OPINION ARTICLE

From Technique to Wholeness: A Systemic Approach to Aortic Valve Replacement with Traditional and Rapid-deployment Valves

De la técnica al todo: enfoque sistémico del reemplazo valvular aórtico con válvulas tradicionales y de rápido implante

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ABSTRACT

In recent decades, the number of patients with aortic valve disease requiring aortic valve replacement (AVR) has increased due to longer life expectancy. Many of these patients, especially those who are elderly and have comorbidities, face high preoperative risk. The complexity of cardiovascular disease and the adaptation of these patients to the intervention require a comprehensive and holistic approach, considering biological, genetic, and psychosocial factors. This article addresses the importance of understanding AVR as part of a complex system, emphasizing the interaction between multiple elements of the cardiovascular system such as the myocardium, conduction system, and coronary circulation, which affect surgical outcomes. It also highlights how the selection of heart valve prosthesis and other unpredictable factors can influence postoperative mortality, which should not be viewed as a simple cause-and-effect phenomenon. The use of advanced technologies, such as artificial intelligence, can improve outcomes in the preoperative, intraoperative, and postoperative phases of treatment. In conclusion, to improve outcomes in patients undergoing surgical RVA, it is essential to adopt a systemic approach, within the framework of complexity theory, that integrates innovative technologies and considers the individual characteristics of each patient. This could contribute to reduce in-hospital mortality.

Key words: Heart valve surgery -Valve dysfunction - Complexity analysis

RESUMEN

En las últimas décadas, el aumento de la esperanza de vida ha incrementado el número de pacientes con enfermedad valvular aórtica que requieren un reemplazo valvular aórtico (RVA). Muchos de estos pacientes, especialmente los de edad avanzada y con comorbilidades, enfrentan un alto riesgo preoperatorio. La complejidad de la patología cardiovascular y la adaptación de estos pacientes a la intervención requieren un enfoque integral y holístico, considerando factores biológicos, genéticos y psicosociales. En este artículo, se aborda la importancia de comprender el RVA como parte de un sistema complejo. Destaca la interacción entre múltiples elementos del sistema cardiovascular, como el miocardio, el sistema de conducción y la circulación coronaria, que afectan los resultados quirúrgicos. Se destaca, además, cómo la elección de la prótesis y otros factores no predecibles pueden influir en la mortalidad postoperatoria, que no debe ser vista como un fenómeno simple de causa-efecto. El uso de tecnologías avanzadas, como la inteligencia artificial, puede mejorar los resultados en cada fase del tratamiento: preoperatoria, intraoperatoria y postoperatoria. En conclusión, para mejorar los resultados en pacientes sometidos a RVA quirúrgico, es esencial adoptar un enfoque sistémico, desde el marco de la teoría de la complejidad, que integre tecnologías innovadoras y considere las características individuales de cada paciente. Esto podría contribuir a una menor mortalidad intrahospitalaria.

Palabras clave: Cirugía cardíaca valvular - Disfunción valvular - Análisis de la complejidad

INTRODUCTION

In recent decades, the number of patients with aortic valve disease requiring aortic valve replacement (AVR) has increased due to longer life expectancy, with a higher incidence in older age groups. Most patients with severe aortic stenosis (SAS) are elderly patients with several comorbidities and, therefore, high surgical risk. (1,2) This risk is also related to the challenges older patients face in adapting to cardiovascular disease and recovering from surgery, which can be affected by a reduction in their physiological adaptive capacity. This reduction can be understood as a decrease in the entropy of the cardiovascular system. The development of new technologies and therapies

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has tried to solve this situation by reducing surgical risk. Patients with aortic valve disease, considered in their biological and social dimensions, are made up of multiple agents that interact and adapt to constant hemodynamic changes in the cardiovascular system. This interaction occurs at cellular, tissue, genetic, and environmental levels. (3)

IMPORTANCE OF AORTIC VALVE REPLACEMENT WITH A COMPLEX SYSTEM APPROACH

Our center has recently published the results obtained in intermediate-risk patients in terms of in-hospital mortality associated with the use of traditional valve prostheses versus novel rapid-deployment valves (RDV). These results indicate a trend toward lower mortality with RDV (5.7% vs. 0%, p = 0.057). (4) However, when taking into account patient's specific cardiovascular disease, the procedure performed, the type of heart valve prosthesis utilized, and the surgeon responsible for the procedure, as well as the interrelated and unpredictable factors that collectively form a complex entity, it becomes challenging to assert that mortality can be attributed exclusively to the use of a specific type of heart valve prosthesis. It is imperative for cardiovascular surgeons to conduct a thorough analysis of all these elements to comprehensively assess postoperative mortality and to avoid an evaluation of solely the type of prosthesis. This holistic view is crucial to contributing to the success or failure of the surgical outcome in intermediate-risk patients.

