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RABIES POST-EXPOSURE PROPHYLAXIS SUPPLY PATTERNS IN JORDANIAN MILITARY HOSPITALS: A FIVE-YEAR ANALYSIS OF VACCINE AND IMMUNOGLOBULIN DISTRIBUTION.

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ABSTRACT

Background: Even though the government is working to stop rabies from spreading it is still a big public health problem in Jordan because animals bites can still spread it to people and because rabies is almost always deadly once symptoms appear, timely and effective post-exposure prophylaxis (PEP) is still the most important approach to stop the disease from spreading, this intervention which combines rabies vaccine to create active immunity and rabies immunoglobulin to give immediate passive protection in severe cases of exposures is highly necessary in order to prevent human deaths which making it vitally important to understand and keep an eye on the supply patterns and the availability of these important PEP components in order to make the best use of available resources, to avoid stockouts, to understand how they are supplied and to make sure that those life-saving treatments are always available to everyone in need.

Objectives: This study will examine the distribution patterns of rabies vaccine and immunoglobulin in three principal Jordanian military hospitals within the Jordanian royal medical services (JRMS) over a five-year period (2020–2024) and It will try to find patterns in those medications supply and distribution, to examine the hospital to hospital differences in supply and to assess implications of the resulted trends and variation for the JRMS supply chain management and standardization.

Methods: The study will embrace a retrospective descriptive design through the use of data from King Hussein Medical Hospital, Prince Hashem Ben Al-Hussein Military Hospital and Princess Haya Military Hospital. The dataset will contain the mean monthly quantities which were issued of rabies vaccine and rabies immunoglobulin over the study period to those hospitals. the analyses will involve the calculation of vaccine-to-immunoglobulin ratios, and year-over-year percentage changes. The findings will be presented in tables and then visualized in graphs and further discussed in relation to World Health Organization guidelines and best practices in rabies PEP delivery.

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1. INTRODUCTION:

Rabies is one of the worlds oldest known diseases with references dating back to over than four millennia to ancient Mesopotamian writings, however despite this long awareness it remains a serious threat to public health because of its almost universal fatality once its symptoms develop (1,2), the disease is caused by a neurotropic virus of the *Lyssavirus* genus in the family *Rhabdoviridae* and it continues to stand as a key example of a vaccine-preventable illness in which the timely intervention is critical and vital for survival.

According to the World Health Organization rabies claims about 59,000 lives each year with the majority of it in Asia and Africa where domestic dogs function as the main reservoirs of the virus (3), this figure is likely underestimated due to factors such as weak surveillance, insufficient diagnostic capacity and capabilities and to cultural factors that limit the reporting of animal bites and deaths, the impact of rabies spreads far beyond human mortality, contributing to economic losses, psychological distress and social disruption in affected communities.

The virus replicates and spreads at the bite site before starting to traveling through axons to the central nervous system, once there it starts to cause progressive encephalitis which is marked by clinical features such as hydrophobia, aerophobia and aggressive or paralytic presentations, the incubation period for the virus is variable and influenced by viral dose and bite location and host immunity but it typically falls within one to three months and once symptoms appear the disease is almost uniformly fatal with only a minority of documented survivors worldwide despite intensive medical care (4).

The World Health Organization has set a bold and ambitious target through its "Zero by 30" initiative which seeks to eliminate dog mediated human rabies deaths by the year 2030 (5), the plan focuses on scaling up post-exposure prophylaxis, increasing dog vaccination coverage, promoting responsible dog ownership and reinforcing surveillance with the One Health concept being central to this approach which include acknowledging the interconnectedness of human, animal and environmental health and asserts on joint solutions across these domains.

In the Middle East region rabies presents unique epidemiological challenges which are shaped by ecological diversity, wildlife distribution and cultural practices that influence human-animal interactions, Jordan which is located at the crossroads of Asia, Africa and Europe is particularly vulnerable because of cross-border animal movement, ecological variety and the differences in control capacities across neighboring states.

Molecular studies have already confirmed the active circulation of rabies virus in Jordan with domestic dogs being identified as the main reservoir species (6), genetic similarities between Jordanian strains and those circulating in the nearby countries underline the transboundary nature of rabies epidemiology and also highlight the necessity of regional cooperation.

