este estudio.

## Conflicto de intereses

Los autores declaran no tener conflicto de intereses.

## Consideraciones éticas

**Protección de personas y animales.** Los autores declaran que para esta investigación no se han realizado experimentos en seres humanos ni en animales.

**Confidencialidad, consentimiento informado y aprobación ética.** Los autores han obtenido la aprobación del Comité de Ética para el análisis de datos clínicos obtenidos de forma rutinaria y anonimizados. Debido a la naturaleza del estudio, no fue necesario el consentimiento informado individual. Se han seguido las recomendaciones éticas pertinentes.

**Declaración sobre el uso de inteligencia artificial.** Los autores declaran que no se utilizó ningún tipo de inteligencia artificial generativa para la redacción ni la creación de contenido de este manuscrito.

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ARTÍCULO ORIGINAL

# Comparación de la sedación con propofol frente a propofol-midazolam en endoscopia

## *Comparison of sedation with propofol versus propofol-midazolam in endoscopy*

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## Resumen

**Antecedentes:** *La sedación es fundamental en la endoscopia digestiva, ya que mejora la tolerancia del paciente y facilita el procedimiento. El propofol se utiliza ampliamente por su rápido inicio y corta duración; sin embargo, en algunos casos se combina con midazolam, lo que podría modificar el tiempo de recuperación.* **Objetivo:** *Comparar el tiempo de recuperación de la sedación con propofol frente a propofol más midazolam en procedimientos endoscópicos.* **Material y métodos:** *Estudio observacional, comparativo y transversal en la unidad de endoscopia de un hospital terciario del Instituto Mexicano del Seguro Social en Puebla, México. Se incluyeron 60 pacientes sometidos a endoscopia entre mayo y agosto de 2024. Se agruparon según el esquema de sedación: propofol o propofol más midazolam. La recuperación se evaluó con la escala de Aldrete a los 5 y 10 minutos. Se empleó estadística descriptiva y prueba de* $\chi^2$. **Resultados:** *Ambos esquemas mostraron puntuaciones similares en la escala de Aldrete. A los 5 minutos se observó una mayor proporción de puntuaciones altas en el grupo de anestesia combinada, sin diferencias estadísticamente significativas.* **Conclusiones:** *Las sedaciones con propofol y con su combinación con midazolam presentan una recuperación comparable, siendo ambas opciones seguras y efectivas.*

***Palabras clave:*** *Sedación. Escala de Aldrete. Endoscopia gastrointestinal.*

## Abstract

**Background:** *Sedation is essential in gastrointestinal endoscopy, as it improves patient tolerance and facilitates the procedure. Propofol is widely used because of its rapid onset and short duration; however, in some cases it is combined with midazolam, which may affect recovery time.* **Objective:** *To compare recovery times from sedation with propofol versus propofol plus midazolam during endoscopic procedures.* **Material and methods:** *An observational, comparative, cross-sectional study was conducted in the endoscopy unit of a tertiary hospital of the Mexican Social Security Institute in Puebla, Mexico. The study included 60 patients who underwent endoscopy between May and August 2024. Patients were grouped according to the sedation regimen: propofol or propofol plus midazolam. Recovery was assessed using the Aldrete scale at 5 and 10 minutes.*

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Fecha de recepción: 31-03-2026
Fecha de aceptación: 14-05-2026
DOI: 10.24875/AMH.M26000162

Disponible en internet: 24-07-2026
An Med ABC. 2026;71(3):207-211
www.analesmedicosabc.com

*Descriptive statistics and the chi-square test were used.* **Results:** *Both protocols yielded similar scores on the Aldrete scale. At the 5-minute mark, a higher proportion of high scores was observed in the combined group, though there were no statistically significant differences.* **Conclusions:** *Sedation with propofol and its combination with midazolam result in comparable recovery times, with both options being safe and effective.*

***Keywords:*** *Sedation. Aldrete scale. Gastrointestinal endoscopy.*

## Introducción

La endoscopia gastrointestinal es un procedimiento diagnóstico y terapéutico ampliamente utilizado para la evaluación de patologías del tracto digestivo, que permite identificar alteraciones inflamatorias, lesiones estructurales y sangrado gastrointestinal. A pesar de ser mínimamente invasiva, puede generar ansiedad, dolor e incomodidad, lo que dificulta su realización. Por ello, la sedación se ha convertido en un componente esencial, ya que mejora la tolerancia del paciente, optimiza las condiciones del procedimiento y aumenta la satisfacción del equipo médico[1].

El objetivo de la sedación es proporcionar confort y reducir la ansiedad sin comprometer la seguridad. Para ello, es indispensable mantener un equilibrio entre la profundidad de la sedación y la estabilidad hemodinámica y respiratoria. Las guías clínicas recomiendan una valoración preprocedimiento adecuada y una monitorización continua durante la intervención para detectar posibles complicaciones[2,3].

Tradicionalmente se han empleado benzodiacepinas, opiáceos o sus combinaciones. El midazolam ha sido uno de los fármacos más utilizados por sus efectos ansiolíticos, sedantes y amnésicos; sin embargo, puede presentar variabilidad en la respuesta y prolongar el tiempo de recuperación[2,4]. En contraste, el propofol se ha consolidado como una alternativa eficaz debido a su rápido inicio y corta duración, lo que favorece una recuperación más temprana[5,6]. Su mecanismo de acción se basa en la potenciación del sistema GABA en el sistema nervioso central, y puede asociarse a eventos adversos como hipotensión y depresión respiratoria, por lo que requiere una monitorización estrecha[2,7,8].

Con el fin de optimizar la sedación y disminuir la prevalencia de efectos adversos se utilizan combinaciones farmacológicas, como propofol más midazolam, que buscan potenciar el efecto sedante y mejorar la tolerancia al procedimiento. Los estudios han reportado resultados favorables en términos de eficacia y seguridad[6,9].

Finalmente, la elección del esquema de sedación debe considerar la eficacia durante el procedimiento y también la recuperación posterior, que influye en la estancia hospitalaria y en la eficiencia de las unidades de endoscopia. Asimismo, factores clínicos como la comorbilidad pueden modificar la respuesta a los fármacos[5,10]. En este contexto, evaluar las estrategias de sedación disponibles resulta fundamental para mejorar la seguridad del paciente y optimizar los recursos en la práctica clínica.

Así, el objetivo de este trabajo fue comparar en tiempo de recuperación de la sedación en procedimientos endoscópicos con propofol frente a propofol más midazolam en pacientes sometidos a endoscopia digestiva alta.

## Material y métodos

Se realizó un estudio comparativo, observacional y transversal, en la unidad de endoscopia de un hospital terciario del Instituto Mexicano del Seguro Social en Puebla, México.

La población de estudio se conformó por 60 pacientes a quienes se efectuó endoscopia digestiva alta con fines diagnósticos o terapéuticos, con aplicación de sedación durante el procedimiento. Se incluyeron pacientes mayores de 18 años que contaran con registro completo de las variables clínicas necesarias para el análisis. Se excluyeron los pacientes con contraindicación para el uso de propofol o de midazolam, antecedentes de reacciones adversas a estos fármacos o expedientes clínicos incompletos. Se eliminaron del análisis los casos en los que no se registraron adecuadamente los datos relacionados con la recuperación posterior al procedimiento.

Los pacientes fueron divididos en dos grupos: uno que recibió sedación con propofol y otro que recibió sedación con la combinación de propofol más midazolam. La recuperación posterior a la sedación se evaluó mediante la escala de Aldrete, aplicada a los 5 y 10 minutos de finalizar el procedimiento endoscópico.

Se analizaron las siguientes variables: edad, sexo, tipo de sedación administrada (propofol o propofol más midazolam) y puntuación en la escala de Aldrete a los 5 y 10 minutos.

Los datos obtenidos se analizaron mediante estadística descriptiva. Para las comparaciones se utilizó la prueba de $\chi^2$ y se consideró significativo un valor $p < 0.05$.

El protocolo de investigación del presente estudio fue aprobado por el Comité de Investigación en Salud No. 2101 del Instituto Mexicano del Seguro Social. Toda la información se manejó con estricta confidencialidad y para los fines exclusivos de la investigación.

## Resultados

Se incluyeron 60 pacientes sometidos a procedimientos de endoscopia digestiva alta diagnósticos o terapéuticos. La edad promedio de los participantes fue de 54.1 años (± 11.5). En cuanto al sexo, la muestra tuvo una distribución uniforme, con 30 hombres (50%, n = 30) y 30 mujeres (50%, n = 30).

Los participantes se distribuyeron en dos grupos de acuerdo con el esquema de sedación administrado durante el procedimiento: sedación con propofol (24 pacientes) y sedación con la combinación de propofol más midazolam (36 pacientes).

En la evaluación de la recuperación mediante la escala de Aldrete a los 5 minutos, en el grupo con propofol 14 pacientes (58.33%) obtuvieron 9 puntos y 10 pacientes (41.67%) alcanzaron 10 puntos. En el grupo con propofol más midazolam, 20 pacientes (55.56%) obtuvieron 9 puntos y 16 pacientes (44.44%) alcanzaron 10 puntos (p = 0.83).

A los 10 minutos, en el grupo con propofol 3 pacientes (12.50%) obtuvieron 9 puntos y 21 pacientes (87.50%) alcanzaron 10 puntos. En el grupo con propofol más midazolam, 5 pacientes (13.89%) obtuvieron 9 puntos y 31 pacientes (86.11%) alcanzaron 10 puntos (p = 0.87).

En general, ambos esquemas de sedación permitieron una recuperación adecuada y temprana de los pacientes, sin evidenciar diferencias significativas en las puntuaciones de recuperación evaluadas en el periodo inmediato posterior al procedimiento endoscópico (Fig. 1).

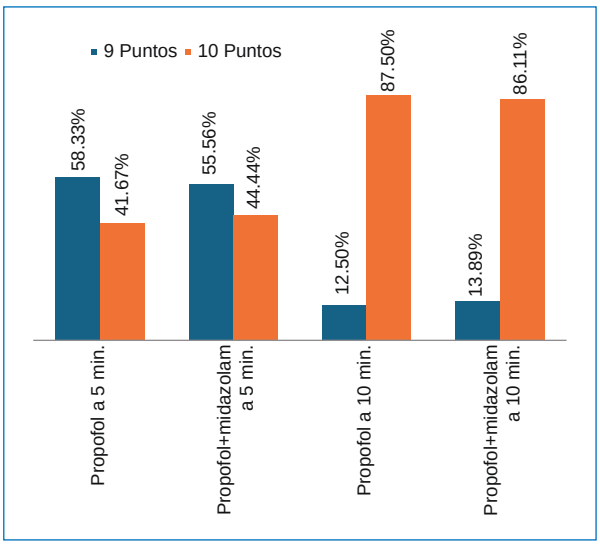


**Figura 1.** Comparación de la escala de Aldrete a los 5 y 10 minutos según el tipo de sedación.

## Discusión

La sedación durante los procedimientos de endoscopia gastrointestinal constituye un elemento fundamental para garantizar el confort del paciente, facilitar la realización del estudio y mejorar la calidad del procedimiento. El uso de sedantes de acción corta, como propofol, midazolam o ketamina, permite alcanzar un nivel de sedación adecuado con una recuperación rápida y segura, y favorece la eficiencia de los servicios de endoscopia[11,12].

En este estudio se evaluó el comportamiento clínico de la sedación en pacientes sometidos a endoscopia digestiva alta y se observó una adecuada recuperación anestésica en la mayoría de los pacientes evaluados mediante la escala de Aldrete a los 10 minutos del procedimiento. Estos hallazgos sugieren que el esquema de sedación empleado proporciona condiciones adecuadas tanto para el procedimiento como para la recuperación temprana.

La evidencia científica respalda ampliamente el uso de propofol en procedimientos endoscópicos debido a su rápido inicio de acción, corta duración y perfil farmacocinético favorable. Los ensayos clínicos y los estudios comparativos han demostrado que el propofol ofrece una recuperación más rápida y un mayor grado de satisfacción del paciente en comparación con otros esquemas sedativos tradicionales[13-15].

Asimismo, algunos estudios señalan que la combinación de propofol con otros fármacos sedantes, como el midazolam, permite el uso de dosis menores de cada agente, optimiza el efecto sedante y reduce la aparición de efectos adversos[9,16]. Estudios similares en unidades de endoscopia han reportado que los esquemas basados en propofol permiten alcanzar niveles adecuados de sedación con tiempos de recuperación más cortos[6,17].

Algunos trabajos con grandes series de pacientes manejados con endoscopia han encontrado que el propofol administrado bajo monitorización adecuada

presenta una incidencia baja de complicaciones y un perfil de seguridad favorable[18-20].

Las recomendaciones de diferentes sociedades científicas enfatizan la importancia de la monitorización continua del paciente, la evaluación previa del riesgo anestésico y la capacitación del personal para el manejo de posibles complicaciones relacionadas con la sedación[3,21,22]. Estas medidas contribuyen a mejorar la seguridad del procedimiento y a disminuir la incidencia de eventos adversos.

Por otra parte, diversos factores clínicos pueden influir en la respuesta a los sedantes utilizados durante la endoscopia, como la edad, el estado clínico del paciente, la presencia de comorbilidad y las alteraciones en el metabolismo hepático de los fármacos[10]. Además, condiciones como trastornos respiratorios del sueño pueden incrementar el riesgo de complicaciones relacionadas con la sedación, por lo que su identificación previa resulta fundamental para una adecuada estratificación del riesgo[23]. Asimismo, la evaluación cuidadosa de los pacientes y el cumplimiento de los protocolos de sedación contribuyen a mantener unas bajas tasas de complicaciones en los procedimientos endoscópicos ambulatorios[24,25].

## Conclusiones

Los resultados del presente estudio muestran que tanto la sedación con propofol como la sedación con la combinación de propofol más midazolam permiten una recuperación adecuada en pacientes sometidos a procedimientos de endoscopia digestiva alta, evaluada mediante la escala de Aldrete durante el periodo inmediato posterior al procedimiento. Aunque se observó una tendencia a puntuaciones ligeramente mayores en los pacientes que recibieron la combinación de fármacos, no se identificaron diferencias estadísticamente significativas entre ambos esquemas de sedación.

Estos hallazgos sugieren que ambos protocolos pueden considerarse opciones seguras y eficaces para la sedación en procedimientos endoscópicos, siempre que se realicen bajo adecuada monitorización y con personal capacitado. No obstante, se requieren estudios con mayor tamaño de muestra y diseños metodológicos más robustos que permitan confirmar estos resultados y establecer con mayor precisión las diferencias clínicas entre los distintos esquemas de sedación utilizados en la práctica endoscópica.

## Financiamiento

Los autores declaran no haber recibido financiamiento para este estudio.

## Conflicto de intereses

J. Loría-Castellanos es miembro del comité editorial de la revista *Anales Médicos*. Los demás autores declaran no tener conflicto de intereses.

## Consideraciones éticas

**Protección de personas y animales.** Los autores declaran haber seguido las normas éticas del comité de experimentación pertinente, de acuerdo con la Asociación Médica Mundial y la Declaración de Helsinki. Los procedimientos contaron con la aprobación del Comité de Ética institucional.

**Confidencialidad, consentimiento informado y aprobación ética.** Los autores han seguido los protocolos de su institución para acceder a los datos de las historias clínicas. Se ha obtenido el consentimiento informado de los pacientes y se cuenta con la aprobación del Comité de Ética. Se han seguido las recomendaciones de las guías SAGER.

**Declaración sobre el uso de inteligencia artificial.** Los autores declaran que no se utilizó ningún tipo de inteligencia artificial generativa para la redacción ni la creación de contenido de este manuscrito.

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REVIEW ARTICLE

# Psychological safety in debriefing

## *La seguridad psicológica en las sesiones de análisis posterior*

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## Abstract

*Psychological safety (PS) has emerged as a key factor in simulation-based medical education, particularly during debriefing sessions, where reflection and feedback are essential for meaningful learning. This narrative review explores the role of PS in facilitating effective debriefing, emphasizing how it influences learners' confidence, emotional regulation, and engagement in reflective dialogue. A literature search was conducted in PubMed and Google Scholar for articles published between 2020 and 2025, using the terms "psychological safety," "debriefing," "medical simulation," and "assertive communication." Findings suggest that establishing PS before and during debriefing fosters inclusion, open communication, and emotional support–conditions that enhance both technical and non-technical skill development. Facilitators play a central role by promoting respectful interactions, empathy, and assertive communication, which strengthen group trust and reduce stress-related barriers to learning. Moreover, structured debriefing models such as PEARLS, Diamond Debrief, and LEARN provide frameworks that sustain PS by integrating reflection, emotional expression, and shared meaning-making. The creation of psychologically safe environments contributes to reduced error incidence, improved teamwork, and the development of resilient, self-aware healthcare professionals. This review underscores the need to integrate PS training into simulation facilitation to ensure reflective, humane, and effective learning experiences in medical education.*

***Keywords:*** *Psychological safety. Debriefing. Simulation-based education. Assertive communication. Medical education.*

## Resumen

*La seguridad psicológica (SP) se ha convertido en un factor clave en la educación médica basada en la simulación, especialmente durante las sesiones de debriefing, en las que la reflexión y la retroalimentación son esenciales para un aprendizaje significativo. Esta revisión narrativa explora el papel de la SP en la facilitación de un debriefing eficaz, haciendo hincapié en cómo influye en la confianza de los alumnos, su regulación emocional y su participación en el diálogo reflexivo. Se realizó una búsqueda bibliográfica en PubMed y Google Scholar de artículos publicados entre 2020 y 2025, utilizando los términos «seguridad psicológica», «debriefing», «simulación médica» y «comunicación asertiva». Los resultados sugieren que establecer la SP antes y durante el debriefing fomenta la inclusión, la comunicación abierta y el apoyo emocional, condiciones que mejoran el desarrollo de habilidades tanto técnicas como no técnicas. Los facilitadores desempeñan un papel central al promover interacciones respetuosas, la empatía y la comunicación asertiva, lo que fortalece la confianza del grupo y reduce las barreras al aprendizaje relacionadas con el estrés. Además, los modelos de debriefing estructurados, como PEARLS, Diamond Debrief y LEARN, proporcionan marcos que sostienen la seguridad psicológica al integrar la*

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Date of reception: 25-03-2026
Date of acceptance: 01-05-2026
DOI: 10.24875/AMH.M26000161

Available online: 24-07-2026
An Med ABC. 2026;71(3):212-217
www.analesmedicosabc.com

*reflexión, la expresión emocional y la construcción compartida de significado. La creación de entornos psicológicamente seguros contribuye a reducir la incidencia de errores, a mejorar el trabajo en equipo y al desarrollo de profesionales de la salud resilientes y conscientes de sí mismos. Esta revisión subraya la necesidad de integrar la formación en SP en la facilitación de la simulación para garantizar experiencias de aprendizaje reflexivas, humanas y eficaces en la educación médica.*

***Palabras clave:*** *Seguridad psicológica. Debriefing. Educación basada en la simulación. Comunicación asertiva. Educación médica.*

## Introduction

Simulation-based education is associated with significant effects on the knowledge, skills, and behaviors necessary for patient care. It is a continuously studied educational tool that has been shown to have a positive impact on the quality and safety of medical care[1]. Learning through simulation consists of several components and phases, all equally important for ensuring success; one of the most relevant being debriefing.

Debriefing is the phase designed to provide feedback, analyze actions, and encourage participants to improve their future performance. During debriefing, students should be guided through the process of reflecting on the decisions they made during the simulation. It is a largely conversational process in which students feel confident expressing their emotions, insecurities, fears, and uncertainties to create a learning experience before actual medical practice[1].

This process ensures increased knowledge among students, acquisition of skills, improved techniques, and a greater confidence in medical practice. However, to guarantee this learning process, the facilitator must have the necessary tools; otherwise, the full implementation of this learning process may be compromised, thereby undermining the simulation's objective[1].

