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Structural Analysis Of Critical Factors Of Postoperative Complications In Diabetic Patients: Application Of The MICMAC Method

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ABSTRACT

Background: Diabetes mellitus significantly increases the risk of postoperative complications, but most studies have analyzed risk factors in isolation, without considering their systemic interdependencies.

Methods: A prospective-analytical study with a structural approach was carried out using the MICMAC method to identify and classify critical variables associated with postoperative complications in diabetic patients. Variables were selected through a systematic review (2015–2023) and validated using a modified Delphi panel with experts in surgery and related medical disciplines. A matrix of direct influence was constructed, and driving force and dependency indices were calculated.

Results: A total of fifteen variables were analyzed. Perioperative glycemic control, cardiovascular comorbidities, duration and complexity of surgery, antibiotic prophylaxis, and adherence to perioperative protocols were classified as key determinants with high driving force in the system. Link variables, such as preoperative glycosylated hemoglobin and type of anesthesia, among others, showed high influence and high dependence, evidencing system instability. Dependent factors such as diabetic nephropathy and advanced age appeared as consequences of the system. Sensitivity analysis confirmed the robustness of the classification.

Conclusions: Postoperative complications in diabetic patients arise from a highly interrelated system that combines clinical, surgical, and organizational determinants. The MICMAC method represents an innovative approach to prioritize risk factors and design safer surgical protocols tailored to this high-risk population.

Keywords: Hyperglycemia, immunity, wound healing, protocols, perioperative morbidity, hospital management.

INTRODUCTION

Diabetes mellitus is one of the most prevalent chronic diseases, and its impact on surgical practice is increasingly relevant. According to the International Diabetes Federation (IDF) Diabetes Atlas, more than 500 million adults are living with diabetes, with projections that this number will exceed 780 million by 2045 (Sun et al., 2022). This condition significantly increases the risk of postoperative complications, resulting from alterations in wound healing, immune response, and metabolic homeostasis (Martin et al., 2016).

Several studies have documented that diabetic patients have a higher incidence of surgical site infection, delayed healing, cardiovascular complications, and postoperative mortality compared to patients without diabetes (Smiley & Umpierrez, 2006; Luo, et al., 2022). A study by Bitzer, et al. (2021) confirmed that diabetes is an independent risk factor for surgical infections, while Shohat et al. (2018) showed that poor perioperative glycemic control significantly increases the likelihood of complications. Likewise, population-based studies have shown that diabetes is associated with a significant increase in 30-day mortality in major surgery, confirming its role as an independent risk factor (Belmont et al., 2014).

Despite these advances, the state of the art reveals that most research has addressed risk factors in isolation, such as glycemic control, obesity, smoking, or duration of surgery, without considering the interdependencies between clinical, surgical, and systemic variables (Galway et al., 2021; Hagedorn et al., 2023). This limited approach diminishes the possibilities that professionals have to understand the multifactorial nature of postsurgical complications in diabetics and hinders the prioritization of effective preventive interventions.

The objective of the study is to analyze the determining factors of postoperative complications in diabetics, using the MICMAC method (Multiplication Cross Impact Matrix Applied to a Classification), to classify, prioritize variables, and obtain a greater understanding, thereby seeking to obtain an integrative vision that allows a design of safer surgical protocols in this high-risk population.

The justification for this study is based on the need for an analytical tool capable of not only identifying risk factors but also providing visibility into their hierarchical interactions. The MICMAC method, used for prospective studies in various sectors, including public and hospital health (Arcade et al., 2014; Godet, 1994), offers an innovative approach to analyzing complex systems and prioritizing strategic variables. However, it has not been applied to studies of surgical complications associated with diabetes.

In this sense, the contribution of the present study lies in applying the MICMAC method to map, classify, and order the factors that are critical in postoperative complications of diabetic patients. This will allow for: (1) obtaining information on the relations between clinical and surgical variables, (2) showing those determining elements with great motor capacity, and (3) providing practical evidence for the design of safer surgical protocols and hospital strategies aimed at reducing morbidity and mortality in this population. In this way, an innovative analytical framework is proposed that can be applied to both clinical optimization and institutional planning.