Characteristics of the complex system

Understanding the characteristics of a complex system in patients undergoing AVR with heart valve prostheses may offer a renewed approach to their management and potentially improve surgical outcomes. (5)

1. *Large number of elements:* The myocardium consists of billions of myocytes. These structures exhibit a high degree of similarity and act and respond together, maintaining synchrony during physiological situations. (6) In addition, the coronary circulation displays a fractal geometry from the left main coronary artery to the tiny septal arteries.
2. *Dynamism:* Patients with aortic valve stenosis experience remarkable dynamism, with hemodynamic and structural ventricular changes. The progression of valvular heart disease, which often includes pure aortic stenosis and, in some cases, aortic stenosis and regurgitation, directly affects the left ventricle, which develops hypertrophy as an adaptive mechanism. However, this mechanism may not be sufficient, leading to heart failure and progression of symptoms, culminating in the need for AVR and subsequent improvement in ventricular function and reverse ventricular remodeling.
3. *Penetrance:* The elements of the system interact simultaneously and across different dimensions. For instance, the use of heart valve prostheses with a smaller effective orifice area can result in prosthesis-patient mismatch in many patients. This can lead to increased transvalvular gradients without a simultaneous reduction in ventricular afterload. (7)
4. *Non-linearity:* The response to a surgical procedure is not always predictable using traditional methods. Proper placement of the suture in the aortic annulus is crucial when implanting heart valve prostheses. Similarly, preserving the conduction system in the interventricular septum is essential. If the suture is placed too deeply, it can block the atrioventricular conduction system. This may require the placement of a dual-chamber pacemaker, resulting in a reduced life expectancy compared to patients who maintain sinus rhythm. As illustrated by the concept of the "butterfly effect," this single stitch can have significant consequences; a minimal initial change or action can trigger a substantial outcome in the future. (8)
5. *Recursive interactions:* Hemodynamic function improves after replacing the affected and stenosed valve.
6. *Open:* The patient undergoing surgery requires continuous monitoring by cardiologists and surgeons during the postoperative recovery period. The surgical outcomes are influenced by fluid balance as managed by the attending physician, the use of vasopressors, the necessity for temporary pacemaker implantation and the expertise of the nursing staff.
7. *Imbalance:* A patient who has undergone AVR is not in a state of equilibrium. For example, in a patient with low preload, volume expansion will be necessary, while fluid overload will require the use of diuretics. This ensures a constant supply of energy to maintain optimal hemodynamic responses to changes. Thus, the patient is in a permanent "transition," similar to what occurs in the cardiovascular system and in other contexts, as described, for example, in the case of patients with hypertension. (9)
8. *History:* Complex systems have a history, and in this case, the patient improves over time. Initially, the patient presented symptoms due to a stenotic valve, but following the intervention, there was a notable improvement in hemodynamic regulation.
9. *Local information:* The myocardium, conduction system, intrinsic pulmonary pressure, heart valve prosthesis, and aortic valve apparatus operate under their own rules at the local level, but they also interact with other systems. The goal is to achieve a relatively "stable" state, maintaining a cardiac output of approximately 4.5-5 liters/minute.

POSTOPERATIVE MORTALITY AS AN EMERGING PHENOMENON

Postoperative mortality can be considered a complex phenomenon in patients undergoing surgery and

should not be approached with a simplistic cause-and-effect model. Despite the attempts we made (4) to identify an intermediate-risk population using a universally accepted scoring system, such as STS-PROM, (10) it is imperative to acknowledge that each patient is unique. The possibility of death is determined by the interaction of various factors in the patient's system. Surgeons have the responsibility to understand and analyze these interactions, including patient's history of cardiovascular disease, physiology, and context, without limiting themselves to the idea that the selection of heart valve prosthesis will determine survival.

