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A FOUR-YEAR MULTI-HOSPITAL ANALYSIS OF MANNITOL DISTRIBUTION ACROSS THE JORDANIAN ROYAL MEDICAL SERVICES HOSPITALS

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ABSTRACT:

Introduction: Mannitol is a crucial osmotic diuretic which is used extensively in clinical practice for conditions such as raised intracranial pressure, cerebral edema, acute kidney injury and intraoperative renal protection. But despite its widespread use few studies have investigated the institutional distribution of mannitol within a nationally integrated healthcare system,

Methods: The study will adopt a retrospective observational design that utilize warehouse distribution data as an indicator for institutional consumption and a descriptive and comparative analysis will be conducted to quantify the total and annual consumption per hospital, identify peak and minimum utilization years and rank hospitals according to their cumulative use. Temporal fluctuations will be evaluated to understand broader patterns potentially linked to supply disruptions or healthcare system stressors and the study will also plan to perform inter-hospital comparisons to assess whether specific clinical roles such as cardiology, neurosurgery, or intensive care are associated with higher mannitol usage, thereby inferring clinical preference profiles. This research will further attempt to integrate healthcare logistics literature to contextualize its findings which includes considerations of hospital inventory strategies, pharmaceutical demand forecasting and specialty-driven utilization. The methodology will include statistical summaries, consumption indexing, and graphical representation to highlight consumption disparities and institutional trends. This analysis is expected to provide critical insights into how pharmaceutical distribution within a unified military health system reflects operational realities and clinical priorities. In the end the study will aim to support evidence-based strategies for improving inventory management and aligning medication distribution with actual clinical needs.

Results: Over the four-year period, 1,529 units of mannitol were distributed across the eight hospitals. Consumption was highly uneven, ranging from 48 units at Princess Haya Military Hospital to 534 units at Queen Alia Center for Heart Diseases, which, together with King Hussein Medical Hospital, accounted for nearly 70% of total use. Temporal analysis showed a peak in 2021 (+19.5% from 2020), a sharp decline in 2022 (−33.4%), and partial recovery in 2023 (+17.8%), reflecting both pandemic-related disruptions and shifts in clinical demand.

Keywords: Mannitol, pharmaceutical distribution, hospital inventory management, JRMS, consumption analysis

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1. INTRODUCTION:

Mannitol solution represents a central and vital therapeutic agent in nowadays modern hospital practices since it serves multiple critical clinical functions which includes osmotic diuresis, intracranial pressure management and renal protection during various surgical and other medical interventions (1) and as healthcare systems worldwide deal and wrestle with a increasing demand for an efficient pharmaceutical supply chain management practices, understanding the distribution patterns and the consumption trends of the essential medications becomes very paramount for optimizing resource allocation and distribution and for ensuring the continuous availability to maintain a high level of patient care, the Jordanian Royal Medical Services operates and functions as a comprehensive healthcare network in Jordan by serving both military personnel and civilian populations across the country and this network in part encompasses eight major hospitals each of them with its own distinct clinical focuses and patient populations and thereby creating a very unique opportunity to examine pharmaceutical distribution patterns across diverse healthcare settings inside a unified and integrated management structure and the complexity of pharmaceutical supply chains particularly in the case of specialized medications like mannitol requires a sophisticated and comprehensive understanding of the consumption patterns and demand forecasting and distribution optimization.

Mannitol's clinical applications span multiple medical specialties which makes it an ideal pharmaceutical agent for studying the distribution patterns across diverse hospital settings, Mannitol is widely used in the management of raised intracranial pressure, for renal protection in cardiac, vascular and renal transplantation surgery and in the management of rhabdomyolysis (2) and this drug's versatility across clinical specialties creates varying demand patterns which may reflect the clinical focus and patient acuity levels of different healthcare institutions, the significance of this study goes further beyond just the mere pharmaceutical inventory analysis since understanding mannitol distribution patterns will provide insights and perspectives into any clinical practice variations, the resource utilization efficiency and the strategic planning for pharmaceutical procurement within this integrated healthcare systems and such analysis becomes particularly crucial and vital in the context of supply chain disruptions especially in a budget constraint environment and the need for evidence-based resource allocation decisions.