METHODOLOGY

A prospective-analytical study with a structural approach was carried out, aimed at detecting and classifying critical variables associated with postoperative complications in patients with diabetes mellitus by applying the MICMAC method, a complex systems analysis technique that allows classifying variables based on the influences and dependencies that maintain the variables in the system (Godet, 1994).

The initial variables were selected through a systematic review of the literature on postoperative complications of diabetic patients published in journals indexed in Scopus and PubMed between 2015 and 2023. This review included cohort studies, meta-analyses, and clinical guidelines (Martin et al., 2016; Zhang et al., 2015). A modified Delphi method was then applied with a multidisciplinary panel of experts composed of general surgeons, endocrinologists, infectious disease specialists, anesthesiologists, and nurses specialized in perioperative care. This process allowed for the validation and prioritization of a definitive set of relevant clinical, surgical, and systemic variables.

With the agreed-upon variables, the matrix of direct influence (MDI) was constructed, where the experts judged the intensity of the impact of each variable on the rest of them, using an ordinal scale (0 = no influence, 1 = low, 2 = moderate, 3 = strong). This procedure followed the classic structural analysis methodology proposed by Godet (2001) and used in public health for prioritizing risk factors (Mahmoudi & Mohamed, 2018).

The matrix was processed using MICMAC® software, which allows calculating the driving force (capacity for influence) and dependency (degree of vulnerability) of each variable. The results were represented in a driving force -dependency dispersion map, classifying the variables into four categories: Key determinants (high driving force, low dependency); Dependent variables (low driving force, high dependency); Autonomous variables (low driving force and dependency); and Link variables (high driving force and dependency).

To ensure consistency of the results, sensitivity analyses were performed by modifying the weights assigned by the experts and comparing the stability of the final classification of variables. The findings were compared with empirical evidence available in observational studies and recent systematic reviews on postoperative complications in diabetics (Critchley et al., 2018). Furthermore, the study was conducted in accordance with the principles outlined in the Declaration of Helsinki, and the participating experts signed informed consent for inclusion in the study.

RESULTS

This section presents the findings derived from the application of the MICMAC method to the analysis of critical factors associated with postoperative complications in patients with diabetes mellitus. The results are structured in four main stages: first, the characterization of the panel of experts who participated in the modified Delphi process; second, the selection and validation of the initial variables obtained from the systematic review; third, the construction and analysis of the MDI, with the corresponding classification of variables in the driving force-dependence map; and finally, the sensitivity analysis.

1. Characteristics of the expert panel

The Delphi panel consisted of 15 healthcare professionals with experience in the surgical care of patients with diabetes mellitus in Colombia. Table 1 shows the distribution by specialty: 5 general surgeons (33.3%), 3 endocrinologists (20%), 3 anesthesiologists (20%), 2 infectious disease specialists (13.3%), and 2 nurses specialized in perioperative care (13.3%). The average professional experience was 14.6 ± 5.2 years, with a range of 8 to 25 years.

Table 1. Characteristics of the panel of experts participating in the Delphi study

Specialty	n	%
General surgeons	5	33.3
Endocrinologists	3	20.0
Anesthesiologists	3	20.0
Infectious disease specialists	2	13.3
Nurses specialized in perioperative care	2	13.3

Source: Authors

During the validation rounds, a consensus level of 82% was reached in the identification and prioritization of critical variables, exceeding the 70% threshold considered adequate in the methodological literature for Delphi studies (Hsu & Sandford, 2007).

2. Selection and validation of variables

The initial systematic review identified 45 variables associated with postoperative complications in patients with diabetes mellitus. These variables included clinical, surgical, and systemic factors. After applying the modified Delphi method, the multidisciplinary panel reached an 82% consensus to prioritize those with the greatest potential impact on perioperative morbidity and mortality. To optimize the structural analysis, each variable was coded alphanumerically according to its category (VC = clinical variables, VQ = surgical variables, VS = systemic variables). This coding allows for more organized management of information within the MICMAC® software and facilitates the graphical interpretation of the results.

A total of 15 critical variables were defined, as shown in Table 2: 6 clinical variables (VC1–VC6), 5 surgical variables (VQ1–VQ5), and 4 systemic variables (VS1–VS4). The clinical variables include metabolic determinants and comorbidities associated with diabetes; the surgical variables represent characteristics of the procedure and perioperative practice; while the systemic variables integrate organizational and quality of care aspects.

