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A Deterministic Model to Estimate the Cost Impact of Different Varicella Vaccination Strategies in a Tropical Setting with a Diverse Workforce

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Abstract

Background: Objectives of this study were 1. To review the impact of the Institutional Chickenpox Prevention Program (ICPP) at National University Hospital (NUH), Singapore from Jan 2010 – Jun 2014; 2. To compare the costs of different chickenpox vaccination strategies using a deterministic model; in a 1000 bedded tertiary care university hospital with total staff strength of approximately 7300 in Singapore, a country with a diverse population and a high incidence of adult chickenpox. *Methods:* Retrospective audit of incidence, contact tracing data, deterministic modelling to predict number and cost of future varicella infections. *Results:* There were a total of 51 cases of chickenpox, 15 among staff and 36 among inpatients from Jan 2010 to Jun 2014, (average 3.3 staff per year) with two secondary nosocomial transmissions. The median number of staff contacts per patient index case was 4 (IQR 2-13). Total direct cost incurred for diagnosing and treating the Chickenpox cases was 70,001.7 USD (IQR 248.5- 1961.8 per index); while the total person-hours lost were 7,573 (IQR 28-229 per index). Cost of chickenpox infection in high risk wards was four times higher with twice as many man-hours lost as compared with general wards. Maximizing staff immunity to VZV helped minimize outbreaks in deterministic model. *Conclusions:* Nosocomial Chickenpox continues to add significant burden to NUH in terms of costs and man hours lost. Deterministic model shows that maximizing staff immunity to VZV would minimize outbreaks. Locally, additional strategies targeting healthcare worker cohorts in high risk areas and from countries with low VZV sero-prevalence, may be most cost effective.

Keywords: Varicella; Chickenpox; Singapore; Hospital Vaccination Policy; Vaccination of Healthcare Workers; Health Policy; Infectious Diseases; Hospital Infection Control.

Background

Chickenpox is a highly contagious disease caused by infection with *varicella zoster* virus (VZV). Primarily a childhood infection in Europe, Australasia and North America, it is usually more severe in adults, and can be life threatening in immune-compromised patients [1,2,3]. In tropical countries, varicella is often an adult disease for reasons that are not entirely clear [4,5,6,7].

Immunization of healthcare workers against varicella has long been a topic of discussion for healthcare policy makers globally. In the United States, the Infectious Diseases Society of America (IDSA), the Society for Healthcare Epidemiology of America (SHEA), and the Pediatric Infectious Diseases Society (PIDS) recommend mandatory, universal immunization of health care personnel against varicellain line with the Centers for Disease Control and Prevention's (CDC) Advisory Committee on Immunization Practices (ACIP) [8,9].National University Hospital (NUH), a 1000-bed tertiary referral academic medical center in Singapore,has recommendedvoluntary varicella vaccination for all staff in direct patient contact since 2010. Immunity to varicella is reported by existing and new staff based

on self-declared history of previous infection or 2 documented doses of VZV vaccination. Staff who are unsure of their immune status are required to go for free of cost varicella IgG (immunoglobulin G) testing as a marker of immunity to varicella. Other hospitals in Singapore currently recommend similar staff VZV immunization programs. [10,11,12,13,14, 15].

Accuracy of history of VZV varies between different settings and recall cannot be taken as a true predictor of immunity [19]. Different nationalities also differ in their sero-prevalence of varicella. A recent analysis of hospital screening data at our hospital [27]noted marked differences in sero-prevalence for VZV immunity among staff based on nationality as well as age. Those born before 1960 had high levels of immunity with sero-prevalence increasing with increasing age; also, among our workforce, staff from China were noted to have highest VZV immunity levels of 98% (CI: 96-99.6) while staff from India amongst the lowest at 82.5% (CI: 75.7- 88), Singaporean colleagues had a sero-prevalence of 93.2% (CI: 92.1- 94.1), presumably due to natural exposure patterns as routine childhood varicella vaccination has only been introduced relatively recently in Asia.

We reviewed the impact of an Institutional Chickenpox Prevention Program (ICPP) in a tertiary care public hospital in Singapore from Jan 2010 – Jun 2014 in terms of man-hours and direct costs incurred to the hospital from staff and inpatient chickenpox cases;we also compared the cost of different chickenpox vaccination strategies among healthcare workers using deterministic simulation modelling.