Previous research regarding pharmaceutical inventory management has already emphasized the complexity of healthcare supply chains and the number of factors affecting consumption behavior of medications and their complex role in this regard which have made the effective inventory policies and high-quality medical production service key goals shared by all health care industries and systems (3) also prescribing behavior of physicians, case-mix of patients, clinical protocols at institutional level, hospital size have all been recognized as factors that are contributing to the heterogeneity of pharmaceutical utilization in health networks, this study will answer several important research questions about: What are the primary drivers of mannitol variability across JRMS hospitals, how is temporal trend being affected by changes in clinical practice or other outside factors and influences such as supply chain issues and what lessons do these patterns mean for future procurement and inventory management within the JRMS system in this study case.

The research methodology employed a retrospective analysis of pharmaceutical distribution data spanning four years therefore providing a sufficient temporal depth in order to identify any meaningful trends and patterns and this study period encompasses significant global events including the COVID-19 pandemic which may have influenced the pharmaceutical consumption patterns and the supply chain dynamics and by examining mannitol distribution across those eight distinct hospitals within the JRMS network this research will contribute to the broader understanding of pharmaceutical supply chain management in integrated healthcare systems and the findings of this study will offer practical insights for healthcare administrators, pharmacists and supply chain managers who are seeking to optimize medication availability while also maintaining cost-effectiveness in their pharmaceutical procurement strategies.

2. METHODOLOGY:

2.1 Study Design and Setting: This is a retrospective observational study which analyzed mannitol solution distribution data across eight hospitals within the Jordanian Royal Medical Services network over a four-year period from 2020 to 2023, the study employed and used a quantitative approach which utilized pharmaceutical distribution records maintained by JRMS main medical warehouses which serve as the central distribution hub for all medications across the network, the JRMS network encompasses in part eight major hospitals which serve many diverse patient populations and many clinical specialties including King Hussein Medical Hospital which serves as a comprehensive tertiary care facility and the primary referral center for complex medical cases, Queen Alia Center for Heart Diseases which operates as a specialized cardiac center that focuses on cardiovascular surgery and interventional cardiology, the remaining facilities include Prince Rashid Ben Al-Hasan Military Hospital, Prince Hashem Ben Al-Hussein Military Hospital, Prince Ali Bin Al-Hussein Military Hospital, Prince Hashem Ben Abdullah II Hospital, Princess Haya Military Hospital and King Talal Military Hospital each functions by providing various levels of general and specialized medical services.

2.2 Data Collection and Sources: Data collection focused on the pharmaceutical distribution records which are maintained by JRMS central warehouses a warehouse facility which serve as the primary distribution hub for all medications across the network, data collection covered the period from January 2020 through December 2023 thereby providing four complete years of distribution information and the data collection process ensured the consistency of data by focusing on the average monthly distributed quantities which account for potential stock shortage periods and provide standardized metrics for comparative analysis across hospitals and time periods.

2.3 Variables and Measurements: Primary outcome variable was the number of mannitol solution units received at the hospital level in their respective units distributed from central warehouses; secondary variables: yearly distribution patterns and monthly variations; hospital characteristics - hospital consumption patterns (as per unit used); and distribution efficiency metrics which assess the discrepancies of supply and demand pattern variations. Data validation steps included cross-referencing warehouse distribution records with hospital receipt data to ensure accuracy and completeness of the dataset, and quality assurance steps were designed and implemented to identify and correct any inconsistencies/missing data through the collection period.

2.4 Statistical Analysis Methods: Statistical analysis employed and used descriptive statistics in order to characterize the consumption patterns across all the hospitals and time periods and the analysis methods included the calculation of the total consumption by hospital and year, the determination of mean annual consumption across all facilities, the identification of maximum and minimum consumption patterns, the assessment of temporal trends and variations, the inter-hospital consumption comparisons using percentages of total network consumption, the year-over-year percentage changes in order to identify temporal trends, the coefficient of variation calculations in order to assess the consumption stability and the ranking analysis in order to determine the high and the low consumption facilities, the analytical approach also focused on identifying any meaningful patterns and trends in the distribution data while also accounting for potential external factors that may have influenced the consumption during the study period and particular attention was paid to the impact of the COVID-19 pandemic which occurred during a significant portion of the study timeframe.

3. RESULTS AND DISCUSSION:

3.1 Overall Consumption Patterns and Network Analysis: The full analysis of mannitol solution distribution data within the JRMS network highlighted major and critical variation in consumption patterns both between the institutions and over the study periods, with the eight hospitals consuming 1,529 units of mannitol solution during the four-year study period, which represents a significant pharmaceutical utilization across the network (figure 1).