Table 2. Critical variables associated with postoperative complications in patients with diabetes mellitus selected for the MICMAC analysis

Variable category	Code	Variables included	Justification in literature
Clinical (6)	VC1	Perioperative glycemic control	Reported as determinants of complications and mortality in cohorts and meta-analyses.
	VC2	Preoperative glycated hemoglobin (HbA1c)	
	VC3	Nutritional status (malnutrition/obesity)	
	VC4	Cardiovascular comorbidity	
	VC5	Diabetic nephropathy	
	VC6	Advanced age	
Surgical(5)	VQ1	Procedure duration	Associated with increased risk of infection, delayed healing, and mortality.
	VQ2	Surgical complexity	
	VQ3	Type of anesthesia	
	VQ4	Intraoperative blood loss	
	VQ5	Adequate antibiotic prophylaxis	
Systemic (4)	VS1	Adherence to perioperative protocols	Key organizational factors to reduce morbidity and mortality, highlighted in clinical guidelines and systematic reviews.
	VS2	Experience of the surgical team	
	VS3	Access to critical care units	
	VS4	Perioperative interdisciplinary support	

Source: Authors

3. Construction of the MDI

After the identification and consensus validation of the 15 critical variables, the panel of experts proceeded to evaluate the degree of influence of each variable on the rest. To do so, they used the classic Godet ordinal scale (0 = no influence; 1 = low; 2 = moderate; 3 = strong). This process gave rise to the MDI in Figure 1, where each cell of the matrix represents the strength of the relation between the row variable and the column variable, allowing for systematic quantification of the structural interdependencies between clinical, surgical, and systemic factors.

Thus, for example, variables such as perioperative glycemic control (VC1), the complexity of the surgical procedure (VQ2), and adherence to perioperative protocols (VS1) show high levels of influence on a wide range of variables, reflecting their strategic nature as key determinants in the occurrence of postoperative complications in diabetic patients.

On the contrary, factors such as advanced age (VC6), diabetic nephropathy (VC5), and intraoperative blood loss (VQ4) show a more dependent role, receiving a greater impact than they exert on the system. Finally, intermediate variables, such as preoperative glycosylated hemoglobin (VC2), type of anesthesia (VQ3), and perioperative interdisciplinary support (VS4), are positioned as link elements that, while influencing the dynamics of the system, are also modulated by clinical and organizational determinants.

As a whole, this matrix constitutes the analytical basis for calculating the motor and dependency indices, which will allow the structure of the system to be graphically represented and the variables to be classified in the driving force-dependency map.

Figure 1. MDI

	1 : VC1	2 : VC2	3 : VC3	4 : VC4	5 : VC5	6 : VC6	7 : VQ1	8 : VQ2	9 : VQ3	10 : VQ4	11 : VQ5	12 : VS1	13 : VS2	14 : VS3	15 : VS4
1 : VC1	0	3	2	2	3	2	2	3	3	3	3	2	0	0	0
2 : VC2	2	0	2	2	2	2	1	1	2	2	2	2	1	2	2
3 : VC3	2	2	0	1	2	2	2	2	2	2	2	2	1	2	2
4 : VC4	2	1	2	0	2	3	1	2	2	2	1	2	2	2	2
5 : VC5	1	2	1	1	0	2	1	1	1	1	0	1	1	1	1
6 : VC6	1	2	1	1	3	0	1	1	1	2	0	1	1	2	1
7 : VQ1	1	2	2	2	2	2	0	1	2	2	1	1	2	2	2
8 : VQ2	2	2	1	2	2	2	3	0	2	2	1	1	1	2	2
9 : VQ3	2	3	2	2	2	3	1	2	0	2	0	2	1	2	2
10 : VQ4	1	2	2	1	2	2	1	1	1	0	0	1	1	3	1
11 : VQ5	2	2	2	2	2	0	2	1	2	2	0	1	1	2	2
12 : VS1	2	2	2	1	2	2	2	2	2	1	3	0	2	2	3
13 : VS2	1	1	1	2	2	2	1	3	2	2	2	1	0	2	3
14 : VS3	2	2	2	1	2	2	2	1	2	2	1	2	1	0	3
15 : VS4	1	2	1	2	2	1	1	1	2	1	2	2	2	3	0

Source: Authors

2. Calculation of driving force and dependency indices

The driving force indices (the capacity of each variable to influence the system) and dependency indices (the degree of vulnerability relative to other variables) were calculated from the MID. These indices were represented on a four-quadrant Cartesian plane, following the classic methodology of Godet (2001).

