ORIGINAL ARTICLE

Optimization of medication distribution in Mexico through a mathematical model incorporating incidence, prevalence and mortality

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ABSTRACT

Objective: To develop a mathematical model that incorporates the incidence, prevalence and mortality of Mexico's most common diseases—ulcer, hypertension, type 2 diabetes mellitus and obesity—in order to improve the accuracy of future medication demand predictions. The model utilizes Markov chains, Monte Carlo simulations, econometric methods and financial projections. **Materials and methods:** A research design was employed using a predictive mathematical model based on econometric and financial approaches, such as Markov chains and Monte Carlo simulations. A simulated population of 20,000 individuals was analyzed over 10 simulation cycles in Excel, where individuals transitioned among the healthy, sick and deceased states. The model included previously researched rates of incidence, prevalence and mortality. **Results:** Transition tables with probabilities, based on Mexico's most common diseases, were generated in Excel. The considered states included "healthy-deceased," "healthy-sick" and "healthy-healthy." The "sick-deceased" transition was calculated using both disease-specific and overall mortality rates. In the second disease cycle, the annual treatment costs were as follows: 285,120 pesos for ulcer, gastritis and duodenitis; 3,525,120 pesos for hypertension; 35,490 pesos for type 2 diabetes mellitus; and 752,000 pesos for obesity. An increase in the required budget for each disease was observed since no new healthy population was added during these transitions. **Conclusions:** Applying a mathematical model based on epidemiological data, combined with the historical method, could improve the accuracy of pharmaceutical budget allocation. Countries such as Spain, Panama and Peru use methods that combine historical adjustments with morbidity data. More accurate, up-to-date and reliable statistics are needed to optimize the government's financial resources for health.

Keywords: Process Optimization; Pharmaceutical Preparations; Mexico; Patient Compliance (Source: MeSH NLM).

INTRODUCTION

Drug shortages are defined as "a supply that fails to meet the national demand for medications intended for human or veterinary use." Globally, drug shortages continue to increase and represent a recurring problem with serious consequences for patients, healthcare systems and the general population [1-3].

Shortages affect not only patients but also the broader Mexican economy. Inadequate organization and the lack of effective methods for estimating medication needs contribute to these shortages, forcing institutions—such as the Instituto Mexicano del Seguro Social (IMSS - Mexican Social Security Institute) and the Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado (ISSSTE - Institute for Social Security and Services for State Workers—and hospitals to make urgent purchases at inflated prices [4].

Ideally, medication requirements should be estimated prior to the start of the second half of the year. This estimation is based on historical and projected consumption data, potential changes in demand and stock balances in warehouses. Consumption adjustments also consider avoidable losses and waste, including the disposal of expired medications [5].

Most countries maintain a national list of essential medicines. In Mexico, this is referred

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to as the *Cuadro Básico y Catálogo de Medicamentos* (*Basic List and Catalog of Medicines*), while the *WHO Model Lists of Essential Medicines* can be used as global benchmark. These reference models help reduce costs, standardize and enhance treatments, and improve storage and distribution management. Once these lists are established, quantities are calculated based on the expected number of patients and the most prevalent diseases [(6)].

In 2018, a survey revealed that only 75.00 % of the population attending outpatient services received all their prescribed medications. Consequently, 31.55 million individuals did not receive some of their medications, negatively impacting health outcomes and contributing to supply shortages [(7-9)].

Analysts have attributed drug shortages to poor planning and an underestimation of the complexity involved in procurement and distribution processes. In 2019, under López Obrador's administration, the consolidated purchase of medications was transferred from the IMSS to the Secretaría de Hacienda y Crédito Público (SHCP – Ministry of Finance and Public Credit), and subsequently to the Instituto de Salud para el Bienestar (INSABI – Institute of Health for Well-Being). This transition resulted in significant losses in the procurement and distribution of medications, causing delays in bidding processes [(10)].

The underlying causes remain unclear but may include supply chain failures, production plant accidents, contamination of raw materials or finished products, and errors in demand estimation and planning.

In 2019, an alliance of 68 organizations established a platform called cerodesabasto.org, allowing Mexican citizens to report shortages of drugs, medical supplies and vaccines [(11)]. Of the reports, 97 % concerned drug shortages, while the remainder involved supplies and vaccines. In Chihuahua, since the platform's launch, the Centro de Salud Aquiles Serdán (Aquiles Serdán Health Center)—part of INSABI—ranks second among institutions with the highest number of reported shortages. The use of geographic information enhances the analysis of special data to address challenges in medical planning and management [(11-14)].