One of these tools is psychological safety (PS). According to Amy Edmondson,[2] PS ensures that people are not humiliated or punished for expressing ideas, questions, concerns, or mistakes. The following article reviews the importance of PS in debriefing, its theoretical foundations, and its impact on simulation-based education.

## Development

Debriefing is a guided reflection that follows a lived experience. Its importance lies in making the student aware of what they have experienced to facilitate objective learning; for this, reflective feedback must be provided. In this part of the simulation, a space is created to share and analyze theoretical concepts and knowledge related to the practice to complement it[3]. The session must be led by a trained facilitator who uses evidence-based methods such as training in communication techniques, group management, simulation methodology, and emotional management, as well as having observed the entire simulation with great attention[4].

Unlike feedback, debriefing is an interactive, two-way conversation in which the focus is on the learner and their internal reflection on their own learning experiences[5].

It is essential that the facilitator is trained in all the aspects involved in effective debriefing, one of which is PS. PS is responsible for establishing a safe environment for learning and identifying interpersonal risks within a given context; it helps prevent the negative consequences of making controversial or risky interpersonal decisions in the workplace that could adversely affect the simulated scenario[6]. The facilitator is responsible for establishing adequate PS, and this is a skill (specific strategies that the educator can employ) that facilitates the development of conversations without fear of humiliation or mistreatment. In recent years, there has been discussion of mistreatment in the training of medical professionals; these incidents make it even more important to address concepts such as PS, not only in the area of medical simulation but in all aspects of medical training (lectures, in- and out-of-hospital practical training, clinical rotations, simulated scenarios, etc.). In simulation practice, the application of PS is part of the recommendations for pre-briefing and debriefing practices[6].

To build trust and a high level of PS, debriefing should begin by recognizing and accepting the value that each person can contribute based on their beliefs and competencies. Openness and motivation should be encouraged, and mistakes should not be highlighted abruptly or individually; this is a space for guidance and preparation for the participants. All of this will allow team members to feel valued and connected, helping them overcome uncertainty. Trust must be established with the participants to avoid stressful situations that lead to a rejection of the learning process. But how can one meet all these necessary criteria for establishing PS?

Through basic communication skills such as assertiveness–a communication style open to others' opinions that stems from respect for others and for oneself, where

one confidently and clearly states what one wants. Looking the other person in the eyes without averting one's gaze, maintaining a tone of voice appropriate to the conversation (neither shouting nor speaking too softly), self-confidence, attentiveness, receptiveness, perceptiveness, and sensitivity to grasp the feelings underlying the student's words –and above all, empathy and mutual respect– are communication skills that optimize PS. One can use the paraphrasing rule, which involves summarizing what the student is asking (in case of doubt) before answering the question to ensure mutual understanding and provide a better response to the student[7].

Mutual respect is a simple concept that will greatly help team members (students and educators) feel a sense of trust where no one is shamed, punished, or rejected for speaking up[8]. It helps people feel capable of recognizing and changing their behavior in response to organizational challenges and teamwork. According to Schein (1996), PS facilitates overcoming defenses and anxiety related to learning[9].

On the other hand, PS is subject to two sets of factors. The interpersonal elements of the team (which are promoted by the educator) and, on the other hand, individual factors such as self-awareness (individual disposition) or students' self-efficacy, proactive personality, emotional stability, and learning orientation[10].

Much of PS will depend on the individual members' abilities to exchange information and critical ideas; to identify and make explicit small details and problems; as well as their capacity for creativity and performance[2]. PS will also depend on the extent to which team members reflect and communicate openly about objectives, strategies, and processes regarding how they adapt or anticipate current circumstances[9]. While all these individual factors do not depend directly on the educator, they can be promoted by the educator; this is why debriefing models exist.

Among the styles and phases of debriefing are 3-phase models such as Plus-Delta, Good Judgment, 3D Model, and Diamond Debrief, as well as multi-phase models like PEARLS, Team GAINS, and Four E. The goal of these models is for facilitators to create a psychologically safe learning environment.

For example, the Plus-Delta model offers a high degree of PS due to its simplicity, using two columns: Plus (+) for appropriate behaviors, conduct, or actions carried out during the simulation (basically what went well), this encourages learners to feel more confident in themselves so they can later discuss what "went wrong" – specifically, the Delta column for behaviors, attitudes, or actions that need improvement or change in the future[11].

The Diamond model consists of three phases: description, analysis, and application of the case. Some of the questions commonly asked are: "What happened?" and "How did this experience make you feel?" Although these questions sound quite simple, they encourage the participant to share the emotions they felt during the simulation[12].

The four E's model proposes that debriefing be conducted through a discussion addressing Events, Emotions, Empathy, and Explanations[12].

Another example is the LEARN model, which is organized into one phase for learning objectives, another for emotions (participants should be asked to express an emotion related to the simulation), another for actions and reflection, and finally one for next steps[12].

These models help us avoid group silence or silence among participants, which would achieve the exact opposite of a psychologically safe environment, where concerns and doubts are kept to oneself due to a lack of trust[13].

PS is not stable but rather a dynamic and fragile perception; not all team members may experience the same degree of PS at any given moment[8].

A psychologically safe environment focuses on the relationships among all members involved. Edmonson views it as a cognitive construct at the group level; other authors describe it as one of the components of a positive work climate, which translates into positive relationships within teams.

PS supports and highlights qualities such as creativity, ingenuity, commitment, performance, active participation, information sharing, and self-expression[8]. Some individual traits that contribute to PS include a proactive personality (a disposition to act independently of external forces present in the learning situation), emotional stability, and, finally, a learning orientation –the tendency to focus on developing new skills rather than on the apprehension of demonstrating high performance – all of which can in turn be fostered by the facilitator[14].

The importance of fostering PS in high-performance teams for managing critical situations lies in reducing the incidence of medical errors, which are defined as an unintended act that may include communication problems, errors in planning or executing therapeutic management, deficiencies in medical training, unforeseen failures in the hospital system, among other factors[15].

The protocols developed by high-performance teams to address these critical situations began with the "code heart attack" protocol, implemented in 2015 by the Mexican Social Security Institute. Due to its success, this protocol paved the way for subsequent protocols, which

have been created, used, and practiced thanks to medical simulation, which builds confidence among students and healthcare professionals through the acquisition of technical and non-technical skills, such as communication, care management, knowledge sharing, and workload distribution, contributing significantly to the reduction of errors and fostering well-prepared and organized teamwork; however, it is important to emphasize that all these aspects are possible thanks to the PS established and fostered within the various work teams through the use of assertive communication strategies applied in pre-crisis and post-crisis situations, since assertiveness is a subset of behavioral social skills that function to maximize the probability of achieving certain social objectives[16]. As mentioned earlier, some strategies for achieving assertiveness are relatively simple guidelines to follow, such as avoiding both aggressiveness and passivity, being open to ideas, maintaining the desired emotional state, and exhibiting open, comfortable social behavior–which, in addition to being reflected in spoken language, manifests in non-verbal communication such as body posture, gestures, facial expressions, and tone of voice[16].

All of this also reduces employee burnout, as it increases job satisfaction and maintains optimism among team members[15].

In the field of medicine, as in other industries, it is very common to reward employees who do not make mistakes, but no space is ever set aside to discuss them. That is why so many doctors or medical students do not speak up for fear of being embarrassed in front of their peers; mistakes are not corrected, but rather punished, mistreated, or reprimanded without allowing space to discuss them.

Thus, the participants' engagement in the debriefing depends on how educators approach them; if the student feels safe to take risks – for example, by admitting they made a mistake or simply don't know something – then the debriefing in that scenario was successful[17].

In the healthcare field, there is a concept known as "secondary victims," referring to healthcare workers who, for various reasons, are involved in an adverse event, resulting in physical, emotional, psychological, or occupational repercussions. Some countries, such as the United States, have implemented emotional support measures, such as the Resilience in Stressful Events program at Johns Hopkins Hospital in Baltimore[18].

The metaphor of a "container" or a "holding environment" is a term widely used in psychology that originates from psychoanalytic disciplines and helps simulation educators understand how to support students' risk-taking. In debriefing, this safe container is described as a place where difficult conversations, emotions, or feedback can be tolerated and transformed into learning opportunities for students[17] (Table 1).

## Methodology

A narrative review of the available literature on the impact of PS in debriefing for medical education was conducted. The PubMed and Google Scholar databases were consulted. Publications from 2020 to 2025 in English and Spanish were considered. The terms used were "psychological safety," "debriefing," "medical simulation," and "assertive communication." We included original articles and previous reviews, as well as studies directly related to the use of simulation and debriefing in medical education. We excluded articles without access to the full text, editorials or letters to the editor, and studies that did not address debriefing and PS in an educational context. We reviewed titles and abstracts to rule out irrelevant articles, then read the preselected articles in full, removed duplicates, and selected those that met the established criteria.

## Discussion

Inclusive leadership – that is, the words and actions of leaders when they invite and value the contributions of others – promotes PS. Work design characteristics, such as clarity of roles, interdependence and autonomy, optimal planning and implementation by the instructor, peer support, and mutual trust and respect among students, are all features that contribute to building PS[6].

PS does not eliminate the feeling or perception of insecurity; it merely allows participants to take risks and experiment within an environment of trust and active listening. Teachers must demonstrate confidence in students' abilities[2].

It is necessary to identify emotional states through active listening, validate emotions, foster understanding of emotions, accept frustration as a sign of the desire for things to improve, and seek possible solutions through reflection (debriefing)[6].

Specific management strategies for debriefing include intervening, addressing power dynamics, reconciling unproductive differences, leveraging diverse perspectives, and avoiding and resolving conflicts[6].

Lee et al.[19] discuss experiences regarding the explicit and implicit practices provided by facilitators during clinical simulations. Several authors have investigated specific strategies to make debriefing a psychologically safe space; for example, this study discusses how

**Table 1.** Explicit and implicit contributions of psychological safety during debriefing[3]

| Explicit contributions | Implicit contributions |
|---|---|
| Establish the simulation objectives | Conduct the debriefing in a private setting away from distractions |
| Commit to confidentiality and transparency during the process | Pause to listen after asking a question |
| Promote inclusion by allowing all participants to contribute ideas | Accompany questions with non-verbal cues such as eye contact or nodding |
| Use active listening | Ask open-ended questions to encourage students to engage in dialogue |
| Offer emotional support and be available if needed | Avoid displays of contempt |

creating a space for reflection, building trust, and managing emotional dynamics are key actions for generating a simulation environment where participants can feel heard and protected during debriefing[19].

A qualitative interpretive descriptive study by Turner et al.[20] examines what constitutes and sustains student-centered learning in simulation from the perspectives of both nursing students and facilitators. The study was guided by the National League for Nursing's Jeffreys Simulation Theory model, as this model posits that PS is necessary to achieve desired learning outcomes and examines the relationship between the student, the facilitator, and the simulation-based educational strategies employed. In addition, the debriefing model for meaningful learning was used, which is a question-based model that guides reflection, allowing the facilitator to assess how students are feeling and determine whether they are comfortable and engaged through their interactions. It is also a dynamic interaction model where the facilitator can encourage the student to seek clarity or assistance during the simulation if they do not feel supported. Similarly, a physical change of environment was implemented, which consists of conducting the debriefing in a location separate from where the simulation took place, as this fosters PS by removing the pressure associated with the active scenario. The results revealed a "gap" or divergence in thinking between what students and faculty believe constitutes PS in the simulation: while facilitators focus on simulation design, believing that PS "is created" by establishing modifiable risk factors; students focus on the simulation experience (the dynamic interaction with the facilitator) and their self-reliance, where PS depends on the quality of the relationship and communication. In other words, although facilitators believe they have created a psychologically safe environment through design elements and models, this belief is not always shared by students; rather, it depends more on humanistic interaction and the pre-established trust between students and the facilitator[20].

This highlights the need to consider both perspectives to foster PS, thereby promoting deep and meaningful learning[20].

The concept of PS in simulation-based education at the undergraduate level was explored by Armijo et al. (2024)[6] through a small sample of faculty and students who had no prior relationship, concluding that PS is not a facilitator-driven condition but rather a shared, culturally situated process actively shaped by students, faculty, and institutional rituals. They identified five conditions that influence PS in simulation-based education:

- Student capabilities (internal resources: self-confidence, emotional self-regulation, adaptability, and motivation) explain why insecurity, fear of judgment, and personal stressors are associated with the level of participation
- Instructor influence: credibility, empathy, non-judgmental communication tone, quality of feedback, and preparation
- Social and peer dynamics: mutual respect, social trust, collaboration, and support
- Structural and physical environment: planning, clear briefing, scenario flow, and space design
- Institutional and cultural framework: confidentiality agreements and the statement of respect.

This allows us to conclude that improvisation and weaknesses in planning within a given scenario directly influence the PS of that scenario and all students involved. It follows that PS does not depend solely on the facilitator, and just because the instructor believes they have used tools to establish PS during a scenario does not mean they have succeeded in doing so; there are other factors beyond our personal attitude as facilitators that must be managed to effectively establish PS.

This review emphasizes that PS is not simply a "state of mind" or a pedagogical courtesy, but a critical structural component for the success of simulation-based education. Unlike traditional teaching, where error is often penalized, simulation requires students to expose themselves to vulnerability; therefore, without a safe environment, reflective learning is blocked by emotional defense mechanisms.

Despite the clear benefits, implementing PS in medical settings presents deep-rooted cultural challenges.

The traditional hierarchical structure of medicine often conflicts with the horizontal structure necessary for effective PS. Furthermore, individual student factors (self-confidence, emotional stability) can cause different students to perceive varying levels of safety in response to the same stimulus from the facilitator.

It is important to foster students' ability to admit mistakes and express doubts without fear of humiliation; this lays the foundation for a culture of hospital safety. Teams that practice SP in simulation are better prepared to implement critical protocols (such as the heart attack code) and to reduce the incidence of "secondary victims," thereby protecting the mental health of the healthcare professional and the patient's well-being.

## Conclusion

Attempting to establish PS from before the simulation begins through to the debriefing helps participants feel included from start to finish. Simple actions such as tone of voice, pace, eye contact, facial expression, incorporating students' perspectives, and making them feel part of the team can determine the course of the simulation. However, different factors are needed to establish a psychologically safe practice, as it is a co-constructed tool that does not depend solely on the facilitator. Although the criteria for creating an environment with PS may be easy to deduce, implementing it may be difficult, since in the present moment of a practice, various stressors can develop at the same time and may lead us to forget our efforts to maintain a psychologically safe environment. Which is why we consider it extremely important to discuss PS in all learning spaces as part of the facilitator's preparation.

## Funding

The authors declare that they have not received funding.

## Conflicts of interest

J. Loría-Castellanos is member of the editorial committee of the journal *Anales Médicos*. The other authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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REVIEW ARTICLE

# Abdominal perfusion pressure: clinical implications and as an alternative to discontinuing vasopressors

## *Presión de perfusión abdominal: implicaciones clínicas y como alternativa en el retiro de vasopresor*

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## Abstract

*The maintenance of adequate organ perfusion depends fundamentally on mean arterial pressure (MAP) and the proper functioning of the cardiovascular system. Intra-abdominal pressure (IAP) acquires a new point of clinical relevance when the patient requires vasopressor support, given that abdominal perfusion pressure (APP) (defined as the difference between MAP and IAP) is an integral parameter in the evaluation of abdominal organ perfusion and may represent a guide for the increase or decrease of these agents. It has been demonstrated that APP is superior for assessing organ perfusion and overall survival in critically ill patients compared to MAP or IAP in isolation; likewise, its impact is undeniable, particularly in patients with intra-abdominal hypertension. In the anesthetic and critical care setting, there are scenarios in which an increase in IAP may be promoted (surgical procedures, laparoscopic interventions, fluid overload, sepsis, obesity, abdominal trauma, among others), and in response to this increase, significant hemodynamic and ventilatory alterations may be generated; therefore, in patients requiring vasopressors, knowledge of APP constitutes an additional tool in their management. Furthermore, it may guide the adjustment (initiation, titration, or withdrawal) of these agents based on abdominal perfusion and systemic response. The objective of this article is to raise awareness within the medical community about the importance of APP and its use as a tool in resuscitation strategies, as well as its role in the weaning of vasopressors.*

***Keywords:*** *Mean arterial pressure. Intra-abdominal pressure. Abdominal perfusion pressure. Vasopressor.*

## Resumen

*El mantenimiento de una adecuada perfusión orgánica depende fundamentalmente de la presión arterial media (PAM) y del correcto funcionamiento del sistema cardiovascular. La presión intra-abdominal (PIA) adquiere un nuevo punto de relevancia clínica, cuando el paciente requiere soporte con vasopresores, que la presión de perfusión abdominal (definida como la diferencia entre la PAM y la PIA) es un parámetro integral en la evaluación de la perfusión de los órganos abdominales y puede representar una guía en el aumento o descenso de estos. Se ha demostrado que la presión de perfusión abdominal (PPA) es superior para valorar la perfusión de órganos y supervivencia general en pacientes críticamente enfermos en comparación con la PAM o la PIA de forma aislada; asimismo, su impacto es innegable, principalmente en pacientes con hipertensión intra-abdominal. En el ámbito anestésico y de cuidados intensivos existen escenarios en los cuales se puede propiciar el aumento*

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Date of reception: 27-02-2026
Date of acceptance: 12-05-2026
DOI: 10.24875/AMH.M26000160

Available online: 24-07-2026
An Med ABC. 2026;71(3):218-227
www.analesmedicosabc.com

*de la PIA (Procedimientos quirúrgicos, laparoscópicos, sobrecarga hídrica, sepsis, obesidad, trauma abdominal, entre otros) y como respuesta a dicho aumento se puede generar alteraciones hemodinámicas y ventilatorias significativas; por lo que, en pacientes que requieren vasopresores, el conocimiento de la PPA constituye una herramienta adicional en su manejo. Asimismo, puede orientar el ajuste (inicio, titulación o retiro) de estos fármacos en función de la perfusión abdominal y la respuesta sistémica. El objetivo de este trabajo es dar a conocer a la comunidad médica la importancia de la presión de perfusión abdominal (PPA) y su uso como una herramienta en las estrategias de reanimación, así como su uso para retiro de vasopresor.*

***Palabras clave:*** *Presión arterial media. Presión intraabdominal. Presión de perfusión abdominal. Vasopresor.*

## Introduction

To maintain adequate organ perfusion, monitoring and control of effective mean arterial pressure (MAP) is necessary, which requires that the cardiovascular system be in proper functioning; however, in various clinical scenarios, whether originating from sepsis, myocardial dysfunction, severe trauma, hemorrhage, various shock states, etc., cardiovascular dysfunction may be generated.

Organ hypoperfusion can trigger severe repercussions such as ischemia and infarction, which is why it is necessary to maintain a minimum MAP of 60 mmHg, as recommended in several clinical guidelines; if this decreases for prolonged periods, it can cause irreversible damage (Fig. 1)[1].

## Definitions

### *Blood pressure*

It is defined as "the force exerted by blood against the walls of the arteries during its circulation propelled by the heart." This pressure is the result of an interaction between three important variables: cardiac output, blood volume, and systemic vascular resistance; their adequate relationship guarantees good perfusion of tissues and vital organs[2].

It is expressed through two components: systolic blood pressure – the maximum pressure in the arteries during ventricular contraction – and diastolic blood pressure – the minimum pressure during cardiac relaxation. Both determine MAP.

### *MAP*

It is defined as the average pressure in the arteries during a complete cardiac cycle that reflects an effective perfusion pressure of vital organs. It encompasses the cardiac cycle, systole, and diastole and is in turn influenced by cardiac output and systemic vascular resistance.