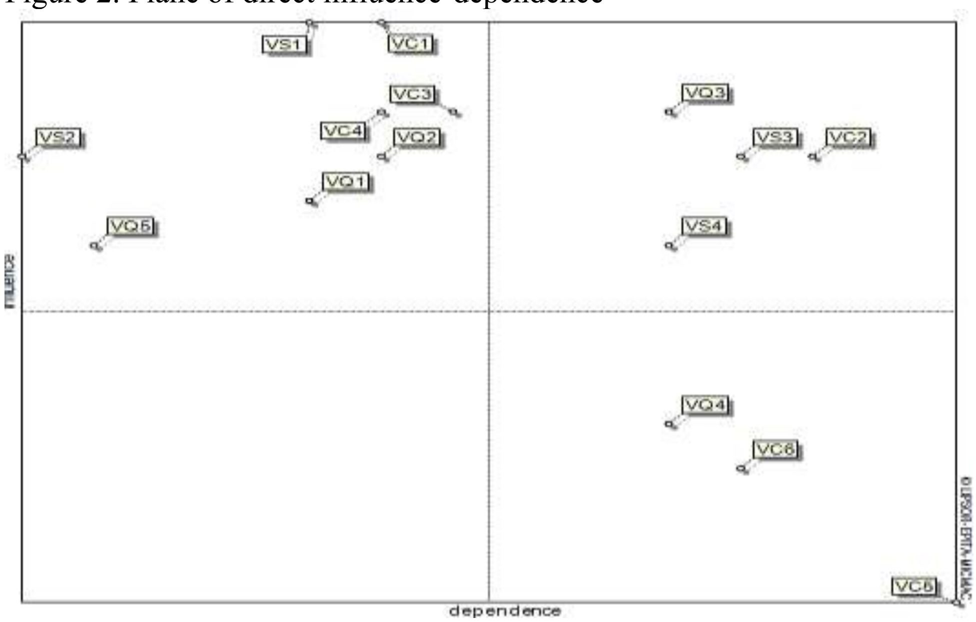
Figure 2 shows the direct driving force-dependence map, where the variables are grouped into four strategic categories:

Key determinants (high driving force capacity, low dependency): These include VC1 (perioperative glycemic control), VC4 (cardiovascular comorbidity), VC3 (nutritional status), VQ1 (procedure duration), VQ2 (surgical complexity), VQ5 (adequate antibiotic prophylaxis), VS2 (surgical team experience), and VS1 (adherence to perioperative protocols). These variables have a decisive structural effect, since they condition the behavior of the system and act as strategic factors for the prevention of complications.

Link variables (high driving force activity and high dependency): These include VC2 (preoperative glycosylated hemoglobin), VQ3 (type of anesthesia), VS3 (access to critical care units), and VS4 (perioperative interdisciplinary support). Their position reflects both their ability to influence and their high sensitivity to other variables, making them unstable elements of the system.

Dependent variables (low driving force, high dependency): These include VC5 (diabetic nephropathy), VC6 (advanced age), and VQ4 (intraoperative blood loss). These variables do not significantly determine the system, but are highly impacted by other factors, representing consequences rather than direct causes. Autonomous variables (low driving force and low dependency): No factors were identified in this quadrant, indicating a highly interrelated system.

Figure 2. Plane of direct influence-dependence



Source: Authors

The driving force-dependency analysis shows that postoperative complications in diabetic patients do not respond to a single isolated factor, but rather to a system of strongly interconnected variables. The absence of variables in the autonomous quadrant confirms that virtually all the factors analyzed maintain mutual influence relations, demonstrating the multifactorial and dynamic nature of these complications.

The identification of key determinants such as perioperative glycemic control (VC1), cardiovascular comorbidity (VC4), and adherence to perioperative protocols (VS1) underscores that complication prevention depends primarily on preoperative clinical optimization and the strengthening of hospital management. The presence of surgical variables (VQ1; VQ2) in this group reflects that the risk of diabetic patients is increased not only by metabolic conditions but also by the burden of the surgical procedure itself, which is not always emphasized in previous studies.