Geographic information systems (GIS) facilitate the storage, manipulation and visualization of spatial data. They help answer the question: What is the most effective way to allocate health resources in a socio-spatial context? GIS enable data visualization through maps, correlating geographic events, analyzing health status in specific populations, identifying high-risk groups, assessing critical areas through health surveillance and monitoring, and evaluating health-promoting and health-protective factors. Furthermore, GIS support decision-making on where additional health services are required and on proposing optimal locations for building health facilities or allocating supplies [(15-17)].

The diverse topics and methodological approaches presented in the articles featured in this issue illustrate the evolving field of health geography. However, certain health geography models seek to understand the conditions under which diseases arise, in order to enable territorial—rather than solely individual—interventions, adopting a macroscopic approach. This broader perspective supports the implementation of strategies aimed at disease prevention, health promotion, improved access to healthcare services, and effective disease management [(18-21)].
The objective of this study was to develop a mathematical model that incorporates the incidence, prevalence and mortality of Mexico's most common diseases—ulcer, hypertension, type 2 diabetes mellitus and obesity—in order to improve the accuracy of future medication demand predictions. The model utilizes Markov chains, Monte Carlo simulations, econometric methods and financial projections.

MATERIALS AND METHODS

Study design and population

A predictive mathematical model based on econometric and financial approaches, such as Markov chains and Monte Carlo simulations. Given the nature of the model, no real-world study population was required. Instead, a simulated population of 20,000 individuals was generated. A sample size of 1,461 individuals met the requirements for a 99.99 % confidence level.

Variables and measurements

The predictive mathematical model integrates geographic data from the city of Chihuahua and the incidence rates of the aforementioned diseases to estimate the quantity of medications required for the population (Instituto Nacional de Estadística y Geografía [INEGI – National Institute of Statistics and Geography], 2022). The independent variables include the proposed mathematical model, the incidence rates of the diseases under study and demographic data from the selected geographic area. The dependent variables comprise medication oversupply, drug shortages and the financial expenditure resulting from medication oversupply.

Statistical analysis

The simulation began with a cohort of 20,000 individuals in a healthy state. Using Excel, 10 simulation cycles were performed, during which individuals transitioned among the healthy, sick and deceased states. Incidence, prevalence and mortality rates for the included conditions were incorporated into the model. For those who became ill, the cost of treating each disease was calculated. Assuming a constant birth rate throughout the simulation cycles, the overall trend showed an increase in both disease and mortality.

Ethical considerations

This study complies with the Ethical Principles for Medical Research Involving Human Participants outlined in the Declaration of Helsinki, the International Ethical Guidelines for Health-Related Research Involving Humans established by the Council for International Organizations of Medical Sciences (CIOMS), the Pan American Health Organization (PAHO), and the General Health Act set forth by the Cámara de Diputados del Congreso de la Unión (Chamber of Deputies of the Congress of the Union, 2022). The study prioritizes maximum benefit to individuals and ensures the confidentiality of all personal data in accordance with the Ley Federal de Protección de Datos Personales en Posesión de los Particulares (Federal Law on Protection of Personal Data Held by Private Parties) [22-26].

The results of this study will be made publicly available, in accordance with the Ley de Ciencia y Tecnología (Science and Technology Law) [26].

RESULTS

Regarding transitions related to ulcer, gastritis and duodenitis, 10.8 % of individuals transitioned to the "sick" state, 98.73 % remained in the "sick" state and 7.42 % progressed to the "deceased" state (Figure 1).

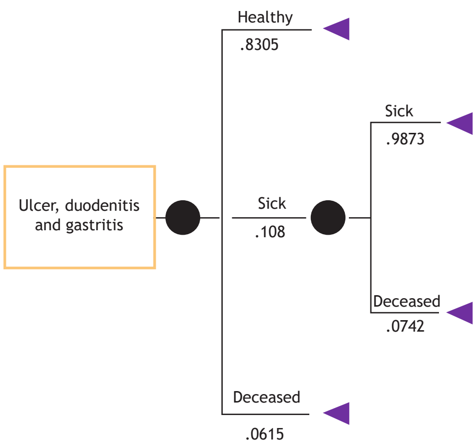

Figure 1. Transition of ulcer, gastritis and duodenitis

In the case of hypertension, 10.2 % of individuals transitioned from the "healthy" to the "sick" state, 92.35 % remained in the "sick" state and 7.65 % progressed to the "deceased" state (Figure 2).