One of the most commonly used formulas is MAP = SBP + 2(DBP)/3. This is why it is important to recognize several terms, as maintaining a MAP below normal values can be related to various factors such as hypotension (vasodilation), whether due to sepsis or anesthesia, low cardiac output, hypovolemia, etc.[3,4].

### *Intra-abdominal pressure (IAP)*

It is the pressure existing within the abdominal cavity, resulting from the balance between abdominal content (viscera, fluids, gas) and the distensibility of the abdominal wall[2]. It is measured with the patient in supine position at the end of expiration with muscle relaxation; values are found in healthy adults at 2-7 mmHg, sick adults at 5-7 mmHg, in obesity, and pregnancy at 10-15 mmHg[4]. The abdominal cavity is a closed compartment that is limited by the diaphragm (superior), vertebral column and dorsal muscles (posterior), abdominal wall (anterior), and pelvis, and sexual and urinary organs (inferior). When a person has a pathology or physiological change that influences the change in these compartments, IAP can be modified, either its increase or decrease in distensibility (example: abdominal tumors, pregnancy, obesity, burns, surgical procedure, etc.). IAP is not constant, as it is modified by various situations such as sustained respirations, cough, certain maneuvers such as Valsalva, mechanical ventilation, and abdominal contraction, etc.[5] (Table 1 and Fig. 2).

### *Abdominal perfusion pressure (APP)*

It is defined as the relationship that exists between MAP and IAP. It has been shown to be a much more precise marker of survival than guiding resuscitation strategies solely with MAP or IAP. It is described in the literature that APP values below 60 mmHg showed significantly higher mortality in the short and long term in correlation with values above this threshold[5,6]. Therefore, active measurement of APP and its use as

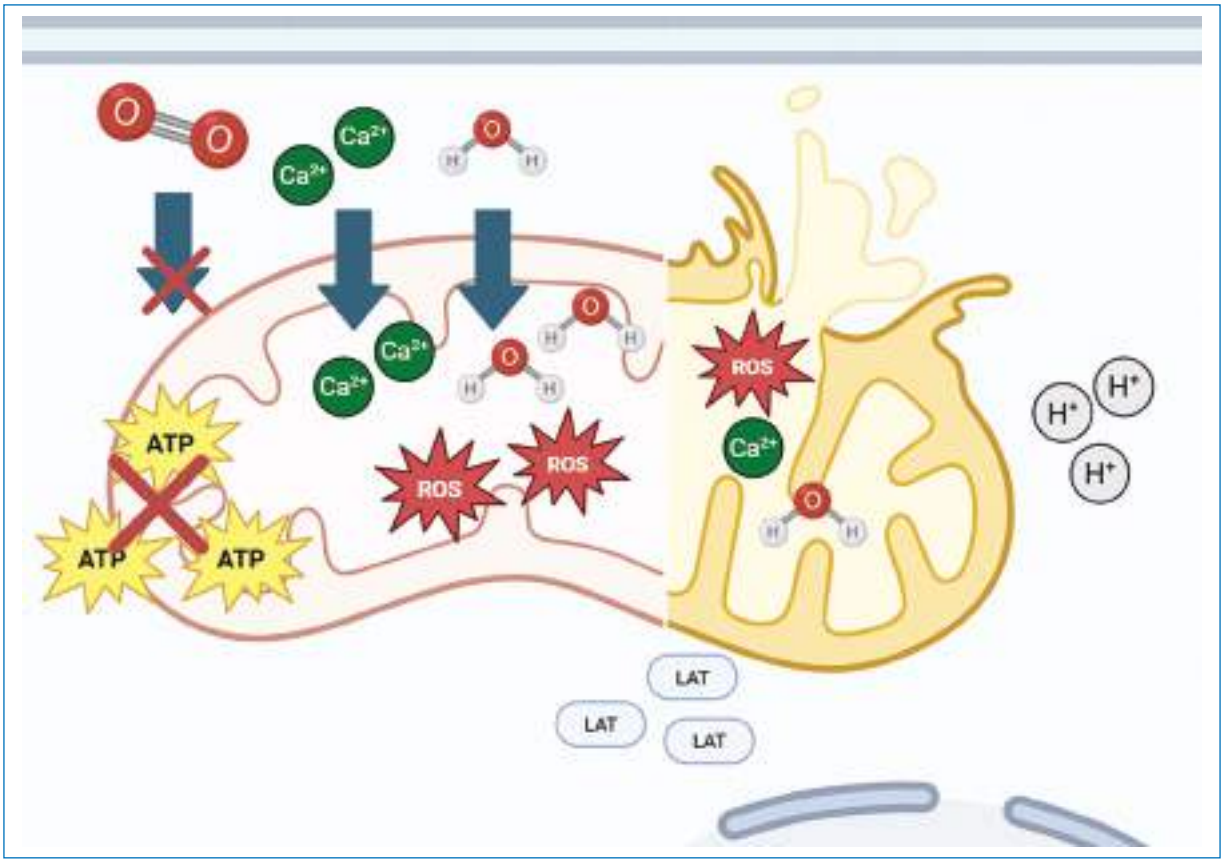


**Figure 1.** Schematic representation of the pathophysiology of ischemia-induced mitochondrial damage. The diagram illustrates the cascade of deleterious cellular events following $O_2$ deprivation. In the initial phase (left half), hypoxia halts the electron transport chain, resulting in an abrupt drop in ATP synthesis (crossed-out stars). This bioenergetic failure incapacitates transmembrane ionic pumps, provoking a massive influx of $Ca^{2+}$ and $H_2O$ toward the mitochondrial matrix, initiating edema. With damage progression (right half), severe architectural disruption is observed with loss of mitochondrial cristae and overproduction of ROS (red stars), which exacerbate damage to lipid membranes. At the cytosolic level, metabolism shifts toward anaerobic glycolysis, evidenced by accumulation of LAT and H+, which conditions a state of intracellular acidosis that contributes to irreversible cell death. ATP: adenosine triphosphate; $Ca^{2+}$: calcium; $H_2O$: water; $O_2$: oxygen; LAT: lactate; H+: protons; ROS: reactive oxygen species.

an additional guide in the vasopressor management of patients can favor better clinical outcomes for the group of hemodynamically unstable patients, thus favoring safer withdrawal of vasopressors compared to the classical measurement of MAP, especially to avoid abdominal hypoperfusion in scenarios where IAP is increased.[7]

APP is defined as:

$$APP = MAP - IAP$$

In anesthesia, it is of important relevance due to the effect on patient ventilation when subjected to general anesthesia, from increased peak pressure and decreased pulmonary compliance; hemodynamically, it decreases venous return and cardiac output; in renal perfusion, there is intraoperative oliguria; in laparoscopic surgeries, IAP can rise to levels between 12 and 15 mmHg, producing even more hemodynamic and ventilatory changes, leading to decreased APP and the need for vasopressor medication[8].

The variability between APP values is based on the two components from which the calculation is obtained, which are MAP and IAP; it is important to remember that normal IAP is between 5 and 7 mmHg[8,9] (Table 2).

## Role of APP and the use of vasopressors in the critical patient

There is a great dilemma with the use of vasopressors, especially in two aspects: first, the time during which it is necessary to maintain the patient's clinical stability, and second, the correct moment and method for de-escalation and withdrawal.

**Table 1.** Systemic affection secondary to hypoperfusion due to decreased mean arterial pressure

| System | Function | Mechanism of alteration | Injury |
|---|---|---|---|
| Hemodynamic | Global tissue perfusion | ↓ Pressure gradient | Systemic hypoperfusion<br>Brain: ↓ CPP → confusion/ischemia<br>Kidney: ↓ GFR → oliguria/AKI<br>Liver: ↓ flow → ↑ transaminases<br>Heart: ↓ coronary perfusion → ischemia |
| Oxygenation and transport | $O_2$ delivery ($DO_2$) | ↓ Blood flow | Cellular hypoxia; lung: V/Q imbalance → hypoxemia |
| Metabolic | Energy production | Shift to anaerobic glycolysis; ↓ $O_2$ + acidosis | ↑ Lactate; ↓ ATP |
| Ionic and cellular | $Na^+/K^+$and $Ca^{2+}$pumps | ↓ ATP → pump failure | Cellular edema + ↑ $Ca^{2+}$ |
| Oxidative | Redox balance | ↑ ROS (especially in reperfusion) | Damage to lipids, proteins, and DNA;<br>Microcirculation: stasis → dysfunction |
| Structural (membranes) | Cellular and organelle integrity | Phospholipases+$Ca^{2+}$ + edema | Membrane rupture; coagulation: endothelial damage → coagulopathy |

CPP: cerebral perfusion pressure; GFR: glomerular filtration rate; AKI: acute kidney injury; $DO_2$: oxygen delivery; V/Q: ventilation/perfusion ratio; ROS: reactive oxygen species; ATP: adenosine triphosphate; ↑ Increases; ↓ Decreases; → Produces; $Ca^{2+}$: calcium; $O_2$: oxygen; Na+: sodium ion; K+: potassium ion.

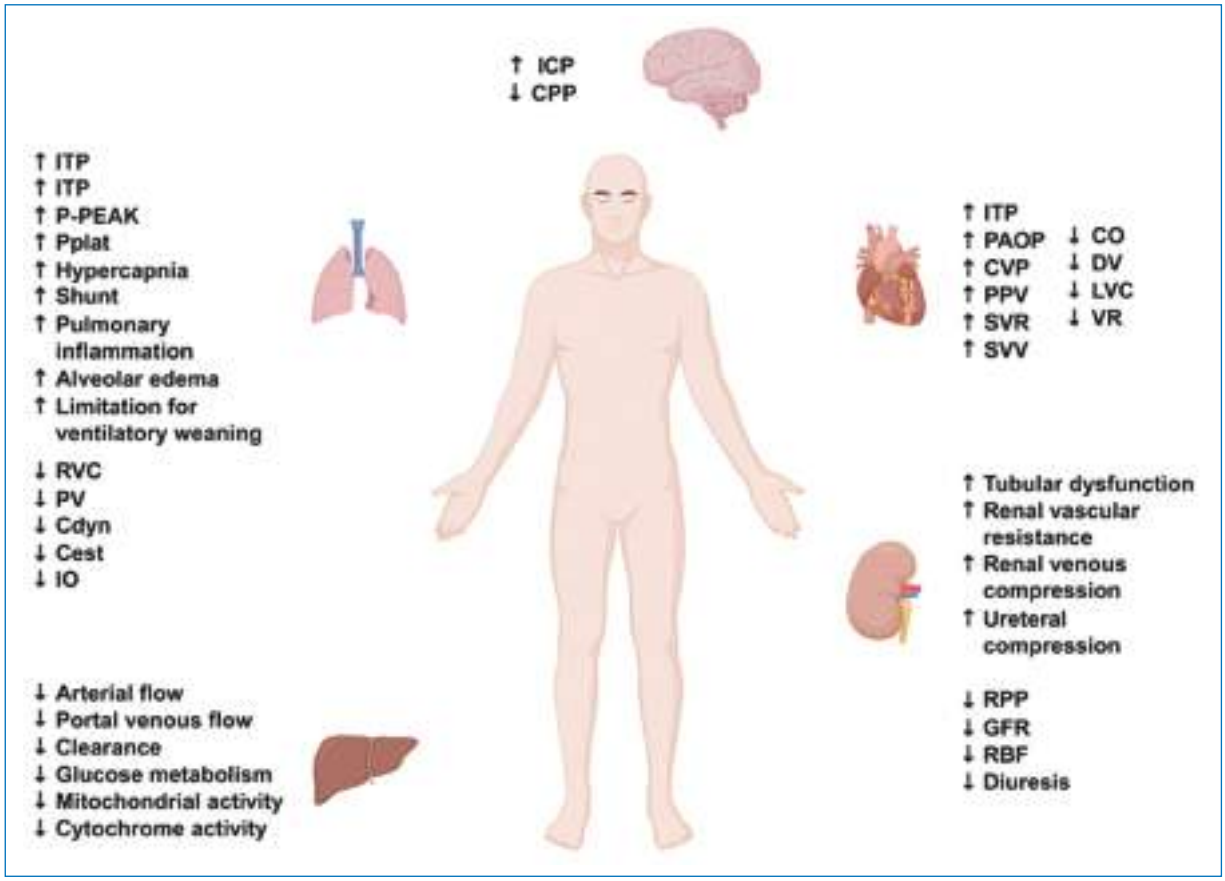


**Figure 2.** Pathophysiological changes of IAH and ACS. ICP: intracranial pressure; CPP: cerebral perfusion pressure; ITP: intrathoracic pressure; PP: pleural pressure; P-PEAK: peak airway pressure; Pplat: plateau pressure; RVC: residual vital capacity; PV: pulmonary volume; Cdyn: dynamic compliance; Cest: static compliance; OI: oxygenation index; PAOP: pulmonary artery occlusion pressure; CVP: central venous pressure; PPV: pulse pressure variation; SVR: systemic vascular resistance; SVV: stroke volume variation; CO: cardiac output; DV: diastolic volume; LVC: left ventricular compliance; VR: venous return; RPP: renal perfusion pressure; GFR: glomerular filtration rate; RBF: renal blood flow.

**Table 2.** Normal and pathological values of intra-abdominal pressure

| Category | p | Context |
|---|---|---|
| Physiological (healthy adult) | ≤ 5 mmHg | Considered normal in adults |
| Range in critical patient | 5-7 mmHg | Expected values in critically ill patients |
| Elevated without pathological significance | 10-15 mmHg | May be observed without implying pathology (e.g., obese patients) |
| IAH | > 12 mmHg | Defined by elevation in 3 consecutive measurements (every 4-6 h) |
| ACS | > 20 mmHg | Sustained elevation+organ dysfunction or failure |

IAH: intra-abdominal hypertension; ACS: abdominal compartment syndrome.

Since their use is associated with various adverse effects such as tachycardia, excessive vasoconstriction (favoring tissue ischemia scenarios), cardiac arrhythmias, metabolic and even immunological alterations; therefore, perfusion and de-escalation strategies have been devised in various protocols seeking to establish a goal at which their withdrawal can be considered safe, and among these, the use of MAP usually has a central role[6-11] (Fig. 3).

Typically, the use of MAP could be considered an efficient standard within the majority of clinical scenarios; however, given the importance of safe environments for the clinical recovery of patients and the diversity of pathologies that require the use of vasopressor medication, scenarios may be found in which a MAP does not translate into adequate tissue perfusion; and it is in these scenarios where concepts such as APP gain value[10-15].

The importance of measuring APP is based on the high incidence of intra-abdominal hypertension (IAH) in critically ill hospitalized patients. In a study conducted by Vidal et al., it was reported that patients in the intensive care unit presented an incidence of this entity in 64% at any time during their stay, also reporting that the main risk factors were mechanical ventilation, respiratory distress, and exhaustive fluid resuscitation[16]. As abdominal hypertension is a frequent entity in critically ill patients or in the intensive care unit, in addition to being an early sign of multiorgan failure and a marker of survival, its use in the titration of vasopressor medication as part of APP is justified, especially to avoid relying solely on MAP as a resuscitation target, since in scenarios with abdominal hypertension, this could generate errors in resuscitation objectives[17,18] (Table 3).

Increased IAP values negatively impact various systems, reducing venous return, increasing inferior vena cava pressure, decreasing cardiac output, favoring oliguria and acute kidney injury, elevating the diaphragm, reducing pulmonary capacity, favoring hypoxia, and even being able to increase intracranial pressure by hindering jugular venous drainage[3,4,6,10,16,19].

Increases in IAP are framed not only in the absolute values expressed in millimeters of mercury but also in a fine relationship between abdominal content and the abdomen's capacity to stretch (abdominal compliance). The measurement of IAP through invasive elements commonly used in patients, such as bladder catheter, can provide reliable data for the calculation of APP[9] (Fig. 4).

Optimization of APP > 60 mmHg, as well as its use as a marker in the management with vasopressors and fluid resuscitation therapy, allows better control of intestinal edema, compression of renal vessels, and tissue ischemia, reducing the risk of complications and clinical deterioration associated with overly aggressive resuscitations[20].

## Use of APP in the withdrawal of vasopressors

The optimal sequence for vasopressor withdrawal in vasodilatory shock has been explained based on the pathophysiological model proposed by Landry et al., which distinguishes between two partially independent mechanisms of vasodilation: the catecholamine-sensitive pathway and a state of relative vasopressin deficiency[21,22].

In septic shock, endogenous vasopressin concentrations initially rise but subsequently decrease due to depletion of neurohypophyseal stores and alteration of its baroreceptor-mediated release, generating a state of relative vasopressin deficiency[22]. This phenomenon contributes to persistent vasodilation that does not respond completely to catecholamines. In this context, exogenous vasopressin administration acts as hormonal replacement therapy, restoring vascular tone through V1 receptors, which remain relatively preserved during shock[21,22]. On the other hand, the catecholamine response, mediated primarily by $\alpha_1$-adrenergic receptors, tends to recover earlier as the inflammatory state improves, despite the desensitization observed in initial phases[21] (Fig. 5).

Based on this difference in the recovery of vasopressor systems, early discontinuation of vasopressin may unmask persistent deficiency and precipitate hypotension, while norepinephrine can be withdrawn more safely in the initial stages.

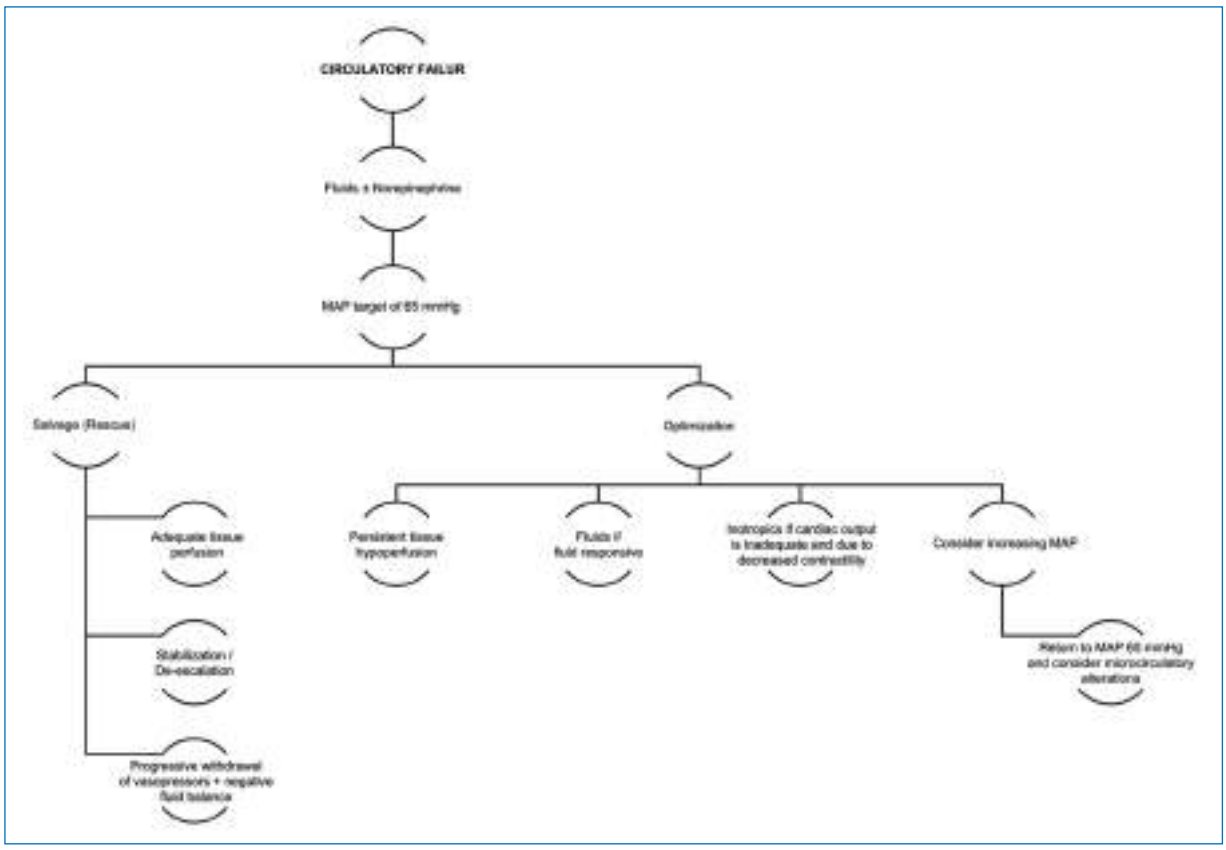


**Figure 3.** Mean arterial pressure-based management algorithm.

**Table 3.** Recommended treatment for intra-abdominal pressure

| IAP level | Definition | Anesthetic objective | Specific treatment (escalated) | Anesthetic considerations |
|---|---|---|---|---|
| Normal (0-5 mmHg) | Physiological | Maintain perfusion (APP > 60 mmHg) | Surveillance | Avoid fluid overload |
| IAH Grade I (12-15 mmHg) | Mild hypertension | Prevent progression | Optimize analgesia and sedation<br>Avoid excessive PEEP<br>Neutral position (avoid Trendelenburg) | Adjust ventilation (↓ Peak pressure) |
| IAH Grade II (16-20 mmHg) | Moderate | Decrease intra-abdominal pressure | Deep sedation<br>Neuromuscular blockade<br>Gastric/rectal decompression<br>Negative fluid balance | ↓ Pulmonary compliance, ↑ Plateau pressure |
| IAH Grade III (21-25 mmHg) | Severe | Restore organ perfusion | Diuretics/ultrafiltration, paracentesis if ascites<br>Percutaneous drainage<br>Avoid excessive crystalloids | Risk of ↓ venous return, hypotension |
| ACS (> 20 mmHg + organ dysfunction) | Abdominal compartment syndrome | Urgent decompression | All previous measures<br>Decompressive laparotomy (Gold standard)<br>Open abdomen (VAC) | Critical induction: high risk of hemodynamic collapse |

IAP: intra-abdominal pressure; APP: abdominal perfusion pressure; IAH: intra-abdominal hypertension; ACS: abdominal compartment syndrome; PEEP: positive end-expiratory pressure; VAC. vacuum-assisted closure.