Control efforts are complicated by the geopolitical instability, armed conflict and by large-scale population displacement in neighboring regions, refugee movements often involve companion animals and livestock which adds further challenges to monitoring and prevention and despite these difficulties Jordan reports relatively only few human rabies cases, this difference between the documented presence of rabies among animals and the infrequency of human cases may result from effective post-exposure prophylaxis, underreporting of exposures or from cultural patterns that limit high risk interactions and this relative success in protecting human lives even with the persistent animal cases further reinforces the essential role of accessible prophylaxis programs in national rabies control strategies.

Post-exposure prophylaxis has experienced major developments in the recent decades as advances in the immunology and vaccine technology have shaped the clinical practice in this area, modern recommendations from the World Health Organization and the Centers for Disease Control and Prevention stress and emphasize the systematic risk assessment and the evidence-based decision-making rather than just the subjective or the overly cautious approaches which was common in the past (7).

The first step in post-exposure management is the immediate and thorough cleansing of the wound with soap, water and with antiseptics, this simple yet crucial

and vital measure helps to reduce the viral load and can significantly lower the risk of infection and after wound care the decision regarding the prophylaxis is based on the circumstances of exposure, the behavior and health of the implicated animal and on the wider epidemiological context.

For severe exposures which involve transdermal bites, mucosal contamination or involve contact with animals suspected of carrying rabies both rabies immunoglobulin and vaccine are recommended, rabies immunoglobulin provides an immediate passive protection by neutralizing the virus at the site of entry and in the systemic circulation, it should be infiltrated around the wound site whenever its possible with any remaining dose to be given intramuscularly and vaccination by contrast functions by inducing active immunity and therefore providing long-term protection, modern vaccines which are produced in cell cultures and in an inactivated forms are far safer than the earlier nerve tissue-derived preparations, current WHO guidelines now allow simplified regimens such as the one-week intradermal schedule while the CDC continues to recommend the traditional four-dose intramuscular course (8).

The ratio of vaccine to immunoglobulin use within healthcare systems may offers much valuable insights and perceptions in the performance of their post-exposure programs specially since it can reflects the harshness of exposure cases treated (9) and how much the international guidelines were used and employed, it can also reflects the efficiency of supply chains and the institutional purchasing policies as well as the consistency of clinical practice and understanding these patterns can also allow policymakers and clinicians to identify any weaknesses and help them to improve resource allocation and therefore strengthen program performance.

Military healthcare systems play a vital role in rabies prevention particularly those in regions where civilian infrastructure is stretched or unevenly distributed, military hospitals regularly function as emergency care providers not only for soldiers but also for civilians either through referrals, humanitarian services or through formal agreements with the local authorities and their contributions to post-exposure prophylaxis are therefore significant.

There are a list of organizational characteristics and features which contribute to the effectiveness of military health services in the control of rabies, centralized procurement activities heavily contribute to the stable supply of vaccines and immunoglobulin; evidence-based clinical practices also are generally more standardized and rigorously implemented in terms of hierarchical order of command in the military settings; regular training initiatives can help to sustain the clinical excellence and maintain compliance with international standards; and also sound logistical and supply-management systems which operate on the principle of being always prepared to act can help to assure a stable provision of essential medical supplies, nevertheless military institutions have their own special challenges in regards to epidemiology since the service members may be more vulnerable in the course of the training exercises in the natural settings or by positioning of the troops to endemic zones, or working in places of the low-veterinary facilities, their existence makes strong prophylaxis systems more critical in terms of military healthcare as well as an example of how the experience in this field triggers the development of the more general measures on the country level.

2. Methods:

Study Design and Setting:

This investigation employed a retrospective data and used a descriptive analytical approach to comprehensively and fully examine and investigate the rabies post-exposure prophylaxis supply distribution patterns within the Jordanian military healthcare system over the five year period of 2020 through 2024 and this study involved three major military medical hospitals that are representing a significant component of Jordan's military healthcare infrastructure and the three hospitals were: King Hussein Medical Hospital, Prince Hashem Ben Al-Hussein Military Hospital and Princess Haya Military Hospital and they were chose and selected based on many several factors and criteria which included their status as major referral centers within the military healthcare network and their geographic distribution though the different regions and areas of Jordan which enables a good representation of the many and diverse epidemiological conditions and also their consistent

participation in the centralized medical supply distribution system throughout the entire study period and their role in providing care to considerable and large populations that include active military personnel, military dependents and civilian populations.

