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Influencing factors analysis and modeling of hospital-acquired infection in elderly patients

Xiaohui Liu[1] · Ni Zou[2] · Dan Zhu[2] · Dan Wang[2]

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Abstract Hospital-acquired infection threatens the patients' health and life and also impacts medical quality by decreasing the bed turnover rate, prolonging hospitalization, increasing hospital costs and bringing the patients the huge economic losses. Therefore, hospital infection management is the focus of today's hospital management and one of the most prominent public health problems. The elderly patients are a special group of nosocomial infections as they often suffer from a variety of serious underlying diseases and their immune function are low so their incidence of nosocomial infection is also higher than the average population. This paper establishes model by the statistical analysis tools and analyzes the influencing factors of all kinds of nosocomial infections in elderly patients based on the investigation of incidence of nosocomial infection in Shanghai General Hospital.

Keywords Hospital-acquired infections · Elderly patients · Statistical analysis · Influencing factors

1 Introduction

According to data from the sixth national census, China's population was 13.328 billion, of which 1.776 million were over 60 years old, accounting for 13.33% of the total population. The World Health Organization estimates that between 2000

✉ Ni Zou
kathyzou76@163.com

Xiaohui Liu
liuxiaohui@sspu.edu.cn

1 Shanghai Polytechnic University, Shanghai 201209, China

2 Shanghai General Hospital, Shanghai Jiaotong University, Shanghai 200080, China

and 2050, the world's population over 60 years old will double from 11 to 22% and the absolute number of people over 60 years old would grow from 605 million to 2 billion over the same period. Along with the acceleration of the pace of population aging, the problem of the elderly is becoming more and more prominent. Hospital-acquired infection (HAI) is an infection that is acquired in a hospital or other health care facility, including infection during hospitalization and infection in the hospital after being discharged. Such an infection can be acquired in hospital, nursing home, rehabilitation facility, outpatient clinic, or other clinical settings. HAI threatens the patients health and life and also impacts the hospitals medical quality by decreasing the bed turnover rate, prolonging hospitalization, increasing hospital costs and bringing the patients the huge economic losses. The elderly patients are a special group of nosocomial infections as they often suffer from a variety of serious underlying diseases and their immune function are low so their incidence of nosocomial infection is also higher than the average population. Therefore, this paper builds the model to research the influence factors of hospital-acquired infection in elderly patients aged 65 years or older to identify risk factors for HAI with emphasis on those most relevant to the elderly.

Hospital-acquired infection (HAI) is a global problem which currently affects approximately 10% of patients throughout the USA and Europe, causing respiratory, gastrointestinal, urinary tract, surgical site and blood-borne infections, complicating recovery and contributing to patient mortality. According to a report by Grand View Research, Inc., global hospital-acquired infections diagnostics market is expected to reach USD 11.6 billion by 2022. The global hospital acquired infections diagnostics market is projected to grow at a healthy CAGR during the period of 2015–2022. Advancing age of geriatric population is one of the main factors attributing to the growth of the market. In the United States, the Centers for Disease Control and Prevention estimated roughly 1.7 million hospital-associated infections (Klevens et al. 2007). In Europe, where hospital surveys have been conducted, the category of gram-negative infections is estimated to account for two-thirds of the 25,000 deaths each year.