This physiological foundation is supported by clinical evidence. *Post hoc* analyses of the VASST study and subsequent observational studies have demonstrated a higher incidence of hypotension when vasopressin is discontinued before norepinephrine[23]. Therefore, several experts recommend a strategy in which

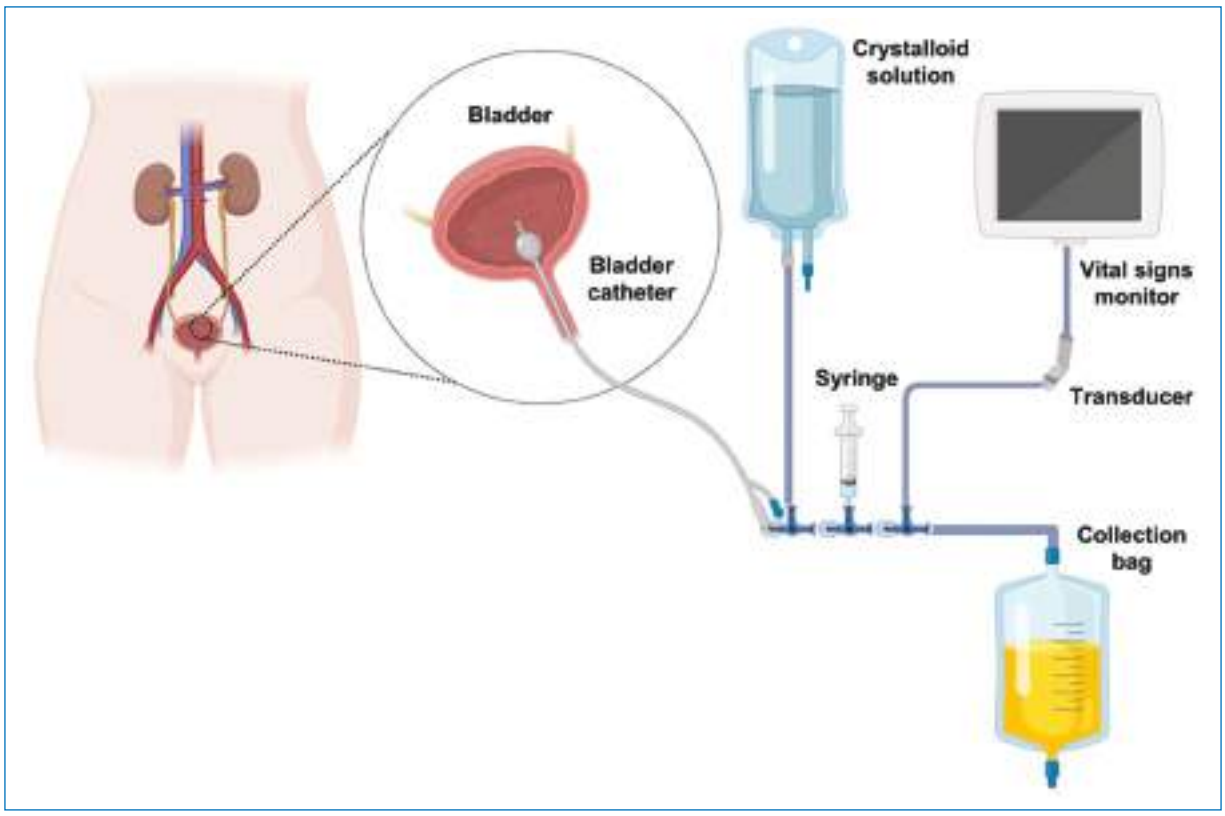


**Figure 4.** Diagram of intra-abdominal pressure measurement through bladder.

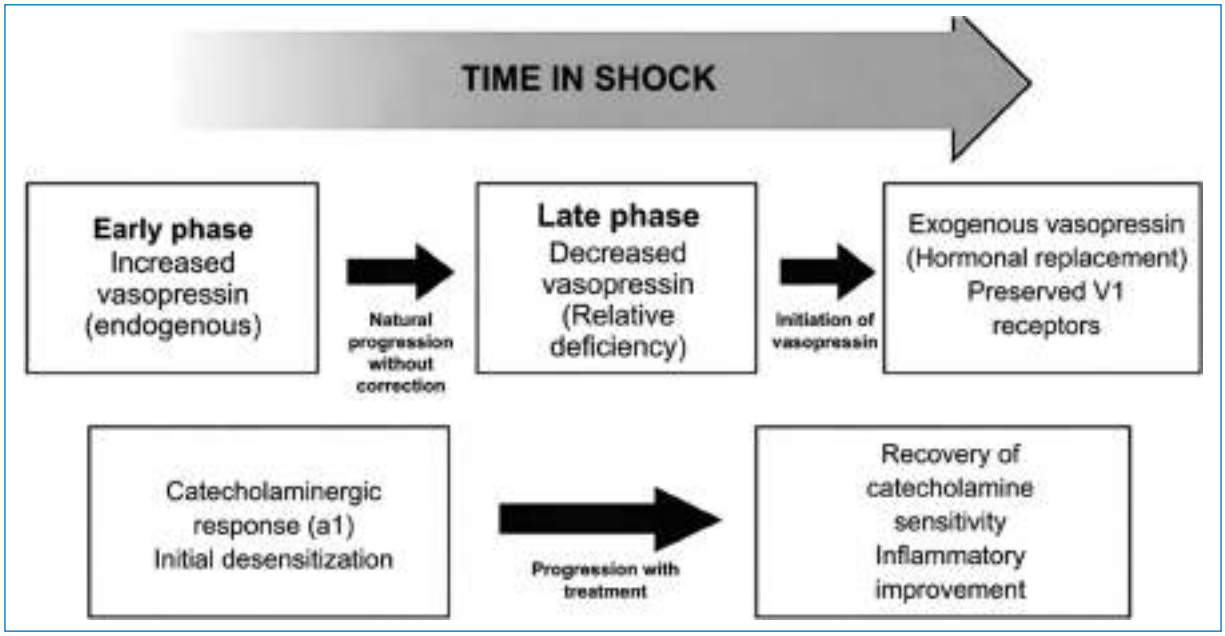


**Figure 5.** Shock dynamics.

norepinephrine is reduced first, maintaining low doses of vasopressin until hemodynamic stability is ensured.

From a clinical perspective, the interaction between vasopressor withdrawal and IAP may modify patient management. Consider a patient recovering from septic shock who remains on low doses of norepinephrine and vasopressin. In a scenario with normal IAP, progressive reduction of norepinephrine while maintaining vasopressin is usually well tolerated, as improvement of the inflammatory state allows recovery of catecholamine sensitivity. Once norepinephrine is discontinued and hemodynamic stability is maintained, vasopressin can be withdrawn cautiously[21,22,24,25] (Fig. 6).

In patients with increased IAP, the situation may differ significantly. Increased IAP reduces APP and may compromise venous return, contributing to persistent circulatory instability despite apparent resolution of the inflammatory state[26,27]. In this context, vasopressin may play a particularly relevant role in maintaining vascular tone through non-adrenergic mechanisms. Therefore, early discontinuation of vasopressin in these patients may trigger hypotension, even when norepinephrine requirements are low[28-30]. Therefore, persistent mechanical factors, such as IAH, must be considered when planning vasopressor withdrawal[10,21-25] (Fig. 7).

## Clinical implications and limitations

APP has been proposed as a physiological parameter that reflects the effective perfusion gradient of abdominal organs in critically ill patients. This concept is analogous to that of cerebral perfusion pressure, which integrates systemic arterial pressure and intracranial pressure to estimate the effective driving force of cerebral blood flow. Similarly, APP attempts to consider the mechanical effects of increased IAP on the perfusion of abdominal organs, particularly in patients with IAH or abdominal compartment syndrome (ACS).

The incidence, risk factors, and outcomes of intra-abdominal study: intra-abdominal pressure: risk factors and outcomes, a multicenter prospective investigation, reported that IAH occurs in about half of patients admitted to intensive care units and that its severity independently predicts mortality. Because APP integrates both systemic arterial pressure and IAP, it provides a physiologically more complete assessment of abdominal perfusion than either of these variables separately.

APP has limitations as a perfusion marker; it continues to be an indirect macrohemodynamic parameter and should not be considered a direct measurement of tissue perfusion. Tissue perfusion depends not only on perfusion pressure but also on microcirculatory function, capillary density, endothelial integrity, and cellular oxygen utilization. In conditions such as septic shock, significant microcirculatory dysfunction may persist despite apparently adequate perfusion pressures. In addition, most of the clinical evidence supporting the use of APP comes from observational studies rather than randomized clinical trials. Although associations between low APP values and organ dysfunction are consistent, it is not yet clear whether directing resuscitation specifically toward APP goals improves clinical outcomes compared to traditional MAP-guided strategies. In accordance with these limitations, the guidelines published in 2013 by the World Society of the ACS concluded that available evidence was insufficient to recommend routine monitoring of APP as a resuscitation target.

The relationship between APP and vasopressor therapy is particularly relevant during the management of septic or distributive shock. Vasopressors increase MAP and, consequently, can improve APP when IAP remains constant. In patients with elevated IAP, vasopressors can partially compensate for the reduction in APP by increasing arterial driving pressure.

Vasopressor therapy represents a double-edged strategy in this context. Although increased MAP may improve APP, excessive vasoconstriction may simultaneously deteriorate regional microcirculatory blood flow. Experimental and clinical studies suggest that high doses of catecholamines can reduce mesenteric perfusion and contribute to the development of intestinal ischemia in vulnerable patients. Therefore, increasing vasopressor doses with the objective of maintaining APP, without addressing the elevation of IAP, may not restore effective tissue perfusion.

This has implications for vasopressor withdrawal. During the shock stabilization phase, progressive reduction of vasopressor support is usually attempted as organ perfusion improves. However, in patients with persistent IAH, reductions in MAP may cause disproportionate decreases in APP and subsequent deterioration of renal or splanchnic perfusion. Recognizing this interaction may help interpret apparent vasopressor dependence. Instead of solely increasing vasopressor doses, management should also be oriented toward identifying and treating reversible causes of elevated IAP, such as excessive fluid accumulation, gastrointestinal distension, abdominal wall rigidity, or the presence of intra-abdominal collections. Strategies to reduce IAP include gastric and colonic decompression,


**Figure 6.** Sequential strategy for vasopressor support withdrawal in the critical patient with normal intra-abdominal pressure.

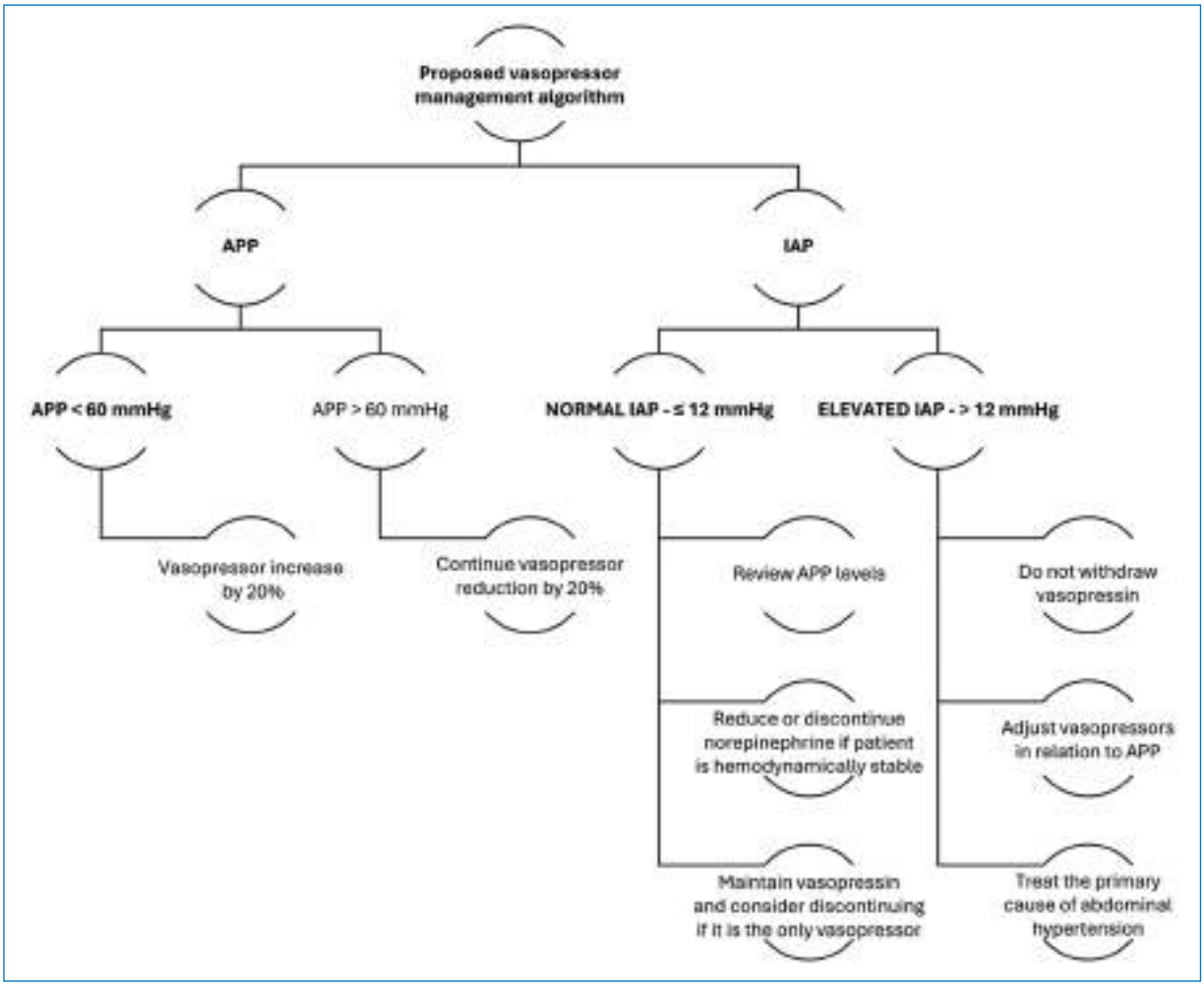


**Figure 7.** Proposed algorithm for management based on APP and IAP measurement. APP: abdominal perfusion pressure; IAP: intra-abdominal pressure.

optimization of sedation and analgesia, avoiding excessive fluid administration, promoting diuresis or fluid restriction when appropriate, and drainage of ascites or intra-abdominal collections. In cases of ACS with organ dysfunction, decompressive laparotomy may be necessary. By addressing both components of the APP

equation – arterial pressure and IAP – it is possible to facilitate safer vasopressor withdrawal and simultaneously preserve abdominal organ perfusion.

## Conclusion

APP should be considered a useful complementary marker in the hemodynamic evaluation of patients with suspected or diagnosed IAH rather than a universal resuscitation target. Despite its solid pathophysiological basis, the role of APP as a therapeutic target in the critical patient is not yet completely defined. Most of the available evidence comes from observational studies or cohorts with limited sample sizes, and there is currently a shortage of high-quality randomized clinical trials evaluating APP-guided resuscitation strategies.

## Funding

The authors declare that they have not received funding.

## Conflicts of interest

The authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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REVIEW ARTICLE

# The relevance of gamification in medical education

## *La importancia de la gamificación en la educación médica*

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## Abstract

*The incorporation of recreational strategies into educational settings has progressively transformed medical education over the past few decades. Gamification, defined as the application of game-like elements in non-recreational settings, has been shown to increase motivation, encourage active participation, and strengthen clinical reasoning. The objective of this study was to analyze the relevance of gamification in medical education, with an emphasis on its integration into clinical simulation and the use of emerging technologies in Obstetrics and Gynecology. A narrative literature review was conducted using a structured search of international electronic databases, prioritizing recent publications related to serious games, game-based learning, virtual reality, and mixed reality applied to clinical training. The reviewed evidence demonstrated benefits in the development of technical and non-technical skills, improved decision-making, greater awareness of the rational use of resources, and increased confidence in simulated scenarios. Furthermore, virtual and mixed reality enable the training of skills in safe and immersive environments, particularly in complex obstetric situations. Although the results are favorable, methodological limitations persist, such as small sample sizes and heterogeneity in assessment tools. In conclusion, gamification constitutes a valuable complementary strategy that can contribute to the training of more competent professionals who are better prepared for clinical practice.*

***Keywords:*** *Gamification. Medical education. Clinical simulation. Virtual reality. Mixed reality. Gynecology and obstetrics.*

## Resumen

*La incorporación de estrategias recreativas en contextos educativos ha transformado progresivamente la enseñanza médica en las últimas décadas. La gamificación, entendida como la aplicación de elementos propios del juego en entornos no recreativos, ha demostrado incrementar la motivación, favorecer la participación activa y fortalecer el razonamiento clínico. El objetivo de este trabajo fue analizar la relevancia de la gamificación en la educación médica, con énfasis en su integración en la simulación clínica y el uso de tecnologías emergentes en Ginecología y Obstetricia. Se realizó una revisión narrativa de la literatura mediante una búsqueda estructurada en bases de datos electrónicas internacionales, priorizando publicaciones recientes relacionadas con juegos serios, aprendizaje basado en juegos, realidad virtual y realidad mixta aplicadas al entrenamiento clínico. La evidencia revisada mostró beneficios en el desarrollo de habilidades técnicas y no técnicas, mejora en la toma de decisiones, mayor conciencia sobre el uso racional de recursos y aumento de la confianza en escenarios simulados. Asimismo, la realidad virtual y mixta permiten entrenar competencias en entornos seguros e inmersivos, especialmente en situaciones obstétricas complejas. Aunque los resultados son favorables, persisten limitaciones metodológicas, como muestras pequeñas y heterogeneidad en los instrumentos de evaluación. En conclusión, la gamificación constituye una estrategia complementaria valiosa que puede contribuir a la formación de profesionales más competentes y preparados para la práctica clínica.*

***Palabras clave:*** *Gamificación. Educación médica. Simulación clínica. Realidad virtual. Realidad mixta. Ginecología y obstetricia.*

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Date of reception: 25-03-2026
Date of acceptance: 15-05-2026
DOI: 10.24875/AMH.M26000156

Available online: 24-07-2026
An Med ABC. 2026;71(3):228-232
www.analesmedicosabc.com

## Introduction

Gamification is the use of game elements in non-game contexts. It is an educational approach that promotes student motivation and engagement[1]. In the field of education, this strategy has emerged as an active, constantly evolving methodology that transforms traditional teaching and learning experiences into more interactive, personalized processes that yield more objective results[2].