Methods

The study methodology is divided into 2 parts: *Part A* was a retrospective audit of epidemiology unit contact tracing data of all staff and non-isolated inpatient chickenpox cases at NUH from Jan 2010-Jun 2014. It was part of internal quality improvement exercise to help inform future policy decisions for varicella vaccination in NUH. Our audit was conducted under the direction of the hospital's infection control committee and relied on the electronic medical records generated from 2010 to 2014. Secondary analysis of this dataset was in keeping with national guidelines as stipulated by Singapore Ministry of Health under the Private Hospitals and Medical Clinics Act that requires licensed healthcare establishments to evaluate infection control procedures on a continuing basis.

Part B involved construction of a prospective deterministic model to compare different vaccination strategies, in terms of costs incurred to NUH, expected number of susceptible staff in each scenario as well as expected number of infections per year.

Inclusion Criteria

All potentially contagious clinically or virologically or serologically diagnosed cases of chickenpox amongst inpatients and staff presenting at NUH were reviewed. For patients, we included those who were either asymptomatic at admission or missed the diagnosis of chickenpox and were admitted to non-isolation wards. For staff, we included those who developed chickenpox and were working at least 48 hours before onset of symptoms in hospital irrespective of patient contact, or those who reported to work with symptomatic varicella disease. These criteria were chosen based on risk of hospital transmission of chickenpox by an index case. We excluded staff who did not report to work in the 48 hours prior to the onset of symptoms or patients admitted directly to isolation wards.

Setting: 1000 bed tertiary care university hospital in Singapore, with total staff strength of around 7300. There are a total of 179 isolation rooms including emergency department, clinics and procedure rooms with negative pressure available in 135 rooms.

Index Case Management and Contact Tracing Process Flow at NUH

Once an index case is identified,clinical management and contact tracing areinitiated simultaneously. Figure 1 summarizes the process flow for staff and inpatient chickenpox index case management in NUH.

Management of Index Case: Any admitted case, is transferred to an isolation ward for treatment; whereas, staff cases at home (on medical leave) are advised to return to an isolation emergency department room for confirmation of diagnosis (clinically or virologically by trained occupational health clinic doctors), but are free to follow up with nearby general practitioners for subsequent treatment and fitness to return to work.

Contact Tracing: Contact tracing considers both staff and patient contacts and is done by a dedicated Epidemiology team based on information from ward nurses and patient movement records from the electronic hospital information system. Patient contacts are managed based on risk stratification and host susceptibility. Staff contacts are screened based on documented IgG levels or immunization records;

if unavailable, history of prior chickenpox or previous VZV immunization (2 doses) are noted as surrogates of VZV immunity. Staff with uncertain or negative history are followed up at the occupational health clinic, for IgG testing and varicella vaccination. Susceptible staff are re-deployed to non-patient contact areas or given leave during the incubation period for varicella infection, usually 10-21 days post exposure.

Costs

The cost of inpatient and staff chickenpox cases were estimated based on the cost of outpatient care, time lost from work, hospitalization, contact tracing as well as laboratory investigations. Each employee was assumed to require 2 outpatient visits costing 19.5 USD each. Average wages for different job grades were computed as per Ministry of Health (MOH), Singapore recommendations. Each exposed, potentially susceptible worker was assumed to require a serological test to ascertain immunity.

Table1 describes assumptions on time and cost, based on laboratory reports, claims as well as hospital records. The cost of hiring temporary staff for furloughed staff was not included in the calculations as it was noted that during these episodes, existing ward staff cross-cover for furloughed staff, cutting cost substantially. The cost for temporary employment of new staff has been found to be significant in studies elsewhere. Time lost from work for exposed susceptible staff was however included in calculations [16,17,18, 19, 20].

Deterministic Model [21,22,23]

A prospective deterministic model was created using key assumptions mentioned in Table1 to compare 3 different vaccination strategies. Strategy A [History First], the optimized current vaccination strategy, where both existing and new staff are screened based on self-reported history of previous chickenpox infection or immunization; those with negative or uncertain history are required to go for IgG testing and subsequent vaccination if needed; Strategy B [Universal IgG Testing] where all NUH staff, both existing as well as new, are required to undergo IgG testing, and those found to be non-immune will be vaccinated; and Strategy C [Universal IgG for New Staff] where existing NUH staff will be screened based on history, while new staff will be screened based on IgG levels.