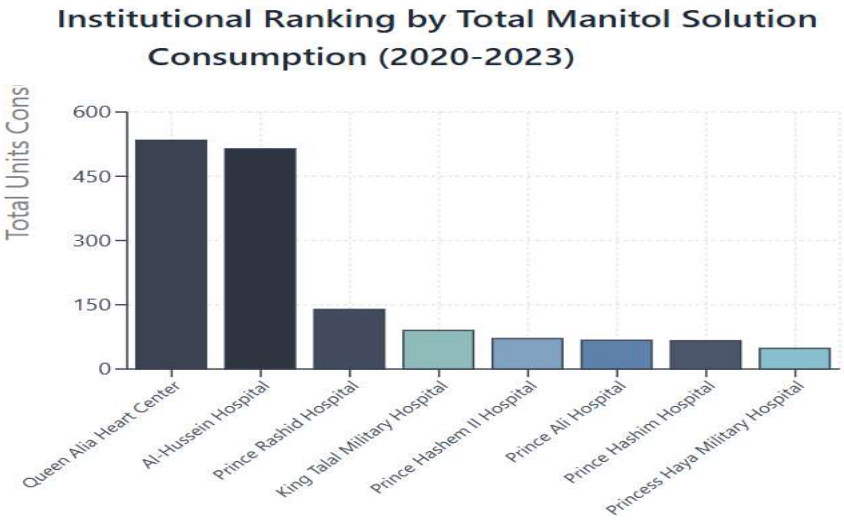

Figure 1: Institutional ranking by total mannitol solution consumption (2020-2023)

The distribution data demonstrated considerable and substantial heterogeneity in the consumption patterns with individual hospital utilization ranging from 48 units at Princess Haya Military Hospital to 534 units at Queen Alia Center for Heart Diseases, this eleven-fold difference between the highest and lowest consuming institutions suggests significant differences in the clinical practice patterns, patient acuity levels or the institutional clinical focus areas that warrant a more detailed examination.

Annual consumption patterns also revealed important temporal trends with the network experiencing a notable fluctuations in mannitol utilization over the study period, the mean annual consumption across all hospitals was 382.25 units providing a baseline for evaluating individual hospital performance and identifying potential optimization opportunities within the pharmaceutical distribution system and these variations highlight the complexity of the demand forecasting in healthcare environments and settings and also underscore the importance of flexible inventory management approaches (figure 2).

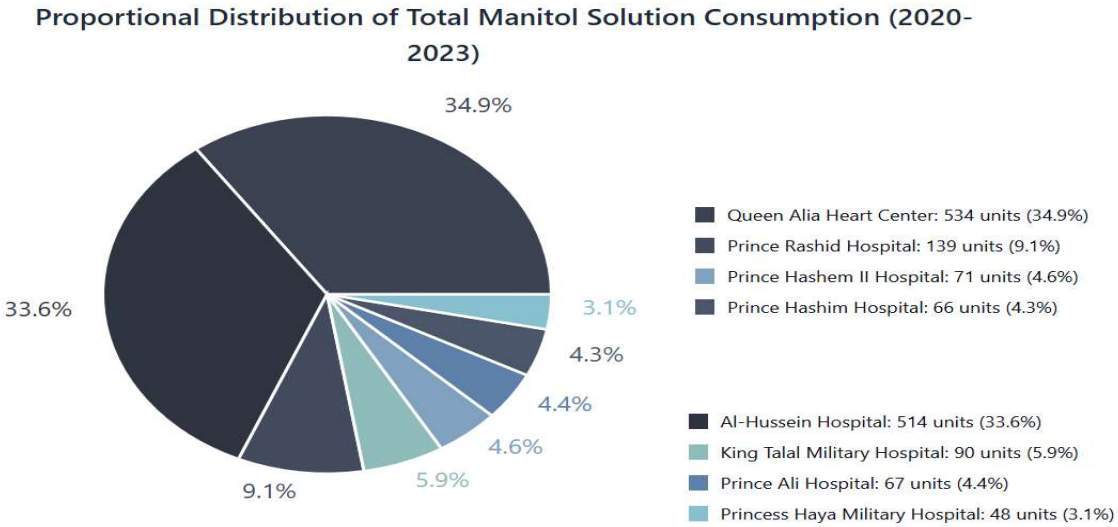

Figure 2: Proportional distribution of total mannitol solution consumption (2020-2023)