The discovery of link variables such as VC2 and VQ3 is important, as their dual role of influencing and depending on other conditions has transformed them into points of extreme instability. This would mean that inadequate preoperative glycemic control or poor anesthesia selection could amplify patient vulnerability, hindering the effectiveness of protocols and opening the door to the need for interdisciplinary support (VS4).

The dependent variables (advanced age, diabetic nephropathy, and intraoperative blood loss) appear as factors that reflect the consequences of systemic interaction. Although they are not drivers of the system, their presence reinforces the need for individualized strategies, as they represent inevitable clinical manifestations in certain patient groups that are enhanced by the key determinants.

Taken together, this pattern reinforces the idea that the prevention of postsurgical complications in diabetic patients cannot be limited to isolated interventions such as strict glycemic control, but rather requires a comprehensive and structural approach, where key determinants are prioritized in clinical protocols and link factors are closely monitored to avoid destabilizing effects on the system.

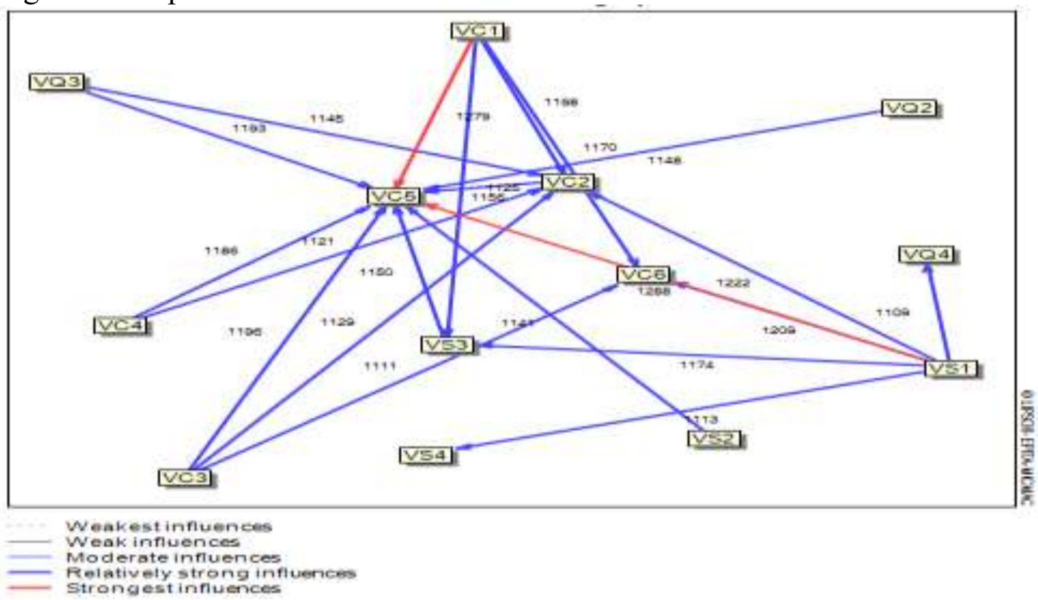
Figure 3 presents the graph of indirect influences among the selected variables, which allows for visualizing the second-order interdependencies in the analyzed system. In this model, no weak or moderate relations were identified, indicating a high degree of structural interconnection among the clinical, surgical, and systemic factors that determine postoperative complications in diabetic patients.

Most of the observed associations correspond to relatively strong influences (thicker blue lines), suggesting that small changes in one variable can generate significant cascading effects on the entire system. This finding reinforces the highly multifactorial and systemic nature of surgical complications in this population.

The presence of two relations classified as strong (red lines) stands out: the interaction between VC1 (perioperative glycemic control) and VC5 (diabetic nephropathy), as well as the influence of VS1 (adherence to perioperative protocols) on VC5. These connections demonstrate the centrality of diabetic nephropathy as a highly vulnerable node of the system, directly influenced by both metabolic control and the quality of hospital management.

The graph confirms that the system does not present peripheral or isolated variables, but is organized around multiple influence nuclei, where clinical interaction (glycemia and comorbidities) and organizational interaction (protocols and interdisciplinary support) define the most critical points for preventive intervention.