Costs for the three strategies were evaluated. Total costs included costs incurred due to inpatient and staff chickenpox cases as well as cost incurred in the staff vaccination strategy. Costs of each additional case of chickenpox averted (in excess of strategy A) in strategy B and C were compared. Inflation and discounting were estimated at 3% for Singapore economy, and were noted to cancel out each other's effect in the calculations for 2010 to 2014 period. Consultation costs for routine vaccination were omitted as they were part of annual employee health screening or employment screening of new staff and did not require a separate consult.

Data Collection

Both clinical and administrative records were analyzed including inputs from contact tracing, occupational health clinic database, hospital information system and human resource (HR) department. Data were anonymized and evaluated retrospectively by an independent researcher. There was no contact with patients or their families, and data related to this audit was kept password protected at all times with only the research team having access.

Average wages were obtained from Human Resources department (based on Singapore MOH recommendations). Data for assumptions in the model were derived from the literature and review of past cases at our hospital [24,25,26].

Statistical Tests

Descriptive epidemiology was used to present demographic variables. Medians were compared using Kruskal-Wallis/Man Whitney U-test. Statistical calculations were performed using Stata 12. Deterministic modelling was performed to compare cost of different vaccination strategies, in terms of cost for each additional case of varicella prevented in newer strategies as compared to the current vaccination strategy.

Results

Part A, Retrospective Audit

A total of 51 cases of inpatient and staff chickenpox were reported between Jan 2010 to Jun 2014, of which 37 (72.5%) were hospital patients. Table 2 describes characteristics for index cases, median age for index cases was 26 years (19-35), 27(52.9%) were females and 21 (41.2%) were non-Singaporeans. There was one case of peri-partum chickenpox in a mother, whose new born was given VZV immuno-globulin (VZIg). No pregnant or immune-compromised staff

received VZIg, during this period there were no varicella mortalities, while one outbreak with secondary nosocomial transmission resulted in two secondary cases.

Figure 2 shows the Epidemiological curve for index inpatient and staff chickenpox cases at NUH from 2010 to Jun 2014. Table 3 summarizes the yearly distribution of cases and contacts; there were a total of 1028 contacts, with a median of 13 contacts per index (IQR 2-27). The median number of staff contacts per index case was 4 (IQR 2- 13) while the median number of non-immune staff contacts was 0 (0-2). The proportion of non-immune staff among total staff contacts was 10%. Distribution of index cases was relatively even across the year with no apparent seasonality and no significant trend among median susceptible staff contacts per index case over the years.

Total costs incurred by the hospital (Table 4) during this period on staff and inpatient Chickenpoxcases was 70,001.7 USD (median 592.4, IQR 248.5- 1961.8 per index); while the total man hours lost were 7,573 (median 117, IQR 28-229 per index).

Costs of chickenpox infection in high risk wards (obstetrics and gynecology paediatric and oncology wards and ICUs) were significantly higher than exposure in other wards, in terms of both direct costand man hours lost. Median cost for these 5 episodes was estimated to be at 1961 (IQR 1933.1-2022.5), 4 times higher as compared to the rest with twice as many man hours lost. Out of 5 index cases in high risk wards, 2 were in obstetrics requiring extensive and more detailed contact tracing and immunity checks of susceptible staff, mothers (peri-partum or immediate post-partum) as well as of the neonates as potential complications could be life threatening. A total of 3 babies were given IVIg requiring hospitalization.

Part B, Deterministic Model

Cost Comparison of Vaccination Strategies: The three vaccination strategies were modeled for 15 years post implementation to study the cost, effects on number of outbreaks as well as decrease in susceptible population. The current vaccination strategy (A), though effective in limiting secondary transmission (together with help of robust contact tracing) will cause the susceptible staff population to remain the same over years, thus resulting in a similar rate ofstaff infections (3.4) per year. Strategies B and C bring down the susceptible population (Table 5), hence reducing the number of infections (Table 5) and also the cost associated with each infection. The cost of each additional case of varicella averted under strategies B and C (as compared to strategy A) are summarized in Figure 3. The cost of each additional varicella case averted comes down year on year for both Strategies B and C. Similar studies of incremental costs in healthcare setting have concluded as mass vaccinations to be unattractive, with cost per case avoided ranging between 32,000 – 50,000 USD [11, 28]. In our study incremental costs are comparable to published data post implementation, however, are noted to be on downward trend to reach about 5800 and 9500 USD per case averted at 10 year mark.