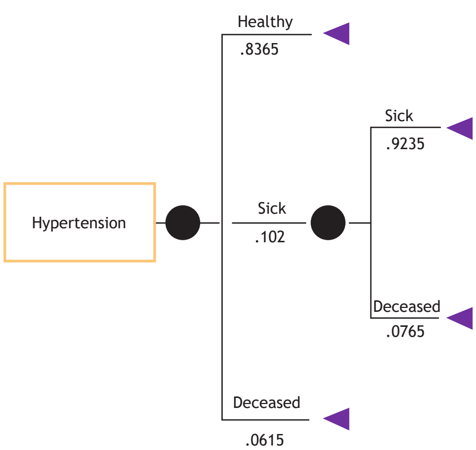

Figure 2. Transition of hypertension

In the case of type 2 diabetes mellitus, 1.95 % of individuals transitioned from the "healthy" to the "sick" state, 93.73 % remained in the "sick" state and 6.2 % progressed to the "deceased" state (Figure 3).

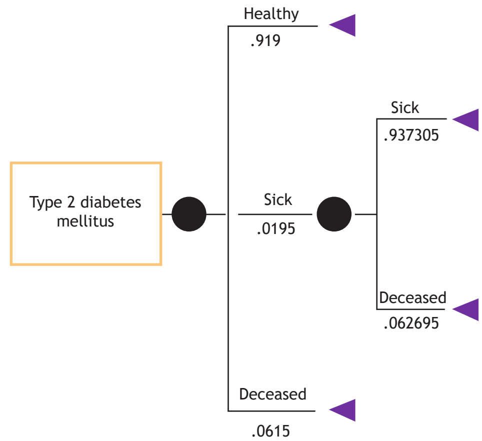

Figure 3. Transition of type 2 diabetes mellitus

In the case of obesity, 4.00 % of individuals transitioned to the "sick" state, 89.25 % remained in the "sick" state and 10.75 % progressed to the "deceased" state (Figure 4).

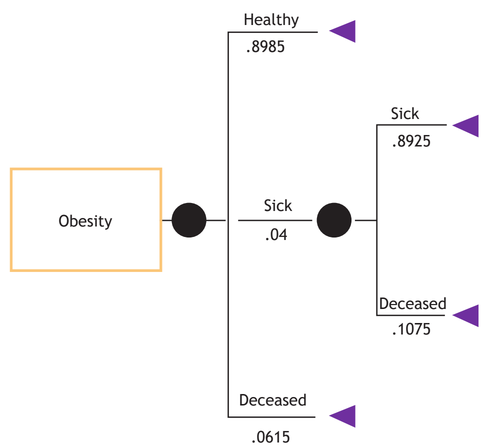

Figure 4. Transition of obesity

Using Excel and matrix multiplication (MMULT), 10 simulation cycles (years) were conducted, considering the "healthy," "sick" and "deceased" states, with an initial population of 20,000 healthy individuals.

Information was gathered from a list of essential medicines on the prices of some of the most commonly used and clinically recommended drugs for the treatment of each disease under study. For the purpose of this model, the lowest-cost medication was selected (Table 1).

In the second disease cycle, the annual treatment costs were as follows: 285,120 pesos for ulcer, gastritis and duodenitis; 3,525,120 pesos for hypertension; 35,490 pesos for type 2 diabetes mellitus; and 752,000 pesos for obesity.

It is important to emphasize that this model does not incorporate annual population growth projections. As a result, the accuracy of the outcomes diminishes over successive cycles (years). Moreover, due to the absence of new healthy individuals entering the simulation, the budget required for each disease increases over time.