3.2 Institutional Consumption Analysis and Clinical Correlations: Queen Alia Center for Heart Diseases surfaced as the highest consuming institution with 534 total units and representing 34.9% of the total network consumption, this finding aligns with clinical expectations given the specialized nature of cardiac surgery and interventional cardiology procedures being performed at this facility since cardiac surgical procedures frequently require mannitol for renal protection during cardiopulmonary bypass which explains the elevated consumption compared to other general medical facilities also the temporal consumption pattern at Queen Alia Center showed interesting variations with 158 units in 2020, reaching a peak of 184 units in 2021 and followed by a significant decline to 92 units in 2022 and a partial recovery to 100 units in 2023 (figure 3).

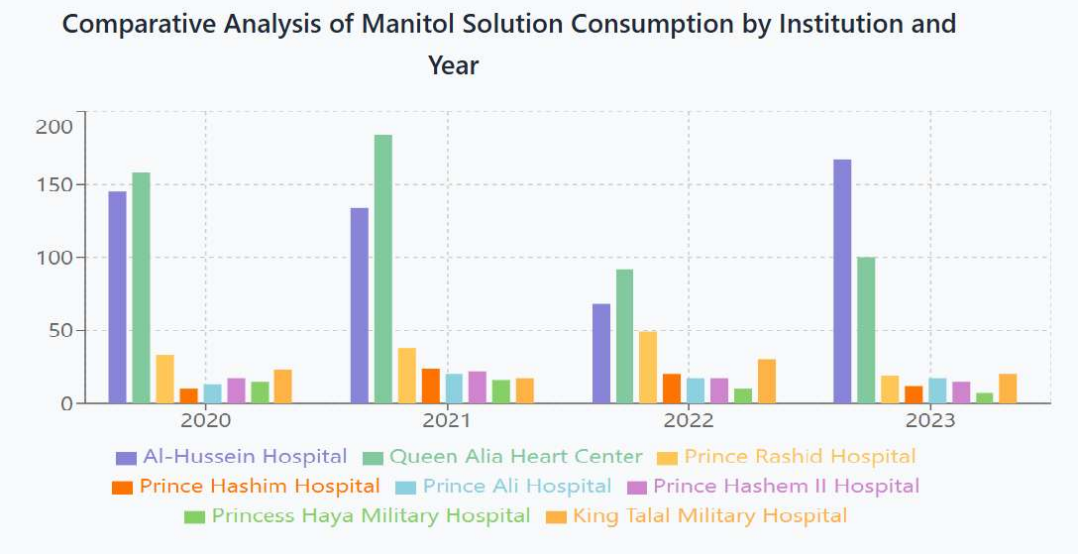

Figure 3: Comparative analysis of manitol solution consumption by institution and year

King Hussein Medical Hospital serving as the primary referral center for the JRMS network demonstrated the second-highest consumption with 514 total units which represents 33.6% of the network consumption, this institution's consumption pattern showed 145 units in 2020 and a slight decrease to 134 units in 2021 and a dramatic decline to 68 units in 2022 followed by a notable recovery to 167 units in 2023 and this pattern suggests and supports the facility's role in managing complex medical cases requiring mannitol therapy with consumption variations potentially reflecting the changes in patient acuity or the used clinical protocols during the study period.

Prince Rashid Ben Al-Hasan Military Hospital consumed 139 total units which represented 9.1% of the network entire consumption and with a gradual increase from 33 units in 2020 to 49 units in 2022 before declining to 19 units in 2023, this pattern may reflect an evolving clinical practices or changes in the patient population served by this facility, King Talal Military Hospital however demonstrated a relatively steady consumption with 90 total units representing 5.9% of network consumption and showing a somewhat consistent utilization across the study period that suggests the presence of a stable clinical operations and patient population characteristics.

The remaining hospitals which includes the following: Prince Hashem Ben Al-Hussein Military Hospital, Prince Ali Bin Al-Hussein Military Hospital, Prince Hashem Ben Abdullah II Hospital and Princess Haya Military Hospital showed a consumption that is ranging from 48 to 71 total units each and their resulted patterns are likely reflective of a smaller facility sizes, a different clinical specializations or patient populations with a lower acuity that's requiring mannitol therapy, Princess Haya Military Hospital showed the lowest consumption amounts at 48 total units with a concerning declining trend from 15 units in 2020 to 7 units in 2023.