Table 1: Key assumptions for Deterministic Modelling and Cost Calculations

Assumption		Sources
Staff strength	7300	Hospital data
Number of staff infections	15 (3.33 per year)	Infection control and contact tracing audit data
Expected number of staff classified as susceptible based on history [from contact tracing data]	10% (730)	Hospital data + Infection control and contact tracing audit data[27]
Risk of infection to staff	3.33/730 per susceptible staff per year (.00456)	Infection control and contact tracing audit data
Prevalence of immunity in NUH staff against varicella (based on annual screening data)	90%	Hospital data[27]
Literature:		*References:
NPV of negative history of varicella infection	40-90% (Taken at 80%)	11,12,19*
PPV of positive history of varicella infection	90%	24,26*
Vaccine efficacy	85%	9,11*
Staff attrition rate	10% per year	Hospital Data

Time taken for vaccination consults	15min per patient (one doctor plus one nurse)	Hospital Data
Costs of Investigations	(In USD)	Hospital Data
IgG, IgM, VZV PCR		
Vaccination 2 doses	22.7, 34, 70.1	
Costs based on man hours lost	62.5	
Contact tracing and Epidemiology		
Epidemiology	16 hours (2 FTE for 1 day)	Infection control and contact tracing audit data
Infection control	8 hours (2 FTE for 0.5 day)	
Ward Team	4 hours (1 FTE for 0.5 day)	
Additional time for high risk contacts	16 hours	
Redeployment (day 11 to 21)	11 days x 8 Hours	
Index Staff		
Outpatient Visits	19.5 USD x2	Hospital Data
Medical Leave	14 days x 8 Hours	Infection control and contact tracing audit data
Inflation	3%	Assumption for Singapore
Discounting	3%	Assumption for Singapore

Table 2: Index Case Characteristics Jan 2010- Jun 2014 (n=51)

Age (Median, IQR)	26 (19-35)
Age Distribution	Numbers (Percentage)
<10	9
10-19	4
20-29	19
30-39	10
40-49	2
50-59	2
60-69	4
70-79	0
80-89	1
Sex	Number (percentage)
Male	24 (47.1%)
Female	27 (52.9%)
Resident Status	Number (percentage)
Resident	30 (58.8%)
non-Singaporean	21 (41.2%)
Patient or Staff	Number (percentage)
Patients	36 (70.6%)
Staff	15 (29.4%)
Staff Job Categories	(n=15) Number (percentage)
Medical	2 (13.3)
Nursing	7 (46.6)
Ancillary Staff	3 (20.0)
Admin Staff	3 (20.0)
Pregnant or Not	
Pregnant	1
Not Pregnant	50
Staff in High Risk areas	(n=5)
Obstetrics/ Neonatology	3
Intensive Care	0
Immuno-compromised	2
Contacts	1028
Patient Contacts	512
Staff Contacts	516
Non-immune contacts	50
Secondary Transmission Episode	1
Number of secondary cases	2
Mortality	0

Table 3: Yearly Distribution of Cases and Contacts

Year	2010	2011	2012	2013	2014 (Jan – Jun)	Total
Number of Index Cases	14	11	12	11	3	**51**
Staff Index Cases	2	1	5	7	0	**15**
Patient Index Cases	12	10	7	4	3	**36**
Total Number of Contacts	97	268	265	371	27	**1028**
Median contacts per index(IQR)	2 (2- 8)	15 (13-28)	12(2-33.5)	27 (19-33)	9 (8- 10)	**13(2-27)**
Kruskal-wallis p= 0.003						
Patient contacts	28	104	176	188	16	**512**
Median (IQR)	0 (0- 5)	7 (0 -14)	6.5 (0-24)	8 (0- 16)	6 (0-10)	**5(0-10)**
			Kruskal-wallis p= 0.108			
Staff Contacts	69	164	89	183	11	**516**
Median (IQR)	2 (2- 4)	12 (8-14)	1.5 (0- 8)	11 (4 – 27)	2 (0- 9)	**4(2-13)**
			Kruskal-wallis p=0.013			
Number of Non immune staff contacts	13	10	7	20	0	**50**
Median (IQR)	1 (0- 2)	0 (0- 2)	0 (0- 2)	2 (0- 3)	0 (0-0)	**0(0-2)**
			Kruskal-wallis p=0.24			
Proportion of Susceptible staff contacts* (Total Non-immune/total staff contacts)	0.2	0.1	0.1	0.1	0	**0.1**

*Standardized to 1 decimal place

Table 4: Costs due to staff and inpatient chicken pox in NUH Jan 2010- June 2014
Man hours lost due to staff and inpatient Chickenpox (in hours)