As a hot topic, a large number of literatures have been studied related to the hospital-acquired infections. Mayon-White et al. (1988) put forward an international survey of the prevalence of hospital-acquired infection. Hussain et al. (1996) put forward a prospective survey of the incidence, risk factors and outcome of hospital-acquired infections in the elderly. Taylor and Oppenheim reviewed the incidence, risk factors and types of hospital-acquired infection in the elderly. Plowman (2000) studied the socio-economic burden of the hospital-acquired infection. Andersen and Rasch (2000) put forward a 3-year survey of hospital-acquired infections and antibiotic treatment in nursing/residential homes, including 4500 residents in Oslo and researched hospital-acquired infections in Norwegian long-term-care institutions. Ellidokuz et al. (2003) studies the hospital-acquired infections in elderly patients on the basis of results of a west Anatolian University Hospital surveillance. Brusaferroa et al. (2006) presented results from a 6-month prospective surveillance of hospital-acquired infections in four Italian long-term-care facilities (LTCFs). Durando et al. (2010) researched hospital-acquired infections and leading pathogens detected in a regional university adult acute-care hospital in Genoa, Liguria, Italy. Avci et al. (2012) determined the frequency, type, microbiological characteristics and outcome of HAIs in the elderly (age 65) and to compare the data with younger patients in a Turkish Training and Research Hospital. Laurent et al. (2012) investigated risk factors for HAIs, especially in the elderly, and described the relationship between comorbidities (number, severity, and specific diseases) and HAIs using a comprehensive inventory of comorbidities. Mehta et al. (2014) put forward the guidelines for prevention of hospital acquired infections. Redder et al. evaluated a system for automated monitoring of hospital-acquired urinary tract (HA-UTI) and bloodstream infections (HA-BSI) and reported incidence rates over a 5-year period in a Danish hospital trust. Hensley and Monson (2015) addressed the predominant resistant healthcare associated pathogens including methicillin-resistant *Staphylococcus aureus*, *Clostridium difficile*, and vancomycin-resistant enterococci to decrease the impact of these healthcare-associated infections. Wolkewitz et al. (2016) provided a case-cohort approach and showed that a full competing risk analysis was feasible even in a reduced data set. Boev and Kiss (2017) explored HAIs specific to risk factors, epidemiology, and prevention, and how nurses can work together with other health care providers to decrease the incidence of these preventable complications.

The rest of the paper is organized as follows. In Sect. 2, we analyze the quantitative characteristics from hospital departments, infective types, hospitalization days and patients' ages of hospital-acquired infection. In Sect. 3, we clarify the influencing factors of elderly patients' hospital-acquired infection, build the mathematical model, conduct the numerical experiments and sum up the result of the study and countermeasures. Finally, in Sect. 4, we come to some conclusions of this paper and put forward our future research directions.

2 The quantitative analysis of elderly patient's hospital-acquired infection

A growing number of the global population is aging; accordingly a higher number of elderly patients are hospitalized for various causes. In this study, we collected the data of 307 elderly HAI patients cases from Shanghai General Hospital during the period from January 2015 to June 2017. In this section, we conduct the following four points of quantitative analysis of elderly patients hospital-acquired infection.

2.1 Hospital departments of HAI

Among 307 cases, the hospital departments and their numbers of HAI are as Table 1 and the probability plot of numbers is as Fig. 1.

The probability plot is usually used to evaluate the fit of a distribution to data, estimate percentiles, and compare different sample. In Fig. 1, the x-axis are the numbers of Hospital Departments of HAI and the y-axis are percentage of numbers in the cases that are less than or equal to it. We plot the x-axis versus the y-axis, along a fitted distribution line (middle line). From Fig. 1, we found that the mean numbers of the Hospital Departments of HAI is 13.35 and SD is 17.42. From Table 1 and Fig. 1, we found that about 60% of the HAIs occurred in the four departments, which are Internal Medicine ICU, Department of Gastrointestinal Surgery, Department of Neurosurgery

Table 1 Hospital departments of HAI and their numbers

The hospital departments	Numbers
Internal Medicine ICU	73
Department of Gastrointestinal Surgery	47
Department of Neurosurgery	34
Department of Thoracic Surgery	31
Department of Hepatobiliary and Pancreatic Surgery	19
Department of Gastroenterology	13
Department of Medical Oncology	11
Department of Gynaecology	9
Department of Cardiology	8
Department of Urology	7
Department of Orthopaedics	6
Department of Orthopedics Trauma	6
Emergency Department	6
Department of Endocrinology and Metabolism	6
Department of Interventional Oncology	6
Department of Neurology	5
Department of Nephrology	5
Department of Cardio-Vascular Surgery	4
Department of Respiratory Medicine	4
Department of Radiation Oncology	2
Department of Ear–Nose–Throat and Head and Neck Surgery	2
Department of Hematology	2
Department of Breast–Thyroid–Vascular Surgery	1
Total	307

and Department of Thoracic Surgery. It reminds us these four departments should be the key control objects of HAI.