The use of game elements in contexts outside of entertainment has been a subject of interest over the past 20 years, giving rise to what we now know as gamification. The term gamification, derived from the word *"game,"* refers to the use of game elements to create experiences in fields such as health and education[3]. Although this concept emerged in the 2000s, we can trace its origins back to the late 19th century, before the term existed as such; specifically to S and H Green Stamps, a program that offered stamps to consumers for their purchases, which they could later redeem for prizes[4]. Although technology as such, or video games, were not used, elements typical of games – such as accumulating points, setting goals, and offering rewards – were applied to encourage people's actions.

With technological advancements, gamification has been used as a tool in education, healthcare, and marketing. The term was formally coined by the British scholar Nick Pelling, who proposed a clear definition of the concept, thereby increasing its visibility. By 2010, gamification began to expand beyond marketing, entering the education sector with platforms such as Duolingo and Kahoot, which aim to serve as virtual learning systems that boost student motivation[5].

In the medical field, gamification had a significant impact. In 200G, HopeLab designed a video game for adolescents with a prior cancer diagnosis, which succeeded in improving treatment adherence and fostering self-care behaviors in patients. In 2011, so-called "serious games in medical education" were developed and used in Brazil in a surgical context to train laparoscopic skills[6].

The theory of learning through play identifies playful dynamics as highly effective pedagogical and andragogical tools for fostering learning, as it asserts that they facilitate cognitive, social, emotional, intellectual, and psychomotor development. This theory is based on the premise that, through play, knowledge is constructed by solving problems presented as challenges, consequences are experienced without real-world impact on the individual's life while retaining the learning they entail, and, above all, development is fostered in a safe, motivating, healthy, and meaningful environment[7].

Various authors and educators have provided theoretical foundations that underpin this practice or the theory behind it; Jean Piaget asserted that play stimulates cognitive development, since the individual engaged in it can organize their thinking by establishing the mental schemas necessary to carry out what is asked of them. Lev Vygotsky, for his part, introduces the concept of the "zone of proximal development," which is the midpoint between the level of "actual development" – what the individual can do on their own – and the level of "potential development" – what the individual could achieve with adequate support and knowledge. He concludes that the former is optimal for learning, and indeed, play allows the individual to reach that point by forcing them to act beyond their current level of development, through the simulation of social or even professional roles, and to resolve situations that would otherwise not be presented or would be highly improbable[4].

The relationship between playful learning and its presumed success is directly linked to the intrinsic motivation it entails. Play is directly related to pleasure, curiosity, and autonomy – three elements that generate the drive to continue engaging in an activity. When a play-based activity is designed correctly, the individual participating in it more easily enters a state of full concentration that enhances the assimilation of knowledge and skills, and this effect is further intensified when the activity is accompanied by elements of immediate feedback, progressive challenges, and decision-making[8].

## Development

In recent years, there has been an increase in the use of gamification in clinical simulation, employing game mechanics and tools to foster meaningful learning. As a result, a positive correlation has been observed with improved patient outcomes, as students and healthcare professionals are able to enhance their skills and clinical reasoning, which enables them to make better diagnostic and therapeutic decisions[9].

A clear example of the significant impact gamification has had on medical students can be seen in decision-making cards (DMCs), as described in a recent study published in BMC Medical Education. In this activity, students work in teams to solve clinical cases using cards that contain diagnostic information along with the corresponding medical costs. As they progressed through the case, they had to make decisions

about which tests and/or treatments to order, considering both the associated costs and the correct diagnosis. This approach improved motivation to learn and helped students become more aware of the efficient use of resources. This method represents a good alternative for medical education focused on maintaining motivation and active learning[10].

There are numerous games that have gradually been adapted and incorporated into medical education; some examples include: Isla Cleft, a game designed to improve medical students' knowledge of cleft lip, in which a child with this condition travels through islands named after treatment protocols, resulting in a significant improvement in treatment outcomes after playing the game; PediatricSim, a game based on the Pediatric Advanced Life Support Provider Manual, which it is based on critical scenarios in pediatrics, such as diabetic ketoacidosis, anaphylaxis, and seizures, among others, in which better clinical outcomes are achieved after completing these simulations; Antibiogame, a game used to teach medical students the proper use of antibiotics, in which students play the role of doctors during a consultation, prescribing antibiotics in real-life primary care scenarios[11-14].

The effect of DMCs on medical students has been studied through the implementation of gamification. These cards present brief clinical cases with relevant patient information, and the rest of the cards in the game allow players to develop a diagnostic and therapeutic approach while spending as little as possible. In this game, players can choose cards by looking only at the front, which includes the card's title and cost; if they decide to purchase a card, they can then view the back and read the additional information needed to resolve the clinical case. Finally, the player who resolves the clinical case at the lowest possible cost wins. It was observed that students gain greater self-confidence when making diagnostic decisions and become more aware of the cost of each procedure requested for patients thanks to gamification[10].

Gamification has been increasingly used through various techniques aimed at strengthening clinical reasoning, including serious games; the most widely used technique involves creating clinical scenarios with scoring systems and feedback; time-limited escape rooms designed to solve clinical cases using a series of puzzles; and simulation games that use scored simulations, challenges, and feedback to enhance learning[9].

Regarding mixed reality, efforts have been made to develop soft-tissue simulators that allow for the simulation of labor through a model capable of reacting as realistically as possible to perineal and vaginal canal tears occurring during labor, while using HoloLens to observe soft tissues during both eutocic and dystocic labor, as well as the residents' reactions, providing immediate feedback and thereby improving care for obstetric patients in real time[15].

It is of utmost importance to train physicians and midwives in the field of gynecology, as it has been observed that simulators facilitate patient-safety-centered learning in a safe and interactive manner, building the confidence to perform procedures on patients. Furthermore, it is important to highlight the recent development of low-cost anatomical simulators that allow physicians to train even when resources are limited, which this means that the future should enable training using accessible technology with significant educational impact, with the aim of ensuring safety and providing better care for obstetric patients[16].

We can also find video games and laparoscopic simulators designed to improve visuomotor and manual coordination for specific surgical skills. One example is Play and Learn for Surgeons, which allows users to repeatedly practice complex surgical procedures, such as arterial ligations[17].

A standout example among these is Body Interact, a gamified simulator based on virtual patients that offers more than 1,200 clinical scenarios, including gynecological and obstetric cases. The design of this simulator allows for the evaluation of clinical reasoning and decision-making in real time, in addition to providing immediate feedback, which creates a safe environment for the student.

There is another platform that uses medical simulation through virtual reality and augmented reality called SimX, where students can practice with virtual patients in realistic clinical scenarios using virtual reality headsets. This tool relies solely on virtual reality and no longer requires physical simulators to create clinical scenarios, which is why it has been adopted by leading emergency departments such as the Mayo Clinic and Stanford, among others.

The use of gamification with virtual reality is part of an innovative approach to training future doctors, especially in situations that require high concentration and place significant pressure on them. Virtual reality allows for the immersive recreation of critical situations commonly encountered in hospitals while creating specific scenarios that generate a safe environment where students can confront intense emotions; thanks to this, it is possible to promote emotional learning in stressful situations. Recent studies have shown that

exposure to virtual reality experiences can help reduce anxiety and increase confidence among healthcare professionals[18].

On the other hand, using gamification to manage stress has shown mixed results. Although many applications include techniques for anxiety and stress management, in numerous cases, they do not effectively integrate game mechanics with emotional regulation strategies[19]. For example, some systems incorporate points, challenges, or rewards, but do not actually teach how to calm anxiety or cope with pressure. To make these tools more useful, it is recommended that gamified experiences include personalized feedback, progressive scenarios, and elements that foster emotional self-regulation. Combining these experiences with immersive virtual reality enhances both the practice of technical skills and emotional preparedness, ensuring that healthcare professionals can effectively manage the emotional burden while making decisions in high-pressure scenarios[20,21].

## Methodology

### *Study design*

This article is a narrative literature review, whose main objective was to analyze the relevance of gamification within the medical field, specifically in its application in the area of clinical simulation and in the use of emerging technologies, with a special emphasis on gynecology and obstetrics.

### *Search strategy*

A structured literature search was conducted in recognized electronic databases, including PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. The search was conducted using combinations of keywords in English and Spanish, such as: gamification, medical education, clinical simulation, serious games, game-based learning, virtual reality, mixed reality, gynecology, obstetrics, and educational technology, employing Boolean operators (AND, OR) to optimize the retrieval of relevant literature.

### *Inclusion and exclusion criteria*

Original articles, literature reviews, observational studies, and educational experiences that use gamification as a teaching strategy in medical education, clinical simulation, or clinical skills training were included. The search focused primarily on publications from the last 5 years, prioritizing those that presented practical applications and results in clinical and educational contexts.

We excluded duplicate publications, abstracts without access to the full text, opinion pieces without a clearly described methodology, and studies unrelated to the fields of health or medical education.

## Discussion

The reviewed literature shows that gamification has a significant impact on medical education, particularly in clinical simulation settings. Several studies have reported benefits in motivation, confidence, decision-making, clinical skill development, and knowledge retention, which reinforces and supports the idea that game-based dynamics are an effective complement to traditional teaching and learning methods in medicine[22].

There are several reported examples that illustrate the aforementioned benefits. DMC*s* had a positive impact on students' awareness of the cost-benefit ratio of certain tests, as well as on their diagnostic skills. Games such as PediatricSim and Antibiogame have proven useful in practicing pediatric scenarios and the rational and appropriate use of antibiotics, respectively. Similarly, the implementation of escape rooms focused on medical education or training for medical personnel has demonstrated benefits in knowledge acquisition, teamwork, problem-solving under pressure, and communication[13,23].

In the field of gynecology and obstetrics, simulators and virtual and mixed reality technologies, such as Body Interact and SimX, have made it possible to safely train critical skills, improving both clinical reasoning and care in obstetric scenarios of varying levels of complexity. Similarly, there has been a notable development of low-cost, accessible, and replicable anatomical simulators that open up the possibility of training specific skills without creating a financial burden when resources are limited[10].

Despite the clearly evident benefits, certain limitations persist in the current literature. Many studies are based on small samples or pilot contexts, which makes it difficult to adequately generalize the findings. Furthermore, there is heterogeneity in study design and in the metrics used for evaluation, which hinders the establishment of broadly applicable conclusions. The literature review identifies a relationship between gamification in medicine as a mechanism for reducing stress and promoting regulation in clinical contexts;

however, the results are not yet sufficient to definitively establish this conclusion[24].

Taken together, the points outlined above suggest that gamification and simulation in medicine constitute a useful, valuable, and growing tool with particular potential in gynecology and obstetrics. However, broader research using standardized methodologies is needed to definitively consolidate the evidence. Similarly, more information on the subject is needed, obtained through studies that have no connection whatsoever with the various companies that promote or own the different programs or simulators, to ensure a significant reduction in the bias that may be present in the current data.

## Conclusion

The findings compiled in this study support the assertion that gamification provides real value in medical education, particularly when integrated into clinical simulation scenarios. Game-based dynamics not only increase student interest and engagement but also promote more agile decision-making and more robust clinical reasoning. Overall, the evidence indicates that this approach can enrich the educational experience and offer complementary support to traditional methods, provided it is applied intentionally and with clear objectives.

## Funding

The authors declare that they have not received funding.

## Conflicts of interest

J. Loría-Castellanos is member of the editorial committee of the journal *Anales Médicos*. The other authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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ARTÍCULO DE REVISIÓN

# Simulación médica como complemento de la enseñanza clínica tradicional

## *Medical simulation as a complement to traditional clinical teaching*

*Joel Rojas-Ibarra[1], Ariana Cerón-Apipilhuasco[2], Jorge Loría-Castellanos[1] y Juan R. Mendoza-Carrillo[3]**

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## Resumen

*La simulación médica es una herramienta que permite al estudiante participar en escenarios clínicos que se asemejan a la realidad y le brindan destreza y confianza antes de enfrentarse a situaciones reales. Surge entonces la pregunta de si la simulación médica puede ofrecer mejores resultados que la enseñanza clínica tradicional. El objetivo de este artículo es analizar el impacto educativo y económico de ambos métodos, con el fin de determinar su efectividad como estrategias complementarias en la formación médica. Se realizó un estudio de tipo revisión narrativa con enfoque comparativo, orientado al análisis del impacto educativo y económico de la simulación médica frente a la enseñanza clínica tradicional. Los hallazgos confirman que la simulación médica se ha consolidado como una estrategia pedagógica efectiva, complementaria e incluso superior en algunos aspectos, para mejorar la adquisición de retención de habilidades clínicas, la autoconfianza y la seguridad en la práctica médica. Este efecto se asocia al principio de práctica deliberada y la retroalimentación inmediata. Desde el punto de vista económico, aunque la simulación requiere una inversión inicial considerable, resulta costo-efectiva a mediano y largo plazo. La enseñanza clínica tradicional continúa siendo insustituible para el desarrollo del juicio clínico, la empatía y la experiencia directa con los pacientes. En conjunto, la evidencia respalda que el modelo educativo más efectivo es la integración de ambos enfoques.*

**Palabras clave:** *Simulación médica. Enseñanza clínica. Educación médica. Costo-efectividad. Estrategias pedagógicas.*

## Abstract

*Medical simulation is a tool that allows students to participate in realistic clinical scenarios, providing skills and confidence before facing real situations. This raises the question of whether simulation can achieve better results than traditional clinical teaching. The aim of this article is to analyze the educational and economic impact of both methods to determine their effectiveness as complementary strategies in medical training. A narrative review with a comparative approach was conducted to evaluate the educational and economic effects of medical simulation versus traditional clinical teaching. Findings confirm that simulation has become an effective pedagogical strategy, complementary and in some aspects superior, by improving the acquisition and retention of clinical skills, self-confidence, and patient safety. This effect is related to deliberate practice*

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Fecha de recepción: 15-04-2026
Fecha de aceptación: 25-05-2026
DOI: 10.24875/AMH.M26000163

Disponible en internet: 24-07-2026
An Med ABC. 2026;71(3):233-239
www.analesmedicosabc.com

*and immediate feedback. Economically, although it requires considerable initial investment, simulation proves cost-effective in the medium and long term. Traditional clinical teaching remains irreplaceable for the development of clinical judgment, empathy, and direct patient experience. Overall, available evidence supports that the most effective educational model is the integration of both approaches.*

**Keywords:** *Medical simulation. Clinical teaching. Medical education. Cost-effectiveness. Pedagogical strategies.*

## Introducción

La simulación médica como técnica educativa se encuentra presente hoy en día como parte importante de los programas formativos de la enseñanza médica. Su auge está directamente relacionado con la inquietud por la calidad y la seguridad en la atención a los pacientes, y la exposición previa a la práctica del personal médico. La simulación médica es una herramienta que permite al estudiante participar en escenarios clínicos que se asemejan a la realidad y los faculta para adquirir destreza y confianza antes de enfrentarse a situaciones reales. La simulación se ha validado como una estrategia pedagógica eficaz que actualmente se encuentra implementada en muchas escuelas de medicina, y distintos marcos teóricos, como la teoría del aprendizaje experiencial de Kolb, sostienen su utilidad. El panorama actual de la educación médica global sigue estas tendencias educativas, tecnológicas y económicas; de maniquíes de baja fidelidad hasta la formación de ecosistemas de alta fidelidad, realidad virtual y simulación basada en inteligencia artificial, entre otros[1].

Cabe entonces preguntarse si la simulación médica es un método que pueda brindar mejores resultados que la enseñanza clínica tradicional. Aquí es importante realizar análisis de costos, ya que los recursos y los presupuestos en salud y educación médica son limitados, y si llega a existir un instrumento que obtiene mayores beneficios formativos se debe incentivar. Otro factor importante del panorama actual es la escalabilidad de la simulación; esta ha demostrado adaptarse y manejar un volumen creciente de estudiantes sin comprometer su rendimiento o eficiencia. La simulación moderna ya no busca solo realizar procedimientos prácticos, sino más bien competencias integrales como trabajo en equipo, ética, resolución de problemas y comunicación, todas ellas competencias que se esperan del médico contemporáneo[2].

La enseñanza clínica tradicional es un sistema detallado y conocido que ha evolucionado y ha producido generaciones de médicos con buenas bases científicas y habilidades clínicas[3]. Brinda a los estudiantes la oportunidad de conocer el entorno clínico y adaptarse a él. Esta modalidad permite experimentar de primera mano la complejidad de la práctica médica real y las dinámicas que se viven dentro de un hospital. También se fundamenta en el conocimiento directamente aplicado, con sus respectivas consecuencias positivas y negativas, lo que se conoce como *bedside teaching*[4]. Sin embargo, presenta desafíos significativos en la actualidad, como exposición limitada a los pacientes, dependencia del tutor y riesgos potenciales para los pacientes, y además es un tipo de educación no estandarizada. La enseñanza clínica tradicional incluye el enfoque en la memorización, escasa participación activa de los estudiantes, tiempo insuficiente de discusión y desglose de cada caso o práctica, e incomodidad del espacio clínico o intrahospitalario para enseñar. Recientemente se ha visto que la limitación más importante de la enseñanza, en el contexto clínico tradicional, es que la educación dentro de la medicina convencional no ha tenido la participación de educadores capacitados, es decir, se consideraba que un alto nivel de experiencia clínica era suficiente para ser un buen educador, y ahora se reconoce que la enseñanza por sí sola requiere capacitación especializada[4].

Estas limitaciones han impulsado la búsqueda de métodos complementarios que ofrezcan un aprendizaje seguro, estandarizado y controlado, como es la simulación médica. La educación médica basada en simulación busca crear escenarios clínicos reales, en los que el estudiante pueda encontrarse en entornos controlados y seguros para su aprendizaje. El beneficio principal es establecer confianza y seguridad, siendo así que, al momento de trasladar el conocimiento de la simulación a la práctica real, la exposición previa y la práctica permitan realizar una mejor ejecución.

La simulación médica ha crecido en los últimos años y al día de hoy se la considera como un complemento de la enseñanza tradicional. Su desarrollo se ha visto impulsado por los nuevos avances tecnológicos y por los estándares internacionales de seguridad y calidad de la atención médica. Sus principales componentes son un crecimiento del mercado global, el costo de la educación médica, la seguridad del paciente, la reducción de los errores médicos y la formación clínica segura.

La educación basada en simulación se utiliza cada vez más como una alternativa a la enseñanza clínica tradicional porque puede reducir los costos de capacitación mientras mantiene o mejora los resultados educativos[5]. El costo anual aproximado de los errores médicos en los Estados Unidos de América es de 17.1 mil millones de dólares[6], muchos de los cuales son medibles y podrían utilizar como recurso la simulación y reducir estos costos. Existe evidencia que demuestra que la capacitación basada en simulación no solo es equivalente, sino que en muchos casos supera a la tradicional y ha demostrado mejoras significativas en conocimientos, habilidades y conductas en comparación con esta[7].