Figure 3. Graph of indirect influences between the selected variables

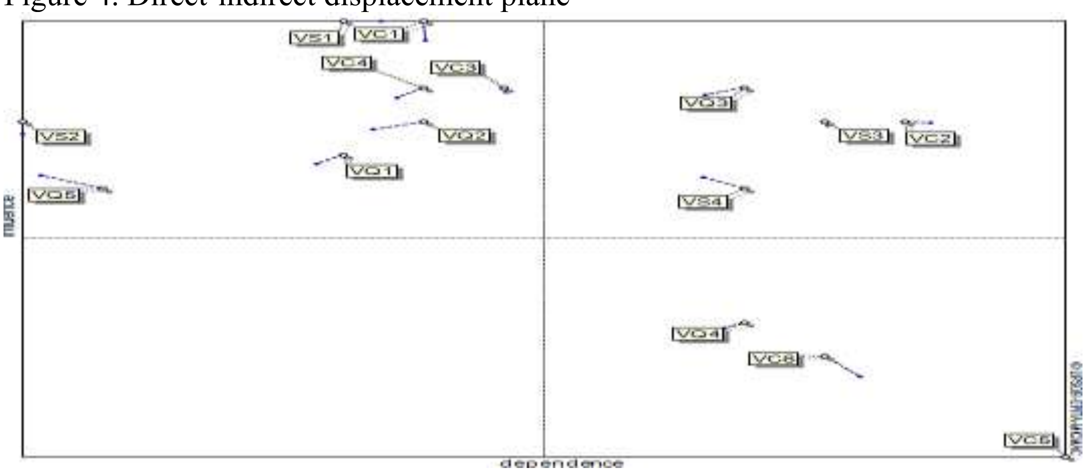


Source: Authors

Figure 4 shows the direct/indirect displacement map, which compares the position of variables according to their immediate (direct) influences versus those mediated by system interdependencies (indirect). This analysis allows for identifying the structural stability or instability of each variable within the model of postsurgical complications in diabetic patients.

Overall, most variables exhibit short displacements, indicating high coherence between their direct and indirect influences. This demonstrates the existence of a robust system, as interactions linked to clinical, surgical, and organizational processes play a role both in the immediate relation and in the cumulative effects.

Figure 4. Direct-indirect displacement plane



Source: Authors

In order to confirm the consistency of the findings, a sensitivity analysis was performed on the MDI, systematically altering the weights that the experts assigned in their matrix in a range of ± 1 on the ordinal scale (0-3), thus recalculating the driving force and dependency indices, and comparing the stability of the final classification of the variables in the four quadrants of the driving force-dependency plane.

The results showed that the overall classification of the system remained stable, showing minimal variations in the relative positions of some link variables (VC2 and VQ3); in these cases, the displacements did not modify their structural condition of high motor capacity and high dependence, thus confirming their role as instability factors in the analyzed system.

Consistently, the key determining variables maintained their position of high motor activity and low dependency, thus reaffirming their strategic centrality in the prevention of postsurgical complications; furthermore, the dependent variables remained highly vulnerable factors, thus confirming that these were a consequence of the system rather than drivers of influence.

The sensitivity analysis supports the robustness and validity of the developed MICMAC model, which ultimately shows that the conclusions obtained do not depend on the assessment of experts, but are the expression of the structure of interdependencies between clinical, surgical, and systemic variables.

Overall, the results from the application of the MICMAC method demonstrate that postoperative complications in diabetics are a highly complex and interdependent phenomenon where clinical, surgical, and systemic variables interact at different levels. The identification of key, link, and dependent determining variables, along with the robustness confirmed by the sensitivity analysis, also allows for a strategic ranking of risk factors. The results not only support the importance of metabolic control and comorbidity optimization but also highlight the importance of adherence to protocols and hospital organization as central axes for complication prevention. Thus, the results offer a starting point for guiding more comprehensive and effective clinical actions and surgical management in this high-risk population.

DISCUSSIONS

Regarding clinical factors, the present study confirms that perioperative glycemic control is the most influential structural determinant in the development of surgical complications in diabetic patients. This observation is consistent with the literature that associates hyperglycemia with a higher incidence of surgical site infections, delayed healing, and higher mortality (De Vries et al., 2017; Smiley & Umpierrez, 2006). Similarly, elevated preoperative glycated hemoglobin (HbA1c) served as a link variable in the model, thus demonstrating its dual role as a measure of chronic metabolic control and as a modulator of perioperative vulnerability. Meta-analyses such as those by Rollins et al. (2016) and Wang et al. (2020) corroborate that HbA1c > 7.0% increases infectious and cardiovascular complications in major surgery.