2.2 Infective types of HAI

Among 307 cases, the infective types of hospital-acquired infections and their numbers of HAI are as Table 2 and the probability plot of numbers is as Fig. 2.

In Fig. 2, the x-axis are the numbers of infective types of HAI and the y-axis are percentage of numbers in the cases that are less than or equal to it. From Fig. 2, we found that the mean numbers of the infective types of HAI is 43.41 and SD is 88.28. From Table 2 and Fig. 2, we found that about 60% of the HAIs occurred in the three types of infection, which are lower respiratory tract (unrelated to catheter) infection, surgical site infection (SSI) and ventilator associated pneumonia (VAP). It reminds us these types of infection should be the key control objects of HAI.

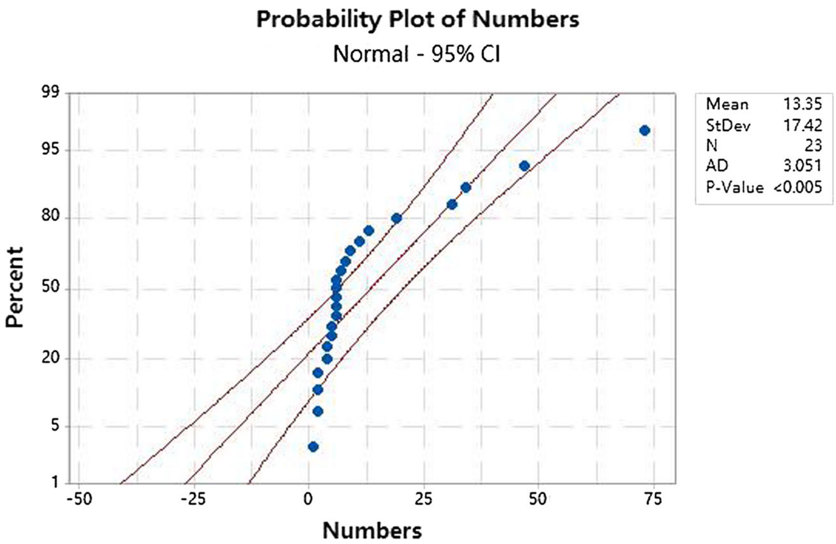

Fig. 1 Probability plot of numbers of hospital departments of HAI

Table 2 Infective types of HAI and their numbers

The infective types	Numbers
Lower respiratory tract (unrelated to catheter) infection	104
Surgical site infection (SSI)	71
Ventilator associated pneumonia (VAP)	41
Catheter associated urinary tract infection (CAUTI)	29
Bloodstream infection (unrelated to catheter)	26
Intraabdominal tissue infection	21
Urinary tract (unrelated to catheter) infection	20
Upper respiratory tract (except for colds) infection	20
Central line-associated bloodstream infection (CLABSI)	12
Skin and soft tissue infection	8
Gastrointestinal infection (except gastroenteritis and appendicitis)	6
Other site infection	5
Disseminated infection	3
Infectious diarrhea	1
Antibiotic associated diarrhea	1
Oral infection	1
Total	369