Table 1. Medications, unit costs and total treatment costs per disease

Medications for ulcer, duodenitis and gastritis	Cost per box (MXN)	Units per box	Boxes needed for full treatment	Total cost (MXN)	Treatment duration
Cimetidine	$217	30 tablets	8	$1,736	8 weeks
Famotidine	$298	20 tablets	3	$894	8 weeks
Ranitidine	$18	20 tablets	3	$54	8 weeks
Lansoprazole	$199	14 capsules	2	$398	4 weeks
Omeprazole	$137	120 capsules (60 doses if taken twice daily)	1	$137	4 weeks
Pantoprazole	$285	7 tablets	4	$1,140	4 weeks
Rabeprazole	$1,296	14 tablets	2	$2,592	4 weeks
Medications for hypertension	**Cost per box (MXN)**	**Units per box**	**Boxes needed for full treatment**	**Total cost**	**Treatment duration**
Losartan / hydrochlorothiazide	$144	15 tablets	12	$1,728	6 months
Telmisartan / hydrochlorothiazide	$460	28 tablets	5	$2,300	6 months
Candesartan / hydrochlorothiazide	$390	28 tablets	5	$1,950	6 months
Medication for type 2 diabetes mellitus	**Cost per box (MXN)**	**Units per box**	**Boxes needed for full treatment**	**Total cost**	**Treatment duration**
Metformin	$91	60 tablets	2	$182	6 months
Medication for obesity	**Cost per box (MXN)**	**Units per box**	**Boxes needed for full treatment**	**Total cost**	**Treatment duration**
Orlistat	$470	60 capsules	2	$940	12 weeks

DISCUSSION

The results show the amount of financial resources needed to cover each case or episode of a given disease, taking into account both the current number of affected individuals and those expected to be added due to incidence. This indicates that pharmaceutical budget allocation will be based on actual drug consumption, reducing losses due to expiration and shortages. This, in turn, results in a more efficient use of government healthcare funds and improved quality of care for patients.

Using data on incidence, prevalence and mortality for each disease, the model outlines several possible scenarios: a healthy individual who remains healthy, a healthy individual who becomes ill (incidence), a healthy individual who dies (general mortality in Mexico, 2021), a sick individual who recovers (considered impossible and assigned a value of zero), a sick individual who remains ill (prevalence) and a sick individual who dies (disease-specific mortality). For transitions related to death, all scenarios were assigned a value of zero, except for the state of “deceased remaining deceased,” which was assigned a value of one.

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In Mexico, the most widely used approach is the adjusted consumption method, which involves reviewing pharmacy medication records and adjusting for current inventory, medication losses due to expiration, and any supply shortages or surpluses [26].

Marqués León (2017) proposed a model using time series analysis techniques supported by computer programs to predict future trends. The model approach integrates each stage of the process and improves communication among all stakeholders involved in the bidding process for medications. It has demonstrated increased reliability in planning and produced low forecasting errors [26].

Talamantes (2015) designed a model that stratifies patients by their risk of developing a disease and introduced an indicator to estimate pharmaceutical expenditures for each risk group, adjusted for morbidity. The incorporation of morbidity into the model improved its explanatory power for overall pharmaceutical spending [27].

The mathematical model presented in this study is relatively simple, and both the data employed and the Excel spreadsheet program are widely accessible. However, it should be noted that no population projection was performed across the cycles (years), which results in an increasing number of individuals classified as “deceased,” without a rise in the “healthy” and “sick” states.

Additionally, the cost estimates generated by the model cannot serve as a complete basis for budget planning for medication procurement, as only one drug was considered for each disease. In clinical practice, however, the same condition may be treated by multiple medications, selected based on the patient’s medical history, allergies, drug interactions and the prescribing physician’s clinical judgment.

The model’s accuracy could be improved by incorporating statistical data or reports on the specific medications used to treat each condition, as well as by integrating up-to-date statistical data on incidence, prevalence and mortality.

In conclusion, applying a mathematical model based on epidemiological data, combined with the historical method, could improve the accuracy of pharmaceutical budget allocation.

Countries such as Spain, Panama and Peru use methods that combine historical adjustments with morbidity data. More accurate, up-to-date and reliable statistics are needed to optimize the government’s financial resources for health.

Author contributions: QMCA contributed to the study conception and design, as well as to data collection, analysis and interpretation. CAVB was responsible for the study conception and data analysis. RIHS and BADC participated in data collection and analysis and also contributed to drafting the manuscript. MDPR conducted the statistical analysis and provided a critical review of the data. LBES contributed to data collection and analysis and critically revised the manuscript. All authors reviewed and approved the final version of the manuscript.

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