Data used was a comprehensive record of the monthly quantities and distribution of rabies vaccine and rabies immunoglobulin to each of the participating hospitals during study period. This was extracted out of the centralized military medical supply-chain management system that has comprehensive databases of all medical products supplied in the network. More importantly, the system maintains a detailed records concerning the movement of products into healthcare facilities, and out of the medical stores, capital procurement to regional distribution centers, which orients to the specific individual hospital pharmacy departments and delivers a all-inclusive visibility to the supply-chain operations

The methods of data-collection were a systematic process of extracting the records concerning applicable data based on standardized product identification codes of the rabies vaccines and immunoglobulin preparations, which are used in the healthcare system of the Jordanian army. Quality-assurance interventions involved consistency in codes over the study interval, verification of hospital identification, verification of measures of quantity and units to assess data completeness and temporal continuity.

The data represent monthly average supply issuance quantities to each hospital pharmacy department rather than direct patient-level administration records or individual treatment episodes, this distinction carries and has significant interpretation concerns since the issued supplies might include safety stocks to service emergency needs, products with an extended shelf life distributed or ordered in the anticipation of some kind of forecasted future variation patterns and small quantities of spoilage in response damages, stress, or other factors that have an impact on the products viability (10).

Analytical Methodology:

Several of the complementary approaches were taken into consideration in order to design this analysis framework used in this study in a bid to completely describe the supply-distribution patterns and discover the trends that may have policy implications and all the study variables in terms of hospitals, years, and product types were subject to a descriptive statistical analysis in order to determine the baseline characters and features and in order to identify the manifest aspects or deviations that need to be explored further.

The calculation of vaccine-to-immunoglobulin ratios was carried out on the basis of each hospital-year combination with reference to the formula: monthly average vaccine dose/monthly average immunoglobulin dose and such ratios yield many essential information on the relative quantities of the use of the two significant components of post-exposure prophylaxis and offer support in perspective of the existing practice-based clinical and epidemiological expectations and norms.

Each data type of the product and the hospital was evaluated on the year-over-year percentage changes using a simple formula of comparing annual results. Multiple statistical values were used as measurement of the inter-hospital variation and they included: the range (Maximum -Minimum) calculations and the coefficient of variation calculations in percentages.

3. Results:

Comprehensive Supply Distribution Analysis: The five-year analysis revealed and showed many reflective and systematic changes in the rabies post-exposure prophylaxis supply patterns across all three military hospitals under study which demonstrates and shows a clear evidence of strategic improvements in the supply chain management and the clinical readiness since the collected and aggregate data present a persuasive and compelling narrative of a transformation from the initially imbalanced and inconsistent supply patterns to a more increasingly standardized and clinically appropriate distributions all which align more closely to the established international guidelines (Table 1).

Table 1: Complete Dataset with Comprehensive Calculated Metrics

Year	Hospital	Vaccine (doses/ month)	Immunoglobulin (doses/month)	V:I Ratio	Vaccine Change (%)	Immunoglobulin Change (%)
2020	King Hussein Medical	8	6	1.33	-	-
2020	Prince Hashem	10	0	∞	-	-
2020	Princess Haya	3	2	1.50	-	-
2020 Total	**All Facilities**	**21**	**8**	**2.63**	-	-
2021	King Hussein Medical	15	13	1.15	+87.5	+116.7
2021	Prince Hashem	9	2	4.50	-10.0	+∞
2021	Princess Haya	3	3	1.00	0.0	+50.0
2021 Total	**All Facilities**	**27**	**18**	**1.50**	**+28.6**	**+125.0**
2022	King Hussein Medical	13	11	1.18	-13.3	-15.4
2022	Prince Hashem	13	13	1.00	+44.4	+550.0
2022	Princess Haya	4	4	1.00	+33.3	+33.3
2022 Total	**All Facilities**	**30**	**28**	**1.07**	**+11.1**	**+55.6**
2023	King Hussein Medical	14	16	0.88	+7.7	+45.5
2023	Prince Hashem	16	15	1.07	+23.1	+15.4
2023	Princess Haya	6	7	0.86	+50.0	+75.0
2023 Total	**All Facilities**	**36**	**38**	**0.95**	**+20.0**	**+35.7**
2024	King Hussein Medical	15	17	0.88	+7.1	+6.3
2024	Prince Hashem	16	15	1.07	0.0	0.0
2024	Princess Haya	6	6	1.00	0.0	-14.3
2024 Total	**All Facilities**	**37**	**38**	**0.97**	**+2.8**	**0.0**