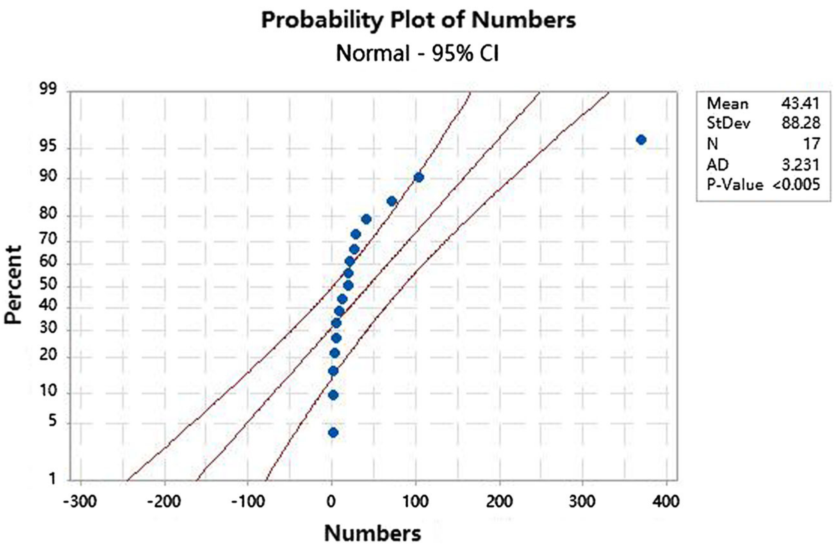

Fig. 2 Probability plot of numbers of infective types of HAI

Table 3 Hospitalization days of HAI and their number

Hospitalization days	Numbers
1–19	80
20–39	136
40–59	51
60–79	21
80–99	9
100–	10
Total	307

2.3 Hospitalization days of HAI

Among 307 cases, the hospitalization days and their numbers of HAI are as Table 3 and the dotplots of hospitalization days is as Fig. 3.

The picture of dotplots is usually used to assess and compare distributions by plotting the values along a number line. We use dotplots to compare distributions of hospitalization days of HAI. In Fig. 3, the *x*-axis for a dotplot is divided into many small intervals. Data of hospitalization days of HAI values falling within each interval are represented by dots. From Table 3 and Fig. 3, we found that about 45% of HAI patients were hospitalized between 20 and 39 days. We checked the original data and found that among the HAI patients who were hospitalized between 20 and 39 days, 34.81% of these patients were suffered from by lower respiratory tract infection. It validates the conclusion of 2.2 and reminds us that lower respiratory tract infection should be the key control object of HAI.

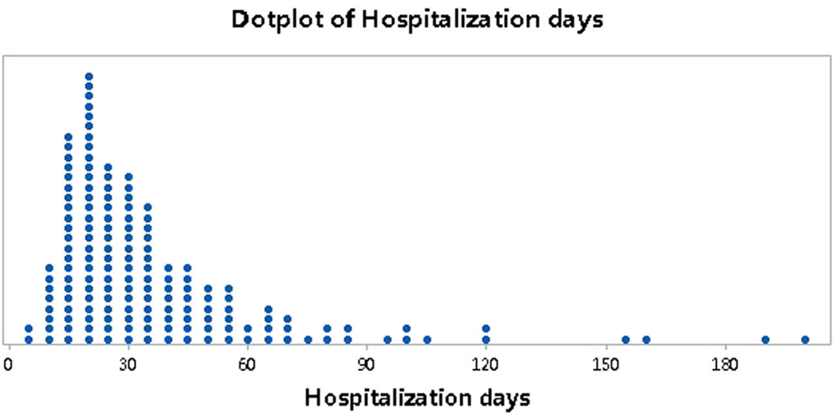

Fig. 3 Dotplots of hospitalization days of HAI

Table 4 Patients ages of HAI and their numbers

Patients ages	Number
65–69	99
70–74	77
75–79	51
80–84	50
85–89	26
90–	4

2.4 Patients ages of HAI

Among 97 samples, the patients ages of hospital-acquired infections and their numbers of HAI are as Table 4 and the histogram of patients ages is as Fig. 4.