Year	Total number of hours lost	Median number of hours lost per index (IQR)
2010	1768.4	116.5 (28- 205.3)
2011	1306.5	28(28- 228.6)
2012	1516.5	140 (28- 172.6)
2013	2897	317.3 (28- 421.9)
2014	84	28 (28-28)
Total	7572.5	116.6 (28-228.6)

Direct Costs to NUH due to staff and inpatient Chickenpox (in USD)

Year	Total Cost	Median cost per index (IQR)
2010	13005.3	745.6 (248.5 – 941.9)
2011	8889.5	248.5 (248.5- 1460.6)
2012	17657.3	592.4 (248.5 – 1528.5)
2013	29704.1	2022.5 (248.5 – 3735.1)
2014	745.5	248.5 (248.5 - 248.5)
Total	70001.7	592.4 (248.5 – 1961.8)

Cost Comparison between Index cases in high risk wards versus other wards

	Man hours (in Hours)		Costs (in USD)	
	Total	Median (IQR)	Total	Median (IQR)
Index in High risk wards (5)	1263.9	228.6 (156-317.3)	16087.4	1961.9 (1933.1- 2022.5)
Index in other wards (46)	6308.6	116.6(28- 205.3)	53914.3	579.9 (248.5- 1460.6)
Kruskal-wallis P Value		0.02		0.01

Table 5: Comparison of Different Vaccination Scenarios in terms of cumulative costs, expected total susceptible staff population and expected number of staff infections per year using Deterministic Model

Cumulative Costs in x1000 USD	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Strategy A: History First	68.6	89.5	110.4	131.2	152.1	172.9	193.8	214.7	235.5	256.4	277.3	298.1	319.0	339.9	360.7
Strategy B: Universal IgG Testing	213.8	237.3	260.8	284.3	307.8	331.3	354.8	378.3	401.8	425.3	448.8	472.3	495.8	519.3	542.8

Strategy C: Universal Testing for New Staff	68.6	104.0	138.2	171.3	203.4	234.7	265.2	295.0	324.1	352.7	380.8	408.4	435.5	462.3	488.8

Expected Total Susceptible Population per Year (Number of Staff)

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Strategy A: History First	745	745	745	745	745	745	745	745	745	745	745	745	745	745	745
Strategy B: Universal IgG Testing	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110
Strategy C: Universal Testing for New Staff	745	681	624	573	526	485	447	413	383	356	331	309	289	271	255

Expected Number of Staff Infections per Year for 7300 Staff Population

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Strategy A: History First	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Strategy B: Universal IgG Testing	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Strategy C: Universal Testing for New Staff	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.2	1.2