Aggregate Supply Trends and System-Wide Analysis:

The system wide transformation across the entir

system is most clearly proved and showed through the collective supply trends seen across all the three facilities since the total monthly vaccine distribution have increased progressively from 21 doses in 2020 to

37 doses in 2024 and thereby representing a cumulative and overall increase of 76 percent over the entire and full study period and this considerable growth demonstrates a significant growth in vaccine procurement and its distribution capacity which in turn reflects either an increasing clinical demand or the use of a strategic stockpiling in order to ensure and maintain treatment availability.

Immunoglobin distribution has changed significantly during the study period with eight doses per month in 2020 and with thirty-eight doses per month in 2024 which made an increase of 375 percent, this large increase has essentially transformed the supply portfolio of the military healthcare system and thereby reflected a clear evidence of a systematic correction of the initial supply imbalance and the recognition of the importance of immunoglobulin in post-exposure prophylaxis guidelines has been recognized, moreover the systematic improvement of the supply-chain strategy is also well evidenced by the development of the aggregate vaccine -immunoglobulin ratio in which the ratio in the system-wide has declined to 0.97:1 in 2024 after it was 2.63:1 in 2020 thereby approaching the balanced ratios as recommended by international standards in health-care systems with populations of unequal exposure-severity distributions.

Individual Hospital Performance Analysis:

King Hussein Medical Hospital appeared as the best and the most consistent performer among the three hospitals during the period of study in which the number of vaccine doses went up during 2020 to eight doses monthly to fifteen doses monthly (87.5 increase) in 2024 thereby in turn indicating a long-term willingness to keep the prophylaxis capacity sufficient and at the same time the number of doses of immunoglobulins have increased from six to seventeen per month, 183 percent, which demonstrating the effective compliance of both elements of prophylaxis.

The vaccine to immunoglobulin ratios transformed and progressed from 1.33:1 ratio in 2020 to a more stable 0.88:1 ration in both 2023 and 2024 which thereby indicating the successful achievement of the balanced supply strategies which are aligned with clinical best practices and this consistency also suggests presences of an effective inventory management processes which were preceded by a stable procurement relationship that enable a predictable supply availability.

Prince Hashem Ben Al-Hussein Military Hospital has showed the most noticeable and dramatic supply patterns transformation since it began the study period with a significant imbalance which then was thoroughly corrected over the subsequent following years and the facility's initial complete lack of immunoglobulin allocation and distribution in 2020 despite it receiving 10 vaccine doses monthly has created an impossible to calculate vaccine to immunoglobulin ratio which in turn highlighted the existence and presences of a severe deficiency in this hospital supply and the transformation achieved by this facility represents and symbolizes perhaps the most considerable evidence of systematic improvement within this military healthcare system since its by 2024 the facility has reached balanced supplies with 16 vaccine doses and 15 immunoglobulin doses monthly which also resulted in a clinically appropriate ratio of 1.07:1 and this extraordinary change demonstrates the potential for rapid improvement when enough systematic attention is applied to supply chain optimization and its management.

Princess Haya Military Hospital has seen a consistent, albeit at a low rate, growth during the study period. The vaccine stock and immunoglobulin stock were both successfully increased 2-fold compared to 2020 baseline, remaining the lowest among the three centers surveyed and the number of monthly vaccine doses increased to six (three previously), and the number of monthly immunoglobulin doses increased to six (two previously), although the hospital was smaller in scale, its vaccine- immunoglobin ratio however remained stable over the study period; it changed between 1.50:1 in 2020 and 1.00:1 in 2024 and thereby showing that standardization was proficient enough despite resource limitations (Table 2).