3.3 Temporal Trend Analysis and External Factors: The network wide annual consumption has revealed some significant and important temporal variations and differences that in turn have provide insights and perspectives into this healthcare system dynamics and external influences or factors since the baseline year of 2020 showed 414 units of consumption which was then followed by a peak year in 2021 with 455 units that is representing a 19.5% increase from the previous year and this increase has occurred despite the ongoing COVID-19 pandemic challenges which in its own turn suggests either a delayed care delivery from the accumulated deferred procedures or a modifications in the clinical protocols that have led to the increased mannitol utilization, changes in patient population severity or the supply chain adjustments including possible stockpiling behavior (figure 4).

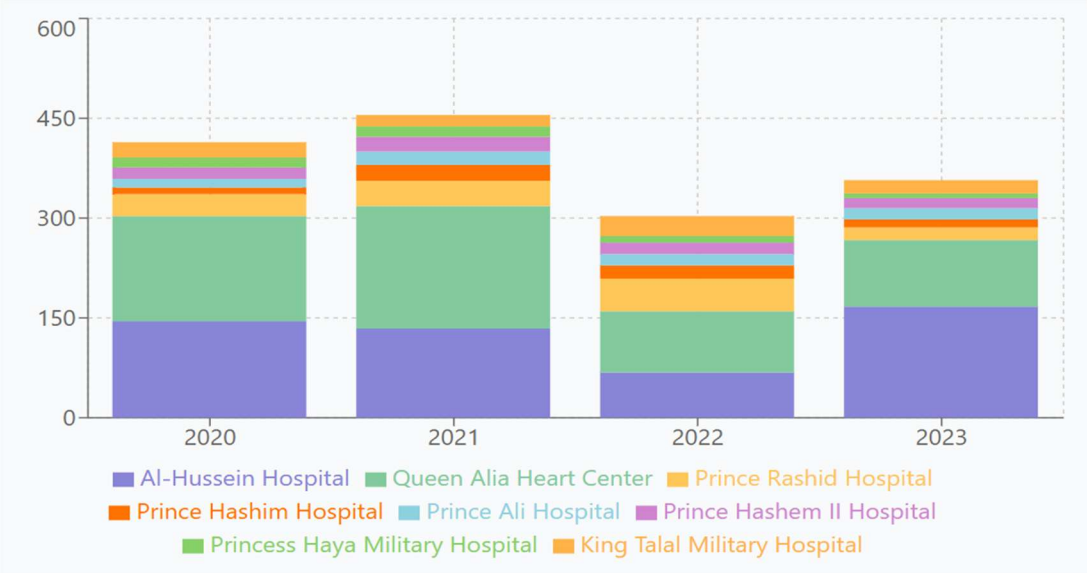

Figure 4: Temporal Trend Analysis and External Factors

The year 2022 held the most significant consumption decline with 303 units which is a dramatic 33.4% decrease from the 2021 peak and this decline affected most hospitals within the JRMS network and therefore suggesting a system-wide factors effects rather than just an institution-specific issues, potential explanations may include a continued effects of COVID-19 on the elective procedures and hospital operations, supply chain disruptions or procurement challenges which are affecting availability, the evolution and change of treatment protocols that are reducing mannitol utilization or an economic factors that are influencing the pharmaceutical procurement decisions.

The recovery pattern observed in 2023 with 357 units and representing a 17.8% increase from 2022 suggests a partial restoration of the normal clinical operations, however the consumption levels remained below both the 2021 peak and the 2020 baseline which is indicative of that the healthcare system had not fully returned to its pre-pandemic utilization patterns and this recovery also suggests a gradual normalization of the clinical operations while a potentially incorporating lessons that have been learned during the pandemic period.

3.4 Clinical Practice Implications and Specialty Correlations: The consumption data reveals a clear correlation between the hospital clinical specialization and mannitol utilization patterns that align with the established clinical applications of the medication, the Queen Alia Center for Heart Diseases with its focus on cardiac surgery and interventional cardiology demonstrated a consumption pattern that is consistent with established clinical uses of mannitol in cardiac procedures and surgeries including renal protection during cardiopulmonary bypass procedures and the management of fluid balance in heart failure patients

and the treatment of cerebral complications associated with cardiac surgery.