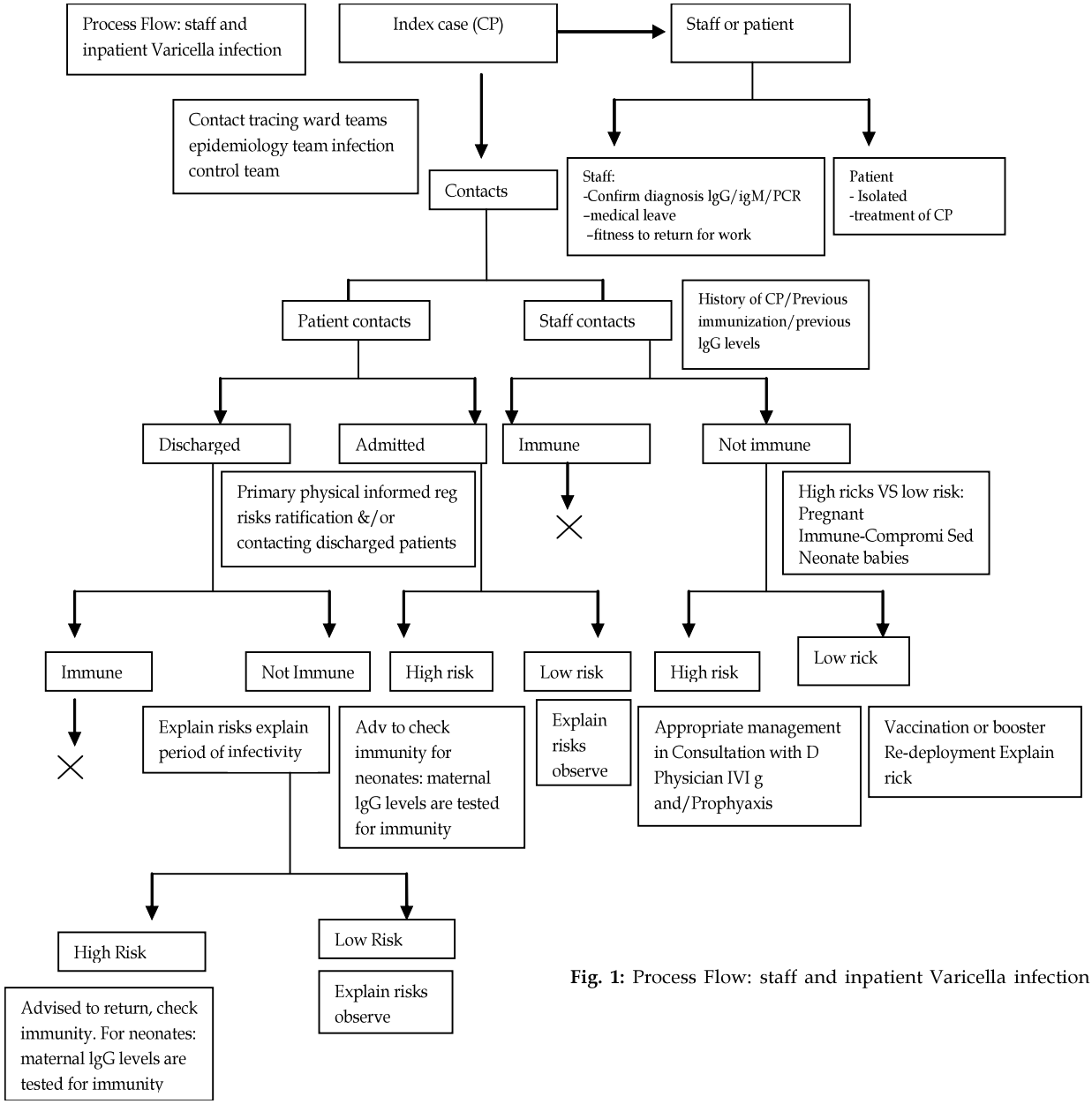


Fig. 1: Process Flow: staff and inpatient Varicella infection

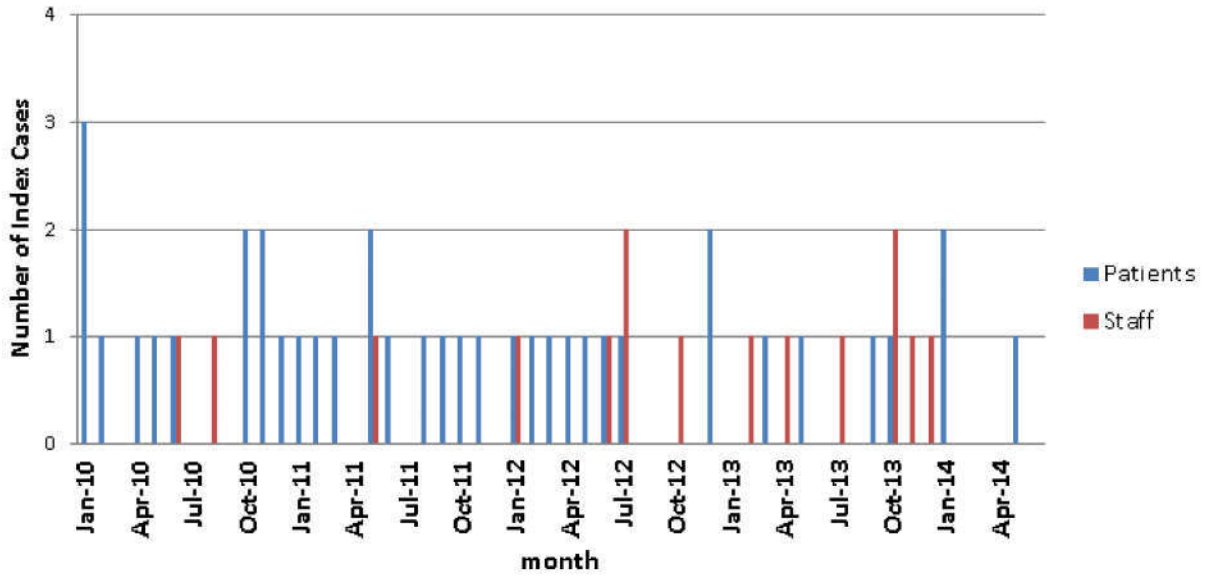
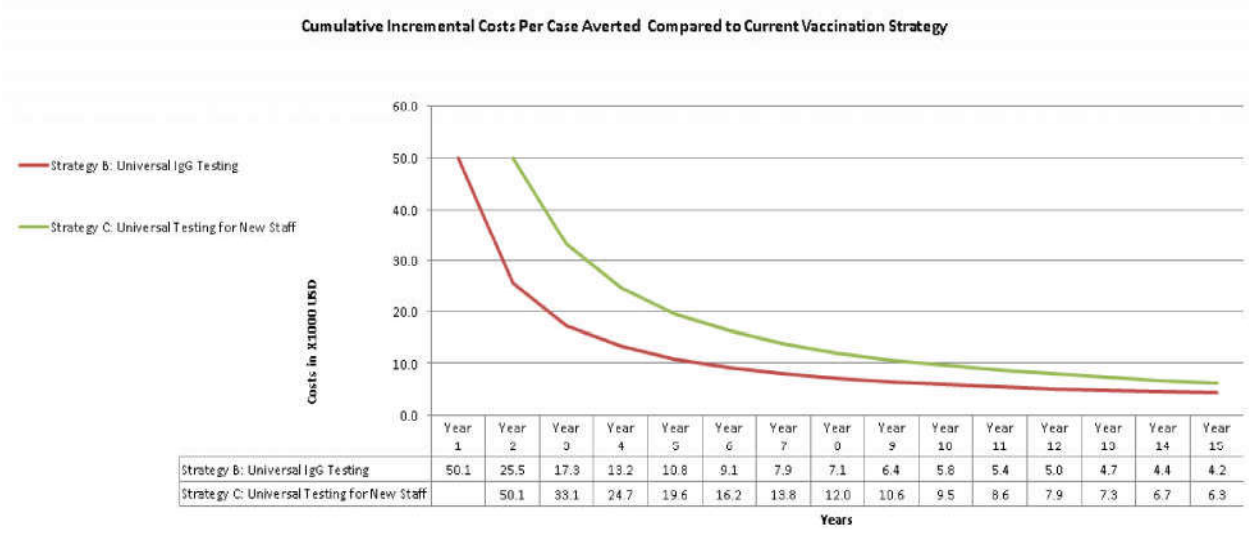