We observed that patients undergoing surgery for functional class I and II heart failure had better outcomes than those with more advanced heart failure, as well as those with moderate to severe ventricular dysfunction. If we could intervene in these patients earlier, they would probably achieve better outcomes. In the clinic, clinical cardiologists may assume that patients do not need surgery until they experience dyspnea on exertion, even if they present elevated gradients on transthoracic echocardiography. This linear approach fails to consider the complexity of unanticipated factors that influence each patient, as well as variations in the perception of dyspnea. Furthermore, it is imperative to assess the patient's psychosocial status, as those with preoperative depression, are more prone to adverse postoperative outcomes.

As surgeons, we can improve postoperative outcomes by understanding perioperative mortality as an emerging phenomenon, allowing us to design a comprehensive strategic plan for the preoperative, intraoperative, and postoperative phases.

Tools for addressing the complexity of patient mortality

A strategic plan for cardiovascular surgery can be approached at three key levels: preoperative, intraoperative, and postoperative. Each level has specific tools that seek to reduce mortality and improve outcomes in patients undergoing surgery.

In the **preoperative** phase, it is imperative to utilize tools that facilitate a multifactorial approach to decision-making. This includes a thorough analysis of patients' psychological status, assessment of their symptoms and their expectations regarding the procedure, among other factors. In addition, the incorporation of data science is imperative, as it facilitates the determination of the optimal heart valve prosthesis based on the available information. The use of international and national registries, hospital databases, meta-analyses, randomized trials and long-term results facilitates the selection of the most appropriate option for each patient. Current guidelines on valvular heart disease and indications for surgery offer a conventional and simplistic approach and do not take into account genetic, epigenetic, or environmental factors that could influence the patient's response. (11) In this regard, the Department of Cardiovascular Surgery at Hospital Italiano de Buenos Aires is launching a project that integrates artificial intelligence (AI) and machine learning techniques to analyze this data and offer more accurate projections when selecting heart valve prostheses during the phase of patient care at the clinic. This approach is consistent with the concept of "precision medicine," which aims to enhance patient survival and outcomes through individualized treatment.

During the **intraoperative** phase, the use of AI-based tools and real-time analysis constitutes a pivotal element for improving the outcomes. Decision-making processes, including the selection of procedures in conjunction with valve replacement (e.g., coronary artery bypass grafting, double valve surgery, or aortic root replacement), or the placement of prophylactic pacemakers, among others, should be based on an accurate and updated evaluation of the patient at the time of surgery. However, it is important to acknowledge that advanced technological solutions may not always be uniformly applicable across all centers. Variables such as costs and economic disparities between services may impede their extensive implementation.

During the **postoperative** phase, one of the most significant advances is the incorporation of AI-driven tools for monitoring in operating rooms and coronary care units. This tools, which allow for real-time feedback, provide continuous monitoring of vital signs, cardiac output, central venous pressure, pulmonary pressure, and vascular resistance, as well as remote and continuous electrocardiographic monitoring. This system enables immediate access to crucial data for surgeons and cardiologists participating in the procedure, thereby enhancing their capacity to respond to any changes in the patient's condition. This technology has only been implemented at a limited number of centers worldwide, and no definitive findings have been published regarding its impact on postoperative outcomes. Nonetheless, it is anticipated that, in the long term, this type of system will become the standard of quality for cardiac surgery centers.

CONCLUSIONS

Postoperative mortality in patients undergoing surgery should not be understood as an isolated or simplistic phenomenon. Rather, it is the result of the complex interaction of multiple factors, both biological and social, that affect each patient in a unique way. These factors range from the patient's specific cardiovascular disease to their genetic, epigenetic, and psychosocial profile, all of which can significantly influence surgical outcomes. The approach to cardiovascular surgery must be holistic and multidisciplinary, considering not only the type of heart valve prosthesis used but also the patient's individual context, the expertise of the surgical team, and the variables that interact throughout the process and are not directly predictable. The key to success lies in the integration of personalized approaches, the use of innovative technologies, and collaboration between the different

actors in the process. This will optimize patient care and offer them a better quality of life after the procedure.

Conflicts of interest

None declared.

(See authors' conflict of interests forms on the web/Additional material).

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