En la mayoría de los contextos en donde los presupuestos de la salud son limitados, la simulación representa una oportunidad costo-efectiva para administrar los recursos, a la vez que permite entrenar competencias clínicas, comunicativas y trabajo en equipo, minimizando las equivocaciones y fortaleciendo la confianza del estudiante.

Actualmente se considera a la simulación médica como un instrumento educativo complementario, que ofrece una oportunidad para que los estudiantes pueden adquirir habilidades antes de presentarse ante un paciente real, reduciendo de manera significativa la tasa de fallos en la práctica y los riesgos para los pacientes. En conjunto, fortalece la calidad de la atención a los pacientes y la formación del profesional.

La simulación médica no solo representa un instrumento pedagógico, sino también un sector con implicaciones económicas crecientes en todo el mundo. La inversión en tecnologías y centros de simulación se ha afianzado en diferentes sistemas educativos y de salud, y hoy en día es una industria en desarrollo con proyecciones sostenidas de crecimiento. Esta tendencia responde a la necesidad de reducir los costos asociados a la práctica clínica en pacientes reales, minimizar los eventos adversos y optimizar la capacitación de los profesionales de la salud utilizando entornos controlados, reproducibles y estandarizados. El mercado global de simulación médica estaba valorado en 3 mil millones USD en 2024 y se proyecta que alcance 8.57 mil millones USD hacia 2033, con una tasa de crecimiento anual compuesta del 15.6%[8,9]. Se estima que el mercado de simulación médica en América Latina crecerá de 220 millones USD en 2024 a 850 millones USD en 2033, con una tasa de crecimiento anual compuesta del 16.19%, siendo Brasil y México los principales contribuyentes[10].

## Objetivo

El objetivo de esta revisión es analizar el impacto educativo y económico de la simulación médica y la enseñanza clínica tradicional, con el fin de determinar su efectividad como estrategia complementaria en la formación de estudiantes de medicina. Se hace una descripción de los fundamentos teóricos y pedagógicos, se comparan las ventajas y las limitaciones de ambos modelos, y se evalúan las relaciones costo-beneficio en el contexto de la educación médica para determinar su impacto en la práctica educativa.

## Método

Se realizó una revisión narrativa con enfoque comparativo, orientada al análisis del impacto educativo y económico de la simulación médica frente a la enseñanza clínica tradicional. La búsqueda bibliográfica se efectuó en bases de datos internacionales, repositorios institucionales, incluyendo artículos originales, revisiones narrativas y reportes técnicos que abordan resultados educativos o económicos de la simulación médica.

La información obtenida se clasificó en fundamentos pedagógicos y teóricos, impacto educativo documentado en conocimientos y habilidades, costos de implementación, operación y escalabilidad. Se omitieron documentos sin evidencia empírica que no contribuyeran al análisis comparativo. Se priorizó seleccionar literatura con relevancia práctica para el contexto educativo, publicada en los últimos 10 años y disponible en texto completo en inglés o español.

La búsqueda se realizó durante los meses de agosto a octubre de 2025, utilizando palabras clave y descriptores controlados como “medical simulation”, “clinical teaching”, “cost-effectiveness”, “educational outcomes” y “simulation-based learning”, combinados mediante operadores booleanos para optimizar la recuperación de información.

Para el análisis se empleó un enfoque temático, organizando los hallazgos según dimensiones pedagógicas, formativas y económicas, y posteriormente se realizó una comparación narrativa y cualitativa entre los resultados reportados para ambos modelos educativos.

La revisión se realizó de manera descriptiva y comparativa, identificando ventajas, limitaciones y puntos de convergencia entre ambos modelos educativos, así como brechas de conocimiento que orienten futuras líneas de investigación en educación médica.

## Desarrollo

La simulación médica ha emergido en las últimas décadas como una herramienta central en la educación de profesionales de la salud, impulsada por la necesidad de mejorar la seguridad del paciente y la efectividad del aprendizaje sin exponer a los pacientes reales a riesgos; en la actualidad se utiliza globalmente en todos los niveles educativos de pregrado, posgrado y especialidad[11]. Suele implementarse en centros de simulación, espacios designados y diseñados para recrear escenarios clínicos que permiten a los estudiantes practicar de manera segura y controlada. En el ámbito mundial existen diferencias notables para aclimatarse a este sistema; los países de altos ingresos han desarrollado centros de simulación de alta fidelidad con tecnología avanzada que incluyen maniquíes programables, realidad virtual, simuladores de procedimientos quirúrgicos y simulación de equipos completos de emergencias. Estos son centros que se enfocan en lo técnico y también en competencias como trabajo en equipo, liderazgo, comunicación y manejo de crisis de igual manera. Por otro lado, en los países de medianos y bajos ingresos, la simulación médica, aunque en ascenso, se ha visto rezagada por la limitación de recursos. La simulación en estos casos se centra en simuladores de bajo costo, métodos de simulación por juego de roles y entrenamientos en modelos anatómicos[11].

En términos de investigación, la simulación médica ha sido objeto de numerosos estudios que demuestran su eficacia. Por ejemplo, los metaanálisis y las revisiones sistemáticas muestran que «la educación basada en simulación produce mejoras significativas en el desempeño clínico, la retención de conocimientos y habilidades, y la reducción de errores»[12]. Este enfoque resalta las tendencias globales de crecimiento de la simulación médica.

La simulación médica ha demostrado ser una estrategia educativa altamente efectiva para la adquisición de habilidades clínicas específicas, especialmente cuando se combina con la práctica deliberada, siendo la retroalimentación lo que se constituye como la característica más importante de la simulación, porque se identifican errores y se refuerzan conductas correctas, lo que traduce en un aprendizaje más sólido y duradero. De manera complementaria, McGaghie et al.[2] evidenciaron en un metaanálisis que la educación médica basada en simulación con práctica deliberada supera de manera significativa a la educación clínica tradicional en el alcance de objetivos de adquisición de habilidades clínicas, con un tamaño del efecto de 0.71 (intervalo de confianza del 95%: 0.65-0.76; $p < 0.001$), lo cual indica que los estudiantes que participan en simulación mejoran de manera moderada-alta en comparación con aquellos que reciben enseñanza clínica convencional. Resalta la eficacia de la simulación para acelerar la curva de aprendizaje. En el contexto de las habilidades técnicas críticas, los estudiantes que participan en programas de práctica deliberada adquieren casi el doble de competencias en la mitad del tiempo en comparación con los que solo realizan observación y práctica clínica[11]. Así, la simulación médica, más allá de ser una herramienta tecnológica, es un modelo pedagógico integral con resultados altamente efectivos.

Sin embargo, además de su impacto en el rendimiento académico, la sostenibilidad económica de este modelo ha cobrado creciente interés en la literatura, pues su implementación implica consideraciones logísticas y presupuestales relevantes para las instituciones educativas. A medida que la simulación médica se consolida como una competencia esencial en el entrenamiento clínico surge la necesidad y se destaca la importancia de evaluar su viabilidad económica. La adopción de la simulación implica un cambio estructural en los modelos de enseñanza, con inversiones iniciales significativas[13]. Un centro de simulación médica requiere una inversión inicial y sus respectivos costos operativos son continuos. La inversión inicial está compuesta principalmente por infraestructura, adquisición de simuladores (que pueden variar en costos dependiendo el tipo de fidelidad o complejidad), *software* especializado y otras categorías adicionales como insumos para los simuladores, *hardware,* personal docente, instructores especializados, etc. La inversión inicial es alta, pero el mantenimiento y los costos operativos han demostrado que es un método de enseñanza que a mediano y largo plazo representa un ahorro importante, por el mantenimiento anual bajo, con una reducción de costos de un 85% en comparación con la enseñanza tradicional[14]. Los estudios estiman que el retorno de inversión de los centros de simulación puede alcanzarse entre los 3 y 5 años posteriores a su implementación, dependiendo del volumen de estudiantes y de la frecuencia de uso[7,8]. Por otro lado, se ha reportado que la formación hospitalaria conlleva unos costos significativos constantes que son difíciles de cuantificar, ya que incluyen varios aspectos, como el tiempo docente, la ocupación de espacios hospitalarios como el quirófano y el riesgo de errores clínicos[7]. Esto ha demostrado que la simulación es una

propuesta muy atractiva al ser eficiente y reproducible, justificando la inversión inicial frente a los costos directos e indirectos de la enseñanza tradicional[15].

La formación médica en el mundo en general implica costos elevados. Los modelos educativos alternativos, como la simulación, no son un sustituto a la enseñanza tradicional, pero sí una forma de optimizar los recursos[13,16].

A pesar de su eficacia educativa, el análisis económico de la implementación de la educación médica basada en la simulación es limitado y la mayoría de los estudios reportan costos incompletos, centrándose principalmente en equipos y materiales[7,17]. Sin embargo, estudios específicos han mostrado que, aunque los costos iniciales de simulación de alta fidelidad son mayores que los de educación tradicional[18], los beneficios en términos de prevención de eventos adversos graves y mejora en competencias pueden superar ampliamente la inversión, considerando los costos directos de estos eventos[19,20]. Además, las innovaciones recientes en simulación, como la realidad virtual con retroalimentación háptica e inteligencia artificial, han demostrado mejorar la precisión, la velocidad de aprendizaje y la retención de habilidades mientras reducen costos a largo plazo, mostrando gran escalabilidad[21]. Desde el punto de vista del volumen de entrenamiento, la diferencia es notable. Un centro de simulación médica puede entrenar en promedio simultáneamente entre 4 y 8 grupos de estudiantes en distintos escenarios o estaciones clínicas, alcanzando una capacidad promedio de 80 a 150 estudiantes por jornada, mientras que en los entornos hospitalarios el aprendizaje suele ser limitado a grupos más pequeños, de 5 a 10 estudiantes por servicio, y además son dependientes de la disponibilidad de pacientes, procedimientos y supervisores[2]. Esta diferencia en capacidad permite a los centros de simulación multiplicar el número de prácticas efectivas, estandarizar procesos de experiencia formativa y un ahorro de costos sumamente importante en el entrenamiento clínico.

El análisis de los costos educativos en el ámbito internacional muestra diferencias marcadas y refleja las capacidades económicas de cada país, sus prioridades y sus estrategias en inversiones educativas. Según los datos comparativos, el costo promedio anual por estudiante de medicina en el mundo es de 100,000 dólares estadounidenses (1.5 millones de pesos mexicanos), lo cual refleja el alto costo del entrenamiento médico tradicional, asociado al uso intensivo de recursos hospitalarios, tiempo docente, materiales clínicos y riesgo inherente de errores médicos, entre otros[13].

Frente a este panorama, la simulación médica se presenta como una alternativa complementaria que ofrece una reducción de los costos frente a la inversión inicial, principalmente por la posibilidad de reutilizar escenarios clínicos, estandarizar procesos educativos y optimizar el tiempo de práctica sin depender de la disponibilidad hospitalaria[7,12].

Desde la mirada pedagógica, la simulación no es un reemplazo de la enseñanza clínica tradicional, sino una herramienta que la optimiza y la complementa donde puede tener limitaciones. Permite establecer una formación homogénea entre estudiantes porque reduce la variabilidad del aprendizaje y asegura la exposición de todos los estudiantes a situaciones críticas en el entorno hospitalario, fundamentales para la seguridad del paciente. Sin embargo, cuenta con limitaciones importantes, como un costo inicial elevado de implementación, la necesidad de personal capacitado y el riesgo de que la experiencia se torne artificial si no se acompaña con una correcta contextualización clínica.

En conjunto, los modelos basados en simulación demuestran ser una alternativa costo-efectiva, escalable y sostenible, especialmente cuando forman parte de un sistema híbrido de formación médica orientado a la excelencia educativa y la seguridad del paciente.

## Discusión

Los hallazgos de esta revisión confirman que la simulación médica se ha consolidado como una estrategia pedagógica efectiva, complementaria e incluso, en algunos aspectos, superior a la enseñanza clínica tradicional. La evidencia en términos educativos coincide en que la simulación mejora significativamente la adquisición y la retención de habilidades clínicas, la autoconfianza del estudiante y la seguridad de la práctica médica. Este efecto se relaciona directamente con el principio de la práctica deliberada y la retroalimentación inmediata, que permiten la identificación de errores de manera temprana y reforzar conductas adecuadas en un entorno controlado, en comparación con el enfoque clínico convencional, en el cual el aprendizaje está sujeto a la exposición de casos y procedimientos dependientes a disponibilidad hospitalaria y del tutor.

En el ámbito formativo, la simulación ofrece una oportunidad equitativa y estandarizada de aprendizaje, y contribuye al desarrollo de competencias transversales, como comunicación, liderazgo, trabajo en equipo y toma de decisiones bajo presión. Esta ventaja resulta relevante en el contexto actual de la medicina, en el que se enfatiza la seguridad del paciente como eje

rector del proceso formativo. Con la simulación se pueden recrear situaciones críticas de alta complejidad sin ameritar un riesgo para los pacientes, y que los estudiantes no dejen de aprender.

Desde la perspectiva económica, los resultados sugieren que la simulación médica, aunque demanda una inversión inicial considerable, se perfila como una alternativa costo-efectiva a mediano y largo plazo. La evidencia muestra que los costos operativos anuales son sustancialmente menores en comparación con la enseñanza tradicional. Además, la capacidad de los centros de simulación para entrenar estudiantes ronda entre los 80-150 por jornada laboral, mientras que un servicio hospitalario contrasta con el promedio de 5-10 estudiantes; esto indica que la simulación incrementa exponencialmente el volumen de formación y la eficiencia educativa. La escalabilidad de la simulación representa una ventaja sustancial frente al modelo tradicional.

El análisis comparativo entre ambos modelos evidencia que la enseñanza clínica tradicional es insustituible en cuanto al desarrollo de juicio clínico, empatía y experiencia directa con los pacientes, pero su estructura presenta limitaciones importantes en la estandarización del aprendizaje, la seguridad del estudiante y del paciente, los altos costos del entrenamiento médico anual y los errores cometidos en la práctica real. En cambio, la simulación médica proporciona un entorno reproducible, controlado y seguro, lo que resulta ideal para la práctica inicial y la consolidación de competencias, especialmente útil para reducir la curva de aprendizaje antes de la exposición hospitalaria, que es en donde luego se va a adquirir la experiencia clínica.

En el ámbito internacional, el costo promedio del entrenamiento médico anual por estudiante ronda los 100,000 dólares estadounidenses. Este dato refuerza la necesidad de estrategias que optimicen los recursos y promuevan una enseñanza eficiente y sostenible. La simulación constituye una respuesta viable ante los retos financieros de las instituciones educativas.

Finalmente, aunque los resultados analizados aseguran los beneficios de la simulación médica, aún existen limitaciones importantes. Muchos estudios presentan variabilidad metodológica y carecen de uniformidad en la evaluación de los costos de cada centro de simulación o de cada simulador en particular. Además, no consideran factores indirectos como el mantenimiento del equipo o el entrenamiento del personal docente, y se requieren investigaciones con metodologías comparativas más robustas que cuantifiquen el retorno de la inversión y el impacto longitudinal en el desempeño del profesional.

La integración de ambos enfoques parece representar el modelo más equilibrado para la formación médica contemporánea.

## Conclusiones

La simulación médica se ha fortalecido como un pilar esencial en la educación médica, al demostrar ser una herramienta y una estrategia pedagógica eficiente. Es complementaria a la enseñanza clínica tradicional en diversos aspectos, ya que su fortaleza radica en la posibilidad de ofrecer una formación estandarizada, segura y reproducible, en la que el error se convierte en una oportunidad de aprender y no en un riesgo para el paciente.

La enseñanza tradicional es insustituible para el desarrollo del juicio clínico y la empatía; el estudiante aprende de cada paciente de manera individualizada de sus síntomas, de su historia y de su contexto social y emocional, siendo estas experiencias las que desarrollan criterio clínico, pero enfrenta limitaciones inherentes a la variabilidad de casos en el entorno clínico.

Desde una perspectiva económica, la simulación médica demuestra ser una alternativa costo-efectiva a mediano y largo plazo, porque refleja una eficiencia operativa superior y una notable escalabilidad del proceso educativo a todos los entornos hospitalarios. En el panorama internacional, la simulación médica ha dejado de ser una herramienta complementaria para convertirse en una industria educativa y tecnológica en expansión.

En conjunto, la evidencia disponible respalda que el enfoque pedagógico más efectivo para la nueva enseñanza clínica es la integración o la adaptación de ambos modelos educativos: la simulación como base estructurada para la adquisición de habilidades y la enseñanza clínica como escenario de aplicación y desarrollo del juicio clínico médico. Esta combinación permite formar médicos no solo técnicamente competentes, sino también empáticos, reflexivos y comprometidos con la seguridad del paciente. Así, la simulación médica no sustituye la práctica clínica, sino que la transforma, la mejora y la proyecta hacia el futuro de la educación médica global.

## Financiamiento

Los autores declaran no haber recibido financiamiento para este estudio.

## Conflicto de intereses

J. Loría-Castellanos es miembro del comité editorial de la revista *Anales Médicos*. Los demás autores declaran no tener conflicto de intereses.

## Consideraciones éticas

**Protección de personas y animales.** Los autores declaran que para esta investigación no se han realizado experimentos en seres humanos ni en animales.

**Confidencialidad, consentimiento informado y aprobación ética.** El estudio no involucra datos personales, historias clínicas ni muestras biológicas humanas, por lo que no requiere aprobación ética. No se aplican las guías SAGER.

**Declaración sobre el uso de inteligencia artificial.** Los autores declaran que no se utilizó ningún tipo de inteligencia artificial generativa para la redacción ni la creación de contenido de este manuscrito.

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CASE REPORT

# Gastric carcinoma in a 25-year-old man with Fanconi anemia: case report and literature review

## *Carcinoma gástrico en un hombre de 25 años con anemia de Fanconi: reporte de caso y revisión de la literatura*

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## Abstract

*Fanconi anemia (FA) is a rare genetic disorder characterized by defective DNA repair, genomic instability, and bone marrow failure. It affects approximately 1 in 200,000 live births and increases the risk of malignancies, including solid tumors. We report a 25-year-old man with FA who presented severe weight loss, vomiting, and oral intolerance. Imaging revealed pyloric stenosis and gastric wall thickening. Endoscopy confirmed intramucosal intestinal-type gastric adenocarcinoma. Despite hematologic optimization, chemotherapy, and total gastrectomy, the patient died from severe malnutrition. Early surveillance and multidisciplinary management are essential to improve outcomes in patients with FA.*

***Keywords:*** *Fanconi. Anemia. Gastric. Adenocarcinoma. Malignancy.*

## Resumen

*La anemia de Fanconi (AF) es un trastorno genético raro caracterizado por defectos en la reparación del ADN, inestabilidad genómica y falla medular. Afecta aproximadamente a 1 de cada 200,000 nacidos vivos y aumenta el riesgo de neoplasias, incluidos tumores sólidos. Se reporta el caso de un hombre de 25 años con AF que presentó pérdida de peso severa, vómitos e intolerancia oral. La panendoscopía mostró estenosis pilórica y engrosamiento gástrico. La endoscopia confirmó adenocarcinoma gástrico intramucoso tipo intestinal. A pesar del manejo hematológico, quimioterapia y gastrectomía total, el paciente falleció por desnutrición severa. La vigilancia temprana y el manejo multidisciplinario son clave para mejorar desenlaces en pacientes con AF.*

***Palabras clave:*** *Fanconi. Anemia. Gástrico. Adenocarcinoma. Malignidad.*

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Date of reception: 05-03-2026
Date of acceptance: 15-05-2026
DOI: 10.24875/AMH.M26000157

Available online: 24-07-2026
An Med ABC. 2026;71(3):240-246
www.analesmedicosabc.com

## Introduction

Fanconi anemia (FA) is a rare genetic disorder associated with profound genomic instability and defects in DNA repair pathways involving the repair of crosslinking between strands. FA occurs in approximately 1 in 200,000 newborns worldwide, with an estimated incidence of 4-7 cases/million live births in Europe[1]. Despite such a molecular deficiency confers vulnerability for a broad spectrum of hematological diseases and solid tumor, only 15% of Fanconi's anemia patients develop malignancies. These are chiefly acute myeloid leukemia and myelodysplastic syndrome, as well as a range of other solid tumors and liver tumors. According to the Cancer Genome Atlas database, the prevalence of somatic mutations in Fanconi anemia complementation group A (FANCA) genes represents ~3% for gastric cancer. FANCA, FANCB, FANCC, FANCE, FANCG, FANCL, and FANCM comprise the FANC family, all representing a variety of genes, making FA a heterogeneous genetic disease. Of these genes, FANCA is the most common and contains a 1455-amino acid nuclear protein and plays a role in a multiprotein complex necessary for DNA repair and chromosomal stability.