The variables cardiovascular comorbidity and advanced age have re-emerged as system-dependent factors. Despite being classically described as independent factors of perioperative mortality (Kotagal et al., 2015), structural analysis reveals that their dominance stems from the interaction with metabolic and surgical determinants. From this perspective, they represent a more dynamic and less linear perspective than that demonstrated by existing studies.

Regarding surgical factors, the key determinants identified were procedure duration and technique complexity. The results are consistent with studies showing that prolonged operating times and complex surgeries result in a higher risk of deep infections and cardiovascular complications in diabetics (Kwon et al., 2013).

For its part, appropriate antibiotic prophylaxis appears as a variable of high driving force and low dependence, thus confirming its protective effect in the prevention of postoperative infections. This variable aligns with the results obtained with the recommendations of the NICE guidelines (2020) and the Enhanced Recovery After Surgery protocols (Ljungqvist et al., 2020), which highlight the need to standardize antibiotic prophylaxis, specifically among immunocompromised patients such as diabetics.

The type of anesthesia was classified as a link variable, which is consistent with the literature that suggests that certain anesthetic techniques can modulate intraoperative glycemic control and the risk of metabolic complications (Martin et al., 2016; Jiang et al., 2021).

Regarding systemic factors, one of the main contributions of this study is that it considers organizational and systemic factors as strategic elements. Adherence to perioperative protocols and the experience of the surgical team are consolidated as high-driving force variables, which correspond to systematic reviews showing that the application of multimodal protocols and the standardization of perioperative care reduce the morbidity and mortality that may occur in major surgery (Critchley et al., 2018).

Perioperative interdisciplinary support and access to critical care units are identified as link variables, suggesting that their effectiveness would be determined both by their integration into clinical protocols and by available hospital resources. These results are corroborated by studies demonstrating the importance of multidisciplinary work in reducing complications in complex patients (Meloni et al., 2023).

The originality of this study lies in the application of the MICMAC method in the field of surgery and diabetes, a method rarely used in the literature. In contrast to other studies that address risk factors through a single introduction, this work, which applies structural analysis, allowed variables to be ranked and interdependencies to be projected, providing a systemic and strategic view.

The sensitivity analysis confirmed the robustness of the model, as the classification of the system's variables held up despite changes in the weights assigned by the experts. This methodological aspect reinforces the validity of the results and demonstrates the feasibility of structural analysis in clinical research and hospital management, as has already been verified in other public health settings (Rathi et al., 2023; Gardas et al., 2022).

Regarding practical implications and future lines of research, the results of this study suggest that, in diabetic patients, strategies to prevent postoperative complications should aim to optimize glycemic control, avoid unnecessary surgical complexity, and strictly implement perioperative protocols. This research also emphasizes the need to strengthen the organizational and interdisciplinary components of care so that intensive care support can be guaranteed for high-risk patients.

In terms of research, this work opens the door to the use of prospective techniques and structural analysis in other clinical axes: for example, transplants, cardiac surgery, or oncological surgery, where the interaction of clinical, surgical, and organizational factors is also present as final determinants.

CONCLUSIONS

This study demonstrates that postoperative complications in diabetic patients are the result of a highly interconnected network of clinical, surgical, and systemic factors. Using MICMAC structural analysis, it was possible to isolate relevant determinants, such as perioperative glycemic control, cardiovascular comorbidities, surgical complexity, and adherence to perioperative protocols, as they exert a significant influence on outcomes. The presence of link variables such as preoperative HbA1c or the type of anesthesia can represent points of instability that propagate the vulnerability of high-risk patients. Dependent variables, such as advanced age or diabetic nephropathy, represent subsequent consequences to the induction of these interactions.

These findings support the need for integrated, multidisciplinary perioperative strategies that go beyond isolated risk management to systemic interventions aimed at reducing morbidity and mortality in diabetic surgical patients. Furthermore, the application of MICMAC also offers an innovative contribution to surgical research methodology, as it provides a framework for prioritizing preventive interventions and optimizing institutional protocols.

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