King Hussein Medical Hospital's consumption patterns also reflect this institution's board and wide clinical responsibilities and function as the primary referral center for complex cases within the JRMS network, the facility's utilization is likely to encompasses multiple clinical scenarios which are including neurosurgical procedures where mannitol is used for intracranial pressure management and prevention of acute renal failure during high-risk surgical procedures and emergency management of increased intracranial pressure from various other causes.

The variations and discrepancies which have been observed among the study military hospitals provide interesting insights and preceptive into their clinical practice differences within similar institutional types, some military facilities demonstrated a stable consumption pattern while others showed significant fluctuations which suggesting a heterogeneity in clinical operations, patient care requirements and potentially several different approaches to pharmaceutical utilization management.

3.5 Supply Chain Management and Inventory Optimization Implications: The significant temporal variations in mannitol consumption also present substantial challenges for demand forecasting and inventory management within the JRMS network since traditional demand forecasting models may require adjustment in order to account for the volatility observed in pharmaceutical consumption patterns, also to incorporate multiple variables including seasonal variations, clinical protocol changes and external factors and forces such as pandemic influences in order to improve forecasting accuracy.

The concentration of 68.5% of the total consumption in two specialized facilities, Queen Alia Center for Heart Diseases and King Hussein Medical Hospital, also has an important implication for inventory management strategies since these high-consumption facilities require a robust safety stock policies and a reliable supply chain in order to prevent stockouts that could compromise the critical patient care while smaller facilities only need adequate supplies for emergency situations without excessive carrying costs.

This centralized distribution system employed by JRMS provides many opportunities for optimization based on the consumption patterns identified in this analysis since understanding institutional consumption characteristics enables a more efficient allocation of pharmaceutical resources and also potentially reduces the overall network inventory requirements while maintaining an appropriate service level across all facilities in this network.

3.6 Economic Considerations and Resource Allocation: The consumption patterns also reveal significant economic implications for the pharmaceutical procurement and the budget allocation within the JRMS network, with Queen Alia Center for Heart Diseases and King Hussein Medical Hospital accounting for nearly seventy percent of the total network consumption these facilities represent the primary cost centers for mannitol procurement and therefore justify the focused inventory management attention and resources and understanding the consumption distribution also will enable a more accurate budget forecasting and potentially supports the negotiations with pharmaceutical suppliers based on this volume commitments, the concentration of consumption in specialized facilities may also justify the differentiated procurement strategies that balance cost efficiency with the clinical requirements across the diverse healthcare network, also the substantial variations in consumption patterns suggest the presences of opportunities for resource optimization through several mechanisms and policies including centralized procurement which leverage this network-wide consumption data for improved supplier negotiations and inventory redistribution mechanisms for transferring any excess inventory between facilities and standardized clinical protocols designed in order to optimize therapeutic utilization and demand management initiatives working with clinical teams in order to understand and potentially influence consumption patterns.

4. CONCLUSIONS:

In this study the comprehensive analysis of mannitol solution distribution across eight different hospitals within the Jordanian Royal Medical Services network

was done in the period from 2020 to 2023 and it revealed many significant and vital insights into the pharmaceutical consumption patterns and the supply chain dynamics and the existing clinical practice variations within this integrated healthcare system and the study's findings contributed to the valuable and important understanding of how specialized medications are utilized across diverse hospital settings and environments and provide an important guidance for optimizing the pharmaceutical inventory management strategies in the complex healthcare environments and this analysis has identified several critical and vital findings that characterize mannitol distribution within the JRMS network, the eleven-fold variation in consumption between the highest and lowest utilizing hospitals demonstrates a substantial difference in the clinical practice patterns, patient populations and the institutional specializations and this heterogeneity also reflects the diverse nature of healthcare delivery within this network while it also highlighting the significant opportunities for practice standardization and for resource optimization through evidence-based approaches also the consumption fluctuations and variations which were noted and observed during the study period particularly the 33.4% decline in 2022 which was then followed by a partial recovery in 2023 has illustrated and showed the significant impact of external factors and forces such as the COVID-19 pandemic on the pharmaceutical supply chains and other healthcare operations and these temporal variations also underscore the need for an agile and resilient inventory management systems which in turn would be capable of adapting the network to the unforeseen disruptions and the evolving clinical demands.

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