Non-synonymous genetic variations (non-synonymous single-nucleotide polymorphisms [nsSNPs]) affecting FANCA carry a specific interest as they modify the amino acid order of the protein and also alter the protein physicochemical and structural properties. These deleterious mutations lead to damage to the repair complex, causing genomic instability and vulnerability to malignant transformation[2].

Similarly, the FANCI gene is involved in the FA repair pathway as a complementary pathway. These pathogenic variants in FANCI impair DNA crosslink repair, leading to progressive bone marrow failure where neoplasms arise from a higher susceptibility[3].

The Fanconi anemia complementation Group D2 (FANCD2)-FANCI interaction through monoubiquitination plays an essential regulatory role in DNA repair, and the dysregulation of FANCD2-FANCI activates cellular stress pathways (ATR-CHK1) and augments alternative, error-prone repair mechanisms, which favors accelerated mutagenesis[4].

The accumulation of somatic mutations and a change of cell cycle checkpoints promote neoplastic transformation in FA[4].

Gastric cancer has been described as one of the frequent solid manifestations in patients with FA; it is characterized by early onset (i.e., 30-40 years) and high histological aggressiveness[5].

Case reports[6,7] demonstrate that even heterozygous variation in genes like FANCA and *FANCD2* may dramatically increase predisposition to gastric adenocarcinoma, indicating that incomplete FA pathway activation will suffice for gastric carcinogenesis activation.

A case about 25-years-old male with FA and Gastric carcinoma is presented.

## Case report

We report a 25-year-old male who was diagnosed at 14 years of age with FA, as shown by peripheral blood tests that were positive for chromosomal fragility (Fig. 1).

He had been on monitoring with hematology and had multiple red blood cell transfusions for transfusion-dependent anemia. His treatment medicines were filgrastim, folic acid, and prednisone. His mother had died of acute lymphoblastic leukemia, according to family history.

The patient presents in April 2025 with unexplained, severe weight loss of 25 kg, an intolerance to oral food and drinks without predilection for solids or liquids, and severe asthenia and emesis.

The physical examination showed a patient with a height of 145 cm, weight of 20 kg, bird-like facial traits as reported in the literature, a small head, small eyes, no bone abnormalities, and genitals consistent with Tanner stage 1. The patient looked chronically ill, pale, and severely undernourished, with severe muscle deficiency consistent with malnutrition (Fig. 2).

Vital signs were stable. On abdominal examination, splenomegaly was present, and a spleen palpable 7 cm beneath the costal margin. There was mild diffuse abdominal tenderness without any evidence of peritoneal irritation. No evidence of peripheral lymphadenopathy.

Laboratory examination demonstrated severe normocytic normochromic anemia, leukopenia, and thrombocytopenia, suggestive of pancytopenia secondary to FA. Biochemically, hypoalbuminemia and electrolyte imbalance were identified, indicative of malnutrition and poor oral intake. The chest and abdomen were detected with a computed tomography (CT) (May, June 2025). The latter showed gastric distention with pyloric wall thickening and stenosis, and splenomegaly. Pulmonary examination yielded a right subpleural pulmonary cyst and a micronodule of non-specific etiology. On follow-up CT, there was progression of at least three solid nodules in the right lung. An increased

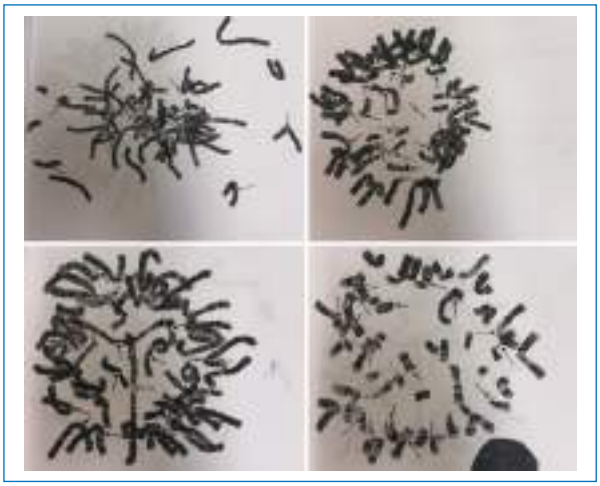

**Figure 1.** Representative metaphase spreads obtained from peripheral blood lymphocyte cultures after mitomycin C exposure, showing increased chromosomal fragility. Multiple chromatid and chromosome breaks, gaps, and structural abnormalities are indicated by arrows, consistent with a positive chromosomal fragility test.

**Figure 2.** Clinical photograph of the patient showing characteristic bird-like facial features and severe undernutrition.

metabolic activity was observed on positron emission tomography-CT (June 2025, at the pyloric area, maximum standardized uptake value of 9.67): Neoplastic activity, with no signs of hypermetabolic pulmonary lesions. Intramucosal gastric adenocarcinoma of intestinal type was identified after upper gastrointestinal endoscopy with biopsy performed in June 2025, a biopsy associated with antral gastritis and incomplete intestinal metaplasia. A *Helicobacter pylori* infection was also identified (Fig. 3).

Treatment was carried out by a multidisciplinary team that included hematology, oncology, surgery, gastroenterology, and nutrition. The initial treatment consisted of filgrastim for hematologic optimization, folic acid 5 mg daily, prednisone 5 mg daily doses, and nutritional watch as a result of severe malnutrition and sarcopenia. The patient underwent five cycles of the FLOT protocol treatment with poor adherence as a result of a lack of drugs and environmental determinants in the family. The main surgical management was total gastrectomy with bursectomy, splenectomy, cholecystectomy, and mechanical esophagojejunostomy with tumor resection. In the post-operative period, hematologic care, nutritional rehabilitation, and follow-up were provided. Ultimately, the patient died as a result of chronic and sustained malnutrition despite all attempts to restore his nutritional status.

## Literature review

### *Methodology*

A systematic review was conducted on PubMed and Google using the keywords: gastric adenocarcinoma and FA, including clinical cases, literature reviews, and original articles, with no restrictions on year of publication.

Forty-one articles were found, of which 32 were excluded due to the lack of association between gastric cancer and FA. Of the nine articles included in the study, three are original articles, three are case reports and literature reviews, and three are case reports only. Artificial intelligence (AI) support was used for spelling and text editing (Fig. 4).

### *Literature review*

Below, we list the reviewed articles on FA and gastric adenocarcinoma published between 1981 and 2025.

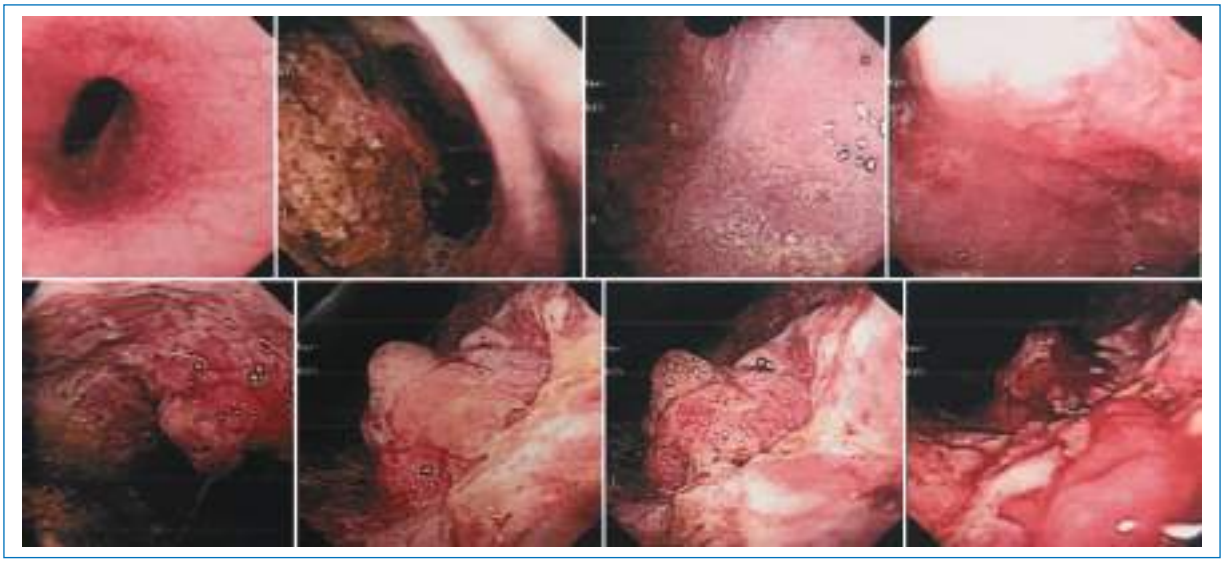

**Figure 3.** Upper gastrointestinal endoscopy images showing an infiltrative gastric lesion involving the antrum and pylorus, with regular mucosa, friability, and marked luminal narrowing consistent with complete pyloric stenosis. Findings are suggestive of gastric neoplasia.

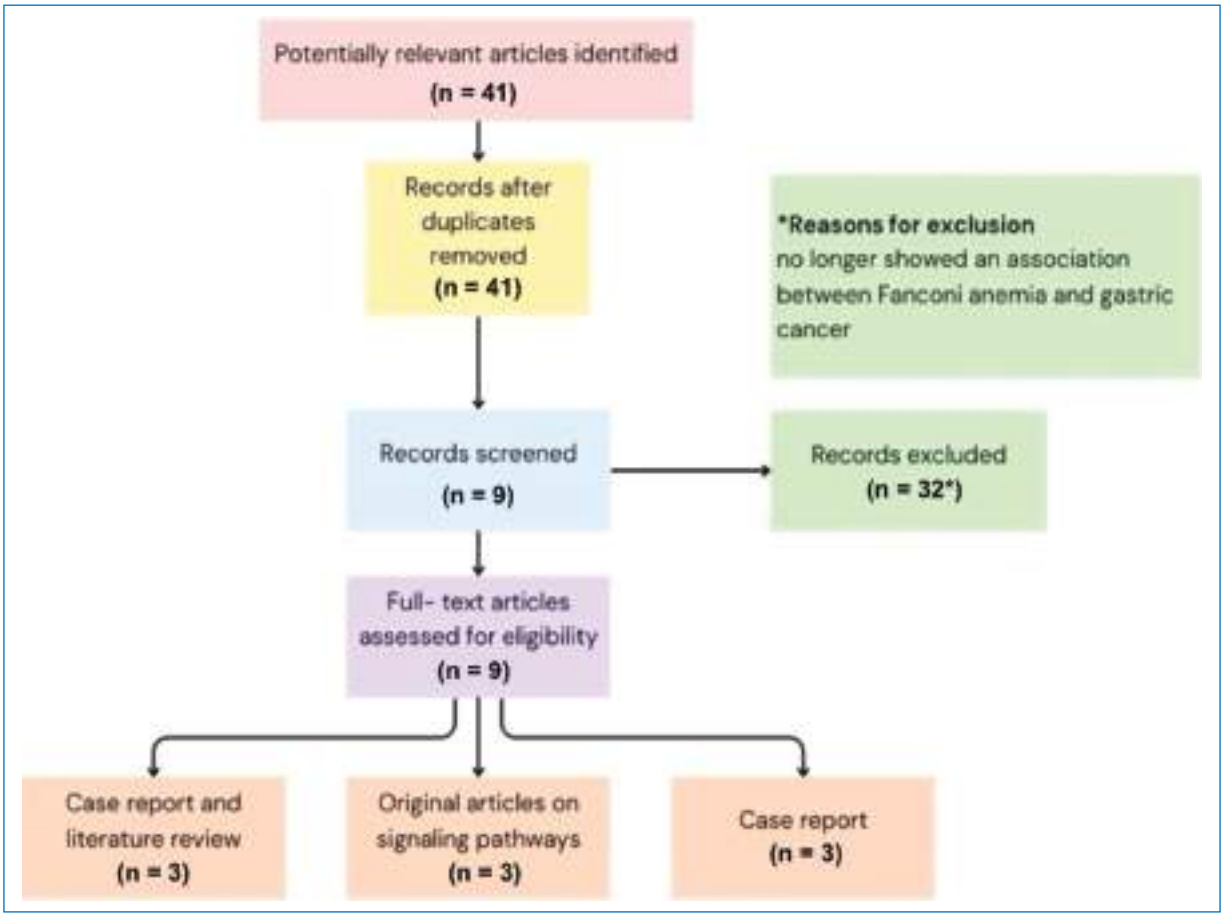


**Figure 4.** Selection of articles regarding FA and gastric cancer. FA: Fanconi anemia.

**Table 1.** Case reports of FA and gastric cancer

| Case | Country | Age | FA gene/ mutation | Type of gastric cancer | Key findings | Outcome/key conclusion |
|---|---|---|---|---|---|---|
| Zheng et al., 2025[4] | China | 32 | FANCD2 pathogenic variant (N1378Sfs*5) | Poorly differentiated gastric adenocarcinoma | Early onset, highly aggressive tumor, severe hematologic fragility | Rapid progression. Authors propose FANCD2 as a genetic risk factor |
| Pavithran et al., 2002[5] | India | 22 | FA diagnosed in adulthood | Intestinal-type gastric adenocarcinoma | FA diagnosed at 22, rapid progression to gastric cancer | Died 4 month later, after diagnosis. Authors recommend early endoscopic checkup |
| Hill et al., 1981[8] | United Kingdom | 21 | Classic FA | Gastric carcinoma | Early historical documentation of FA-associated gastric cancer | Died due to massive gastrointestinal bleeding |

FA: Fanconi anemia; FANCD2: Fanconi anemia complementation group D2.

**Table 2.** Case reports with literature reviews of FA and gastric cancer

| Article | Country | Age | FA gene/mutation | Type of cancer | Contribution | Key conclusion |
|---|---|---|---|---|---|---|
| Huang et al., 2018[7] | Taiwan | 65 | FANCA D1359Y | Gastric adenocarcinoma + diffuse gastric polyposis | Reviews FA pathway alterations through gastric cancer molecular subtypes | Monoallelic FANCA variants may predispose to gastric cancer |
| Xia et al., 2020[6] | China | 48 | FANCA (germline heterozygous mutation) | Gastric adenocarcinoma and thyroid papillary carcinoma. | Revision of primary malignancies associated with FANCA mutations | Increased risk of multiple malignancies associated with FANCA mutation, resulting in poor prognosis |
| Dyaczyński et al., 2024[1] | Poland | 31 | FA | Appendiceal carcinoma (Mucinous, focal mucocellular malignancy, grade 3), lip cancer | Review highlighting the predisposition of multiple malignancies in FA patients | Emphasizes the need for intensive and early oncologic surveillance |

FA: Fanconi anemia; FANCA: Fanconi anemia complementation group A.

Table 1 lists case reports of patients with FA and gastric cancer, table 2 lists cases reports and reviewing the literature on FA and gastric cancer, and table 3 lists original articles on FA and gastric cancer (Tables 1-3).

Patients with FA have consistently developed poorly differentiated gastric adenocarcinomas, frequently due to chronic gastritis, intestinal metaplasia, and polyposis, according to the clinical reports reviewed. Cases reported since the 1980s[5,8] pioneered the first associations between FA and gastric cancer, while recent studies[4] have pinpointed signatures of mutation, including FANCD2 N1378Sfs*5, that change the transcription of more than 30 genes associated with apoptosis and chromatin modulation.

The diagnosis of gastric cancer in patients with FA based on classic oncological approaches (endoscopy, biopsy, imaging studies) is limited by hematological frailty and poor tolerance of aggressive treatment. Early detection is critical – however, the earliest symptoms are usually non-specific (dyspepsia, early satiety, epigastric pain).

The introduction of genetic and proteomic biomarkers based on the nsSNP analysis in FANCA provides novel potential to predictive earlier risk and patient stratification. The *in silico* monitoring enables the detection of deleterious mutations and the association between mutations and patient susceptibility level[2].

New studies[12] showed that the composition of the gut microflora of gastric cancer patients underwent remarkable changes in recent years in the gut microbiome, indicating an important involvement of the microbiota in tumorigenesis and tumor progression.

**Table 3.** Original articles of FA and gastric cancer

| Article | Country | FA gene/mutation | Type of cancer | Contribution/key finding | Outcome/key conclusion |
|---|---|---|---|---|---|
| Wang et al., 2024[9] | China | FANCA overexpression | Gastric cancer | Experimental study, which demonstrates that FANCA promotes G1/S cell cycle progression, proliferation and invasion in gastric cancer cells | Identifies FANCA as an oncogenic driver and a potential target in the treatment of gastric cancer |
| Nepal et al., 2017[10] | United Kingdom | FA pathway genes (FANCA, FANCD2, BRCA axis) | Multiple cancers, including gastrointestinal tumors | Synthesis of FA signaling, DNA damage response, and carcinogenesis | Identifies FA signaling as a tumor suppressor whose disruption promotes cancer |
| Zhang and Fu, 2021[11] | China | ALDH2 pathway (DNA damage, associated metabolism) | Gastric and other gastrointestinal cancers | Reviews the function of ALDH2 dysfunction in aldehyde accumulation, genomic instability, and tumor progression | Positions ALDH2 as a complementary molecular pathway which contributes to gastrointestinal carcinogenesis |

FA: Fanconi anemia; GC: gastric cancer; FANCA: Fanconi anemia complementation group A; FANCD2: Fanconi anemia complementation group D2; BRCA axis: BRCA-related DNA repair pathway; ALDH2: aldehyde dehydrogenase 2.

Bridging genomic and proteomic data in clinical practice is one of the major steps forward to precision medicine.

Functional evaluation of FANCA mutations and complementary DNA repair genes, such as FANCA and other DNA repair genes, informs the development of personalized surveillance and treatment. This work would enable pharmacologically effective therapies with reduced toxicity due to the lower toxicity of the therapeutic compounds and thus a much more complete answer to a critical and widely accepted question about gene therapy in this cancer group.

Moreover, FANCA identification of ligand binding sites represents an opportunity for target therapies that partially reinvigorate DNA repair. Such approaches may further enhance the survival and quality of life of patients with FA and gastric cancer.

AI can be used for automated systematic reviews that can synthesize large literature streams and identify potential patterns. They would then enable interdisciplinary, meta-research to integrate genetic, oncologic, and computational biology considerations[13].

Nevertheless, innovation must be counterbalanced by practical implementation, given the feasibility, accessibility, and equity issues involved in the application of new diagnostic and therapeutic technologies.

## Conclusions

The available data demonstrate that FA and gastric cancer share a similar biological basis in the form of DNA repair deficiency and genomic instability.

Such mutations in FANCA, FANCI, and FANCD2 not only account for hematological predisposition but also predispose the developing of aggressive solid tumors at an early stage in the life course.

Identifying deleterious mutations, generating more proteomic biomarkers, and discovering the gut microbiome provide new approaches to early identification and prevention. But obstacles persist in applying genomic data clinically and devising individualized care protocols.