Inter-Hospital Variability and Standardization Assessment:

Table 2: Comprehensive Inter-Hospital Variability Analysis

Year	Vaccine Range	Vaccine Mean	Vaccine CV (%)	Immunoglobulin Range	Immunoglobulin Mean	Immunoglobulin CV (%)	Ratio Range
2020	7 (3-10)	7.0	35.7	6 (0-6)	2.7	112.5	Variable*
2021	12 (3-15)	9.0	44.4	11 (2-13)	6.0	61.1	3.50 (1.00-4.50)
2022	9 (4-13)	10.0	30.0	9 (4-13)	9.3	32.1	0.18 (1.00-1.18)
2023	10 (6-16)	12.0	27.8	9 (7-16)	12.7	24.0	0.21 (0.86-1.07)
2024	10 (6-16)	12.3	27.8	11 (6-17)	12.7	30.4	0.19 (0.88-1.07)

The interhospital variability analysis also reveals and shows a compelling evidence of those successful adjustment efforts across this entire military healthcare system since the coefficient of variation measurements for vaccine have decreased from 35.7 percent in 2020 to 27.8 percent in 2024 which in turn has indicated a reduced relative variability in their supply despite the absolute growth in volumes across all the three facilities included in this study.

This coefficient of variation of immunoglobulin had a significantly improved trend in that it was at a considerably high value, 112.5 percent in 2020 and 30.4 percent in 2024, this large decrease indicates the elimination of extreme imbalances, such as the lack of immunoglobulin at Prince Hashem Ben -Hussein in 2020, as well as the achievement of more stable allocation patterns in the three facilities.

The result of the ratio of the vaccines and the immunoglobulin levels offers further evidence of convergence towards standardized practices since the range of ratios became more limited by 2021 by the correction of the original imbalances to the consistent range of much narrower values of 0.180 to 0.21 in 2022-2024, thus, demonstrating the exceptional consistency in the supply balance across the diverse facilities and their operational settings.

Growth-rate trends and time series: Annual growth rates indicate that the development of the supply has gone through various stages and provides information on the nature of the supply-chain revolution with the most pronounced growth period being the 2020-2021 transition period in which the aggregate vaccine supply has grown by 28.6% and immunoglobulin supply by 125.0% which in its turn reflecting an awareness of supply gaps and a obligation to quick correction.

The 2021-2022 year also saw the sustained growth at more moderate levels (vaccine +11.1%, immunoglobulin +55.6%), which indicates the stabilization of previous gains and the balancing of relationships with the suppliers and the last years of study, 2023-2024, also saw a shift in growth trends towards stabilization: vaccine supplies grew by 20.0% in 2023 and by 2.8% in 2024, and immunoglobulin growth was 35.7% during 2023 and followed by stability in 2024 (Table 3).

Cumulative Distribution and Resource Allocation Analysis:

Table 3: Five-Year Cumulative Supply Distribution Analysis

Hospital	Total Vaccine	Total Immunoglobulin	% Total Vaccine	% Total Immunoglobulin	Combined Share
King Hussein Medical	65	63	43.0%	46.3%	44.4%
Prince Hashem	64	45	42.4%	33.1%	38.7%
Princess Haya	22	28	14.6%	20.6%	16.9%
System Total	**151**	**136**	**100%**	**100%**	**100%**

The cumulative distribution analysis over the five-year period of the study reveals very important patterns in those resource allocation equity and the institutional roles within this military healthcare system, King Hussein Medical Hospital received the largest share of both product categories which was accounting for 43.0 percent of total vaccine supplies and 46.3 percent of immunoglobulin supplies and thereby establishing its position as the primary post-exposure prophylaxis provider within the network.

A similar and somewhat the same percentage of vaccine allocations (42.4%) was also assigned to Prince Hashem Ben o Al-Hussein Military Hospital; however, with a significantly lower percentages of immunoglobulin allocations that were assigned (33.1) which also indicated and shows the effects of the initial imbalance in supplies in the facility and the time needed to reach balance, Princess Haya Military Hospital received the lowest allocations continuously over the study period (14.6 percent of vaccines and 20.6 percent of immunoglobulin).