Fig. 2: Epidemiological curve for chickenpox index cases at NUH between Jan 2010 and June 2014



	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Strategy B: Universal IgG Testing	50.1	25.5	17.3	13.2	10.8	9.1	7.9	7.1	6.4	5.8	5.4	5.0	4.7	4.4	4.2
Strategy C: Universal Testing for New Staff		50.1	33.1	24.7	19.6	16.2	13.8	12.0	10.6	9.5	8.6	7.9	7.3	6.7	6.3

Fig. 3: Comparison of incremental costs per additional case adverted by strategy B and C for vaccination of hospital staff at NUH

Vaccination Strategies at the End of Year 10

At the end of 10 years[Table 5], expected number of staff infections per year are 3.4, 0.015, and 1.6 under strategies A, B and C respectively. The number of susceptible healthcare workers is expected to be at 745 for A, 110 for B and 356 for C; and cumulative costs (vaccination program plus cost incurred due to cases) for B (425,000 USD) and C (352,000 USD) were 65 % and 37 % higher as compared to A.

Sensitivity Analysis

One of the key assumptions of the model is that the hospital based staff medical records system is robust and immunity is long lasting, so that individuals tested once are not repeatedly tested in consecutive years. The model does not cater for waning immunity. By changing the cost of vaccination or VZV IgG tests in all 3 strategies uniformly, cumulative costs go up significantly but group comparative benefits are maintained(i.e. Strategy B is still advantageous over Strategy C in terms of cost per additional case averted) [21, 25, 26].

Discussion

Nosocomial Chickenpox adds significant burden to health care facilities globally, not just in terms of morbidity and mortality but also in terms of cost as

well as man hours lost [4 5,16,23]. The current vaccination strategy at NUH (and most public hospitals in Singapore) which relies on documented history as a surrogate of VZV immunity, when combined with active hospital contact tracing is likely to keep the number of secondary chickenpox infections low at about less than 3 staff infections per year and is currently the most cost saving strategy for NUH among those studied.

Any vaccination policy should be based on local factors, including number of pregnant and immune-compromised staff, cost of the illness in a staff, as well as sero-prevalence in the workforce. Varicella outbreaks in high risk hospital areas including immune-compromised, pediatric, obstetrics patients could have dire consequences for those individuals affected. Staff working in these areas must have immunity ensured before initiating work. Similarly, paediatric, obstetric and cancer hospitals may consider universal VZV IgG testing for all staff as is currently recommended in the United States in all hospitals.