The future of FA and gastric cancer research is in interdisciplinary cooperation, AI use in the routine review setting, and strategies that integrate science and patients' health.

The patient was very young when he presented, and due to his socioeconomic conditions, it was not possible to determine the cytogenetic alterations of the tumor in time. However, it is vitally important to make recommendations for the timely detection of this type of pathology in patients with FA, given the importance of ensuring the best clinical conditions for the patient to achieve better survival outcomes.

## Funding

The authors declare that they have not received funding.

## Conflicts of interest

J. Loría-Castellanos is member of the editorial committee of the journal *Anales Médicos*. The other authors declare no conflicts of interest.

## Ethical considerations

**Protection of human subjects and animals.** The authors declare that no experiments on humans or animals were performed for this research.

**Confidentiality, informed consent, and ethical approval.** This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

**Declaration on the use of artificial intelligence.** The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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PERMANYER



REPORTE DE CASO

# Síndrome de choque tóxico estreptocócico y paradoja de la microcirculación: reporte de un caso y revisión de la literatura

## *Streptococcal toxic shock syndrome and microcirculation paradox: a case report and literature review*

*Janet S. Aguirre-Sánchez*, Francisco Moreno-Sánchez, Julio C. Rivera-Soto y Jesús G. Hernández-García*

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## Resumen

*Mujer de 57 años en tratamiento con infliximab por enfermedad de Crohn que desarrolló síndrome de choque tóxico estreptocócico fulminante por Streptococcus pyogenes. Evolucionó rápidamente a choque cardiogénico refractario y coagulopatía por consumo, con depleción de proteína C y antitrombina III en menos de 6 horas. A pesar del soporte avanzado con oxigenación por membrana extracorpórea venoarterial y de la normalización de la macrocirculación, la paciente presentó necrosis tisular irreversible. Este caso ilustra la futilidad del soporte extracorpóreo ante una microtrombosis establecida y la necesidad de una sospecha clínica ultratemprana en pacientes inmunomodulados.*

***Palabras clave:*** *Choque tóxico estreptocócico. Oxigenación por membrana extracorpórea. Microcirculación. Infliximab. Coagulopatía.*

## Abstract

*We report a case, 57-year-old female infliximab therapy for Crohn's disease who developed fulminant streptococcal toxic shock syndrome due to Streptococcus pyogenes. The clinical course led to refractory cardiogenic shock and consumption coagulopathy, with protein C and antithrombin III depletion in less than six hours. Despite advanced veno-arterial extracorporeal membrane oxygenation support and normalization of macrocirculatory parameters, irreversible tissue necrosis ensued. This case highlights the futility of extracorporeal support once microthrombosis is established and emphasizes the critical importance of ultra-early clinical suspicion in immunomodulated patients facing septic myocardial injury.*

***Keywords:*** *Toxic shock syndrome. Extracorporeal membrane oxygenation. Microcirculation. Infliximab. Coagulopathy.*

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Fecha de recepción: 07-04-2026
Fecha de aceptación: 25-05-2026
DOI: 10.24875/AMH.M26000164

Disponible en internet: 24-07-2026
An Med ABC. 2026;71(3):247-251
www.analesmedicosabc.com

## Introducción

El síndrome de choque tóxico estreptocócico es una enfermedad fulminante mediada por superantígenos de *Streptococcus pyogenes* (estreptococo del grupo A), caracterizada por una progresión rápida hacia la falla orgánica múltiple y una mortalidad que supera el 30-50% incluso con un manejo intensivo óptimo[1,2]. A pesar de los avances en el soporte orgánico extracorpóreo y las terapias de rescate, la letalidad del síndrome de choque tóxico estreptocócico se mantiene elevada, particularmente en pacientes con factores de riesgo emergentes, como el uso crónico de fármacos inmunomoduladores (por ejemplo, terapias dirigidas contra el factor de necrosis tumoral alfa [TNFα])[3].

La fisiopatología del síndrome de choque tóxico estreptocócico implica un cortocircuito inmunológico. A diferencia de los antígenos convencionales, los superantígenos estreptocócicos (como SpeA y SpeC) se unen directamente al complejo principal de histocompatibilidad de clase II y al receptor de linfocitos T, activando hasta el 30% de la población total de linfocitos T de forma simultánea[4]. Esto desencadena una liberación masiva y descontrolada de citocinas proinflamatorias (interleucinas 1 y6, TNFα), que conduce a vasodilatación extrema, fuga capilar y coagulopatía de consumo catastrófica[5].

Este fenómeno genera lo que se denomina «paradoja hemodinámica»: la posibilidad técnica de restaurar el flujo macrocirculatorio y la presión de perfusión mediante soporte avanzado (vasopresores, inotrópicos y oxigenación por membrana extracorpórea [ECMO]), mientras la microcirculación sucumbe irremediablemente ante una trombosis intravascular diseminada[6].

El presente caso describe el curso clínico de una paciente bajo terapia biológica que desarrolló síndrome de choque tóxico estreptocócico, destacando los límites biológicos del soporte extracorpóreo frente a la microtrombosis establecida.

## Caso clínico

Mujer de 57 años con antecedente de enfermedad de Crohn en tratamiento con infliximab desde hace 14 años. Inició su padecimiento 3 días previos a su ingreso con tos no productiva, malestar general, astenia, adinamia y alza térmica no cuantificada, automedicándose con analgésicos y ciprofloxacino, sin presentar mejoría.

A su llegada al servicio de urgencias mostraba datos de choque: presión arterial 67/42 mmHg, frecuencia cardiaca de 115 latidos por minuto y saturación periférica de oxígeno del 83% al aire ambiente. Los laboratorios iniciales revelaron una respuesta inflamatoria grave, acidosis metabólica y lesión renal aguda (Tabla 1).

Se documentó inicialmente panel respiratorio positivo para SARS-CoV-2, y posteriormente, de forma relevante para la evolución del caso, un cultivo de secreción bronquial y líquido pleural con crecimiento de *Streptococcus pyogenes* (Fig. 1).

Ante la refractariedad al manejo hídrico inicial y el requerimiento de doble vasopresor a dosis máximas, sumado a la documentación ecocardiográfica de miocardiopatía séptica grave con gasto cardiaco crítico, el equipo multidisciplinario decidió el inicio de soporte con ECMO venoarterial.

Tras la canulación y la estabilización inicial en ECMO venoarterial se logró la optimización de los parámetros macrocirculatorios, alcanzando flujos de 4.5 l/min y normalización de la presión arterial media. Sin embargo, en las primeras horas de estancia en la unidad de cuidados intensivos, la paciente presentó coagulopatía de consumo fulminante, evidenciando un colapso total del sistema de control fibrinolítico endógeno (Tabla 2).

De forma concomitante, a pesar de la perfusión sistémica preservada por el soporte extracorpóreo, se observó la aparición y la progresión rápida de necrosis cutánea extensa en las extremidades y el tronco. Este fenómeno confirmó la oclusión de la microcirculación por microtrombosis masiva, fenómeno irreversible, por lo que el dispositivo de ECMO venoarterial resultó fútil como medida de rescate tisular (Fig. 2).

Pese al manejo oportuno con terapia antimicrobiana de amplio espectro y el uso de linezolid para lograr el bloqueo ribosomal de superantígenos, la paciente evolucionó a falla orgánica múltiple refractaria y falleció a los 4 días de su ingreso.

## Discusión

El síndrome de choque tóxico estreptocócico representa uno de los desafíos clínicos y fisiopatológicos más complejos en medicina crítica. La particularidad y la agresividad de este caso radican en un doble golpe sistémico: la inmunomodulación crónica por infliximab y la extrema velocidad de la cascada de la coagulación.

### *Inmunomodulación y presentación atípica*

El infliximab, al inhibir el TNFα, altera la respuesta inflamatoria temprana[7]. Esto explica por qué la paciente

**Tabla 1.** Parámetros de laboratorio y gasometría al ingreso

| Parámetro | Valor al ingreso |
|---|---|
| Biometría hemática y química sanguínea | |
| Leucocitos | 25,600/µl |
| Proteína C reactiva | 31.8 mg/dl |
| Creatinina sérica | 3.4 mg/dl |
| Lactato sérico | 6.50 mmol/l |
| Gasometría arterial | |
| pH | 7.2 |
| $pCO_2$ | 45.3 mmHg |
| $pO_2$ | 28.4 mmHg |
| $HCO_3$ | 18.3 mEq/l |
| Exceso de base | -6.1 |

**Tabla 2.** Criterios diagnósticos de síndrome de choque tóxico estreptocócico cumplidos por la paciente

| Criterio diagnóstico | Hallazgo en la paciente |
|---|---|
| Aislamiento de *Streptococcus pyogenes* | Positivo<br>Documentado en cultivo de secreción bronquial y líquido pleural |
| Hipotensión clínica | Presente<br>Presión arterial 67/42 mmHg al ingreso y choque refractario |
| Afección multiorgánica (≥ 2 órganos) | Presente<br>Falla renal aguda (creatinina 3.4 mg/dl)<br>Coagulopatía de consumo fulminante<br>Síndrome de dificultad respiratoria aguda<br>Necrosis tisular cutánea extensa |

cursó con síntomas iniciales inespecíficos, sin una respuesta térmica regular en los días previos, enmascarando la gravedad de la infección. Como señalan diversos reportes, los pacientes bajo terapias biológicas pueden presentar una disociación entre la magnitud de la carga bacteriana y los signos clínicos clásicos de sepsis, lo que retrasa el reconocimiento del síndrome de choque tóxico estreptocócico[8].

## Fisiopatología de la microtrombosis y depleción de anticoagulantes

La literatura actual, particularmente los trabajos de Atchade et al.[9], enfatizan que en el síndrome de choque tóxico estreptocócico la producción de exotoxinas pirogénicas actúa como un disparador explosivo de la expresión del factor tisular en monocitos y células endoteliales. En nuestra paciente, la ventana de oportunidad terapéutica fue extremadamente estrecha. La tormenta de citocinas indujo un consumo masivo de

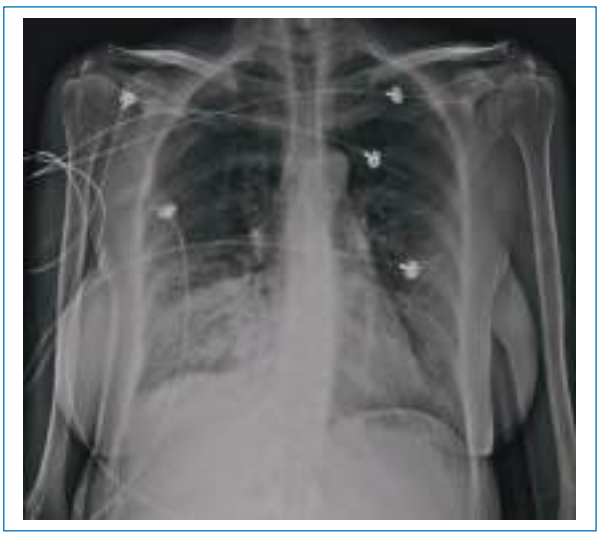

**Figura 1.** Hallazgos de imagen iniciales que evidencian el compromiso cardiopulmonar agudo.

los factores inhibidores de la coagulación; la depleción de proteína C y de antitrombina III ocurrió en cuestión de horas, mucho antes de que las medidas adyuvantes pudieran modular la respuesta inmunitaria sistémica[10] (Fig. 3).

## La paradoja hemodinámica y el rol de la ECMO

El uso de ECMO venoarterial en el choque séptico refractario es una medida de rescate documentada, destinada a proveer soporte circulatorio y oxigenación mientras se resuelve la causa subyacente[11]. Como señalan Hollenberg y Singer[12], la miocardiopatía séptica es profundamente depresora, pero en teoría reversible. Sin embargo, la supervivencia está absolutamente condicionada a la integridad del endotelio capilar.

En este caso documentamos una paradoja hemodinámica: el dispositivo de ECMO venoarterial fue exitoso para mantener la macrocirculación (flujos óptimos, presión arterial media en metas), pero inútil para perfundir los tejidos periféricos, debido a que los lechos capilares estaban ocluidos por microtrombos de fibrina. Esto demuestra que la tecnología extracorpórea tiene un límite biológico infranqueable cuando el daño endotelial es extenso e irreversible[13].

## Terapias adyuvantes

El manejo contemporáneo del síndrome de choque tóxico estreptocócico exige eliminar la producción de toxinas.

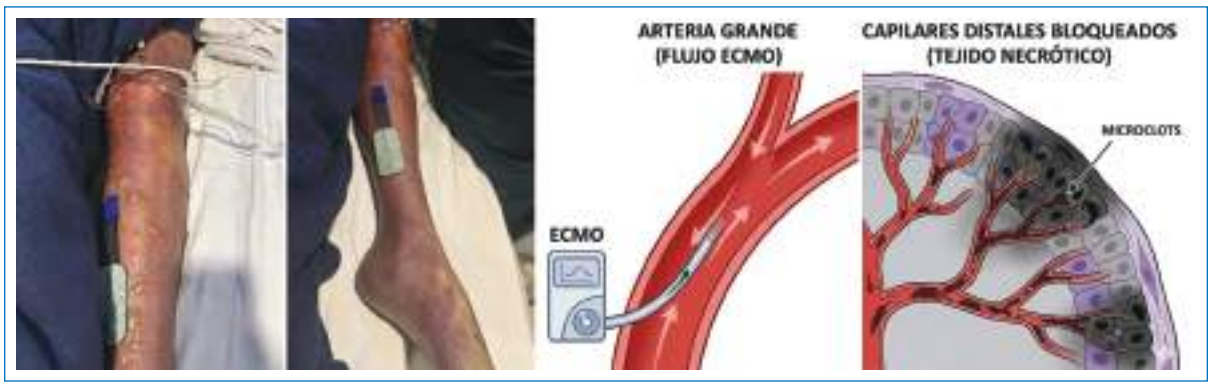


**Figura 2.** Representación de la oclusión microvascular y de la necrosis cutánea extensa en el síndrome de choque tóxico estreptocócico, un estado irreversible ante el soporte extracorpóreo.

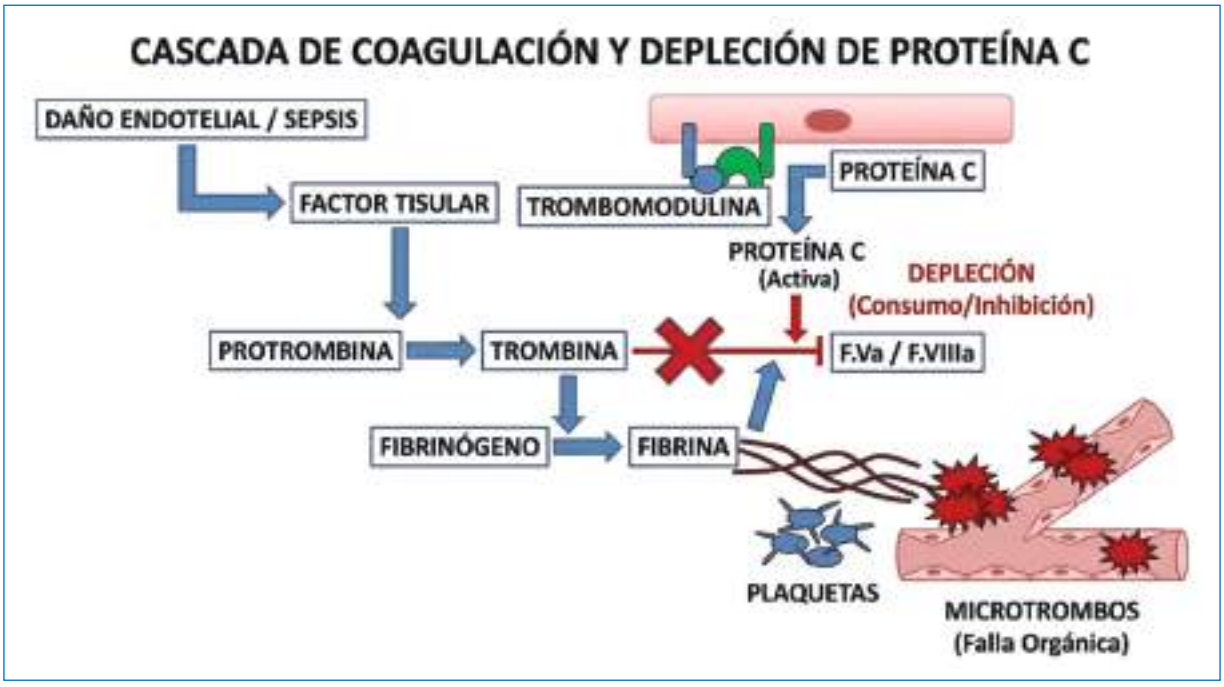


**Figura 3.** Mecanismo de la coagulopatía fulminante: consumo de anticoagulantes naturales inducido por la tormenta inflamatoria.

El uso de betalactámicos, aunque bactericida, puede aumentar transitoriamente la liberación de toxinas al destruir la pared celular. Por ello, es imperativo el uso temprano de inhibidores de la síntesis proteica (clindamicina o linezolid), que bloquean la subunidad ribosomal 50S y detienen la producción de superantígenos independientemente de la fase de crecimiento bacteriano (efecto Eagle)[14]. Además, las guías actuales recomiendan fuertemente la inmunoglobulina intravenosa como terapia neutralizante directa contra los superantígenos circulantes[15].

## Conclusiones

El abordaje del síndrome de choque tóxico estreptocócico exige un cambio de paradigma en la terapia intensiva, transicionando de un soporte meramente hemodinámico a una modulación inmunitaria agresiva y ultratemprana. El presente reporte nos deja tres enseñanzas fundamentales para la práctica clínica de alta especialidad:

– Alta sospecha clínica: en pacientes con terapias inmunomoduladoras (como anti-TNFα), la presentación inicial puede ser engañosa, subclínica o cursar sin fiebre.

La estabilidad hemodinámica inicial es una ilusión que se quiebra abruptamente ante la carga bacteriana masiva.

- Manejo antitoxina como prioridad: la erradicación del patógeno es insuficiente si no se frena la producción de superantígenos. La adición temprana de clindamicina o linezolid es imperativa para lograr el bloqueo ribosomal. De igual forma, el uso de inmunoglobulina intravenosa está altamente recomendado para neutralizar las exotoxinas antes de que se produzca un daño endotelial irreversible.
- El tiempo es microcirculación: la disfunción miocárdica en el síndrome de choque tóxico estreptocócico es potencialmente reversible, pero el soporte avanzado con ECMO será fútil si la microcirculación ha sucumbido ante la coagulopatía de consumo catastrófica. Cada minuto de retraso en la sospecha y el tratamiento dirigido se traduce en isquemia y necrosis tisular.

En última instancia, la complejidad técnica de dispositivos como la ECMO debe ir siempre acompañada de una excelencia clínica y humana que logre anticiparse a la biología implacable del síndrome de choque tóxico estreptocócico.

## Financiamiento

Los autores declaran no haber recibido financiamiento para este estudio.

## Conflicto de intereses

Los autores declaran no tener conflicto de intereses.

## Consideraciones éticas

**Protección de personas y animales.** Los autores declaran que para esta investigación no se han realizado experimentos en seres humanos ni en animales.

**Confidencialidad, consentimiento informado y aprobación ética.** Los autores han obtenido la aprobación del Comité de Ética para el análisis de datos clínicos obtenidos de forma rutinaria y anonimizados. Debido a la naturaleza del estudio, no fue necesario el consentimiento informado individual. Se han seguido las recomendaciones éticas pertinentes.

**Declaración sobre el uso de inteligencia artificial.** Los autores declaran que no se utilizó ningún tipo de inteligencia artificial generativa para la redacción ni la creación de contenido de este manuscrito.

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