4. DISCUSSION:

Principal Findings and Strategic Implications: This comprehensive five-year analysis reveals a very remarkable transformation in rabies post-exposure prophylaxis supply chain management within the Jordanian military healthcare system and providing compelling evidence of systematic improvement in the clinical preparedness and the system resource allocation strategy, the most significant finding involves the progression from a highly imbalanced and variable supply patterns which are characterized by significant gaps in the essential components to an increasingly standardized and clinically appropriate distributions that align closely with the established international guidelines and the epidemiological best practices.

The 375 percent increase in immunoglobulin supplies which substantially exceeding vaccine growth of 76 percent represents a systematic correction of initial supply imbalances and demonstrates the growing recognition of immunoglobulin's critical role in the comprehensive post-exposure prophylaxis protocols and this transformation also reflects not merely the quantitative expansion but also a fundamental strategic reorientation toward an evidence based supply planning that prioritizes the clinical effectiveness over cost minimization (11).

The convergence of vaccine-to-immunoglobulin ratios from a highly variable initial patterns toward a more consistent ratios which are approaching unity across all facilities indicates a successful implementation of the standardized procurement strategies and clinical protocols and this standardization achievement is of particularly noteworthy given that the different operational scales, geographic locations and potentially different patient populations that are served by the three facilities.

Clinical Practice Enhancement and Guideline Adherence: The observed and noted supply pattern evolution carries many profound implications for the clinical practice quality and the adherence to international post-exposure prophylaxis guidelines which were established by the World Health Organization and Centers for Disease Control and Prevention since the current evidence-based

recommendations specify that post-exposure prophylaxis decisions should incorporate a systematic risk assessment considering exposure circumstances, animal behavior and health status, local epidemiological conditions and the patient-specific factors and characteristics including their immune status and previous vaccination history (12).

The achievement of balanced vaccine-to-immunoglobulin ratios that approaching unity suggests either a predominance of severe Category III exposures which requiring both prophylaxis components or a conservative clinical practice that ensuring comprehensive treatment capability for emergency situations, and given the catastrophic consequences of an inadequate treatment and also the relatively brief window for effective intervention such conservative approaches represent a clinically sound and an ethically appropriate resource allocation decisions.

The removal and elimination of supply imbalances specially the complete absence of immunoglobulin which was established at Prince Hashem Ben Al-Hussein in 2020 represents a critical and a vital improvement in this hospital clinical readiness and awareness and it also indicate the enhancement and presences of emergency response capability and since military personnel face unique exposure risks and challenges during their training especially those conducted in natural environments or during their deployment activities in regions or areas with little or limited veterinary infrastructure or their service in areas where animal population control measures and policies may be inadequate making a comprehensive post-exposure prophylaxis capabilities an essential tool to ensure their safety and to maintain their health and protect it.

Economic Considerations and Resource Optimization: The sizable and substantial increase in immunoglobulin procurement holds and carries significant budget implications that require very careful consideration within healthcare resource allocation frameworks since rabies immunoglobulin typically costs substantially much more than vaccine per dose which makes the observed 375 percent increase a major financial commitment that must be justified through the clinical appropriateness assessments and a public health impact evaluations, however the economic evaluation of rabies post-exposure prophylaxis must also consider the extremely high benefit-to-cost ratio of the prevention compared to the treatment of established rabies cases since the direct medical costs of intensive care management for suspected rabies cases combined with the nearly universal fatality rate and the associated psychological trauma for families and healthcare providers create a compelling economic justification for this comprehensive prevention capabilities (13).

5. CONCLUSIONS:

This study shows and suggests that the supply chain of the rabies post-exposure prophylaxis in the Jordanian military hospitals is being managed systematically as supply patterns begin to shift out from imbalance and variability toward a more standardization and predictability which in turn demonstrate by this development a big step toward the alignment with the international health practices, these successful standardization efforts can be used as a guideline to other health systems that can focus on intensifying their rabies prevention programmers and the lessons learned during this military healthcare delivery are valuable and vital in enhancing the services to civilian populations as well as to developing regional coordination and therefore are in line with the World Health Organization eradication goals (14).

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