Universal varicella IgG screening for all staff comes at a cost, but may result in cost savings in the long term as it reduces the number of infections as well as the number of susceptible staff significantly. This will also result in benefits not currently studied as part of this audit including cost savings from hiring temporary staff and improved staff morale through assurance of protection. Additional studies may be needed with larger sample sizes to assess the cost effectiveness of universal screening of HCW with VZV IgG in the tropical Singapore setting. With increased global mobility of healthcare workers many countries now have increasingly diverse healthcare workers originating from many other countries. Singapore has greater than 20% of its HCWs being foreigners coming from a variety of regional countries. Vaccination policies at hospitals must take note of these disease and country specific differences in sero-prevalence. Baracco et al [28] also discuss that Universal IgG testing vaccination strategies may be cost-effective at lower levels of immunity prevalence (<92% for US data). Such a cost-effectiveness analysis, though not part of current model, can be planned at a later date, to better inform policy decisions in the local setting.

Apart from staff vaccination, development of a dedicated contact tracing team, rapid identification and furloughing of susceptible staff are important in preventing nosocomial chickenpox. These efforts are likely to have played major roles in limiting the number of secondary transmissions in NUH to just twoover the duration studied, despite the significant number of exposures. Utility of Strategy B and C is contextual, as the cost per case of chickenpox goes up, hospitals may move towards universal screening adoption either by strategy B or C. But, before rolling out universal VZV IgG screening programs, adequate collation and evaluation of hospital screening data is important (as is planned at our hospital), so that staff with documented IgG immunity are not offered repeated immune checks during annual vaccination exercise [17,18,20].

Limitations

Staff are free to consult private doctors for varicella infections, who vary in treatment protocols as well as consultation costs. We estimated average cost based on claims made through Human Resource department for consultations as well as treatment. This may have led to lower estimation of overall costs of nosocomial chickenpox. We might also have missed staff cases, although this is unlikely given the tight medical leave policy.

Secondary cases data collection among staff is robust; however for patient contacts, particularly those who were discharged from the hospital, the primary teamphysicians contacted them to inform regarding risks and precautions as well as potential period of transmission. Patient contacts who consulted other healthcare facilities and did not inform NUH if they developed Chickenpox eventually could have been missed.

Further, presence of VZV IgG indicates past exposure or immunization, and is not a direct measure of immunity. Individual may still acquire VZV despite a positive serology.

Conclusion

Deterministic model shows that optimizing staff immunity to VZV would minimize the risk of staff chickenpox outbreaks as noted. However, prior to adopting a specific strategy, the unique characteristics of the healthcare setting and background risk of its healthcare workers has to be considered. In a tropical Singaporean setting, strategies targeting healthcare worker cohorts in high risk areas and from countries with low VZV seroprevalence, may be most cost effective.

Abbreviations

ICPP: Institutional Chickenpox Prevention Program,

NUH: National University Hospital,

MOH: Ministry of Health, Singapore,

VZV: Varicella Zoster Virus,

IQR: Inter Quartile Range,

IgG: Immuno-globulin Type G,

VZIg: varicella zoster immuno-globulin.

Declaration

The manuscript has not been published elsewhere, and it is also not currently under consideration for publication by another journal.

A. *Consent to publish:* Not applicable.

B. *Competing Interest:* The authors declare no direct conflict of interest and competing interests.

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Author's Contributions

CM was responsible for data collection, deterministic model as well as manuscript preparation. IV provided guidance for the study design. RL, PT, JS, AG and RS were involved in manuscript revision. DF provided supervision as well as overall strategic direction for the study as well as staff vaccination program in NUH

Ethics Approval & Funding

The audit and secondary analysis of this dataset was in keeping with national guidelines as stipulated by Singapore Ministry of Health under the Private Hospitals and Medical Clinics Act that requires licensed healthcare establishments to evaluate infection control procedures on a continuing basis. Thus, need for ethical approval was waived.It involved retrospective review of anonym zed contact tracing and EMR data. No patients were contacted for the study. No external sources of funding were utilized for the study.

Availability of Data and Materials

Authors have attempted to keep the information lucid with appropriate explanations. However, upon queries on data and materials, the datasets used and/ or analysed during the current study are available from the corresponding author on reasonable request.

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