The picture of histogram is usually used to examine the shape and spread of data. Histogram divide values into many intervals called bins. Bars represent the number of observations falling within each bin. In Fig. 4, the x-axis for the histogram is divided into several small intervals. Patients ages of HAI that fall exactly on each interval boundary are included in the interval to the right. From Table 4 and Fig. 4, we found that the distribution of ages of HAI elderly patients conform to the distribution of ages of hospital elderly patients.

3 Influencing factors model and numerical experiments of elderly patients HAI

3.1 Influencing factors to hospital-acquired infection

Many factors promote hospital-acquired infection occurrence in hospitals. Some of these factors are present regardless of the resources available: prolonged and inappro-

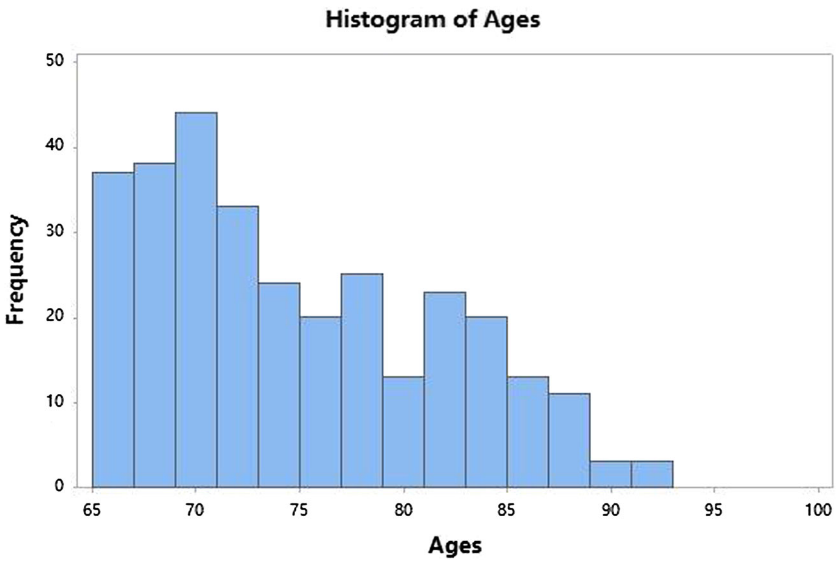

Fig. 4 Histogram of patients ages of HAI

priate use of invasive devices and antibiotics, high-risk and sophisticated procedures, immuno-suppression and other severe underlying patient conditions, insufficient application of standard and isolation precautions. Some determinants are more specific to settings with limited resources: inadequate environmental hygienic conditions and waste disposal, poor infrastructure, insufficient equipment, understaffing, overcrowding, poor knowledge and application of basic infection control measures, lack of procedure, lack of knowledge of injection and blood transfusion safety, absence of local and national guidelines and policies. On the other hand, factors influencing hospital-acquired infections include: age, infected patients, drug resistance, susceptible patients and surgical procedures. Usually neonates and elderly of extreme ages may acquire hospital infection because of their long stay in hospitals and inefficient immunity. And patient with community acquired or non-hospital infection due to pathogenic microorganisms may enter the hospital and spread the infection to close contents. The drug resistant organisms may show increased virulence or transmissibility as well as limiting the choice of therapy. Hospitalized patients with pre-existing diseases (diabetes, immunosuppression, patients in special care units or with prosthetic implants are at risk and more susceptible to hospital infections. The natural defense mechanisms of the body surface may be bypassed by injury or by a diagnostic or therapeutic intervention. We collected 307 patients case and concluded factors that were susceptible to infection as Table 5.

Among 307 cases, the influencing factors to hospital-acquired infections and the numbers that each susceptible factor leads to HAI are as Table 6 and the empirical CDF of numbers is as Fig. 5. Table 6 and Fig. 5 show that the top 3 factors causing HAI are use of three or more antimicrobial agents, hypoalbuminemia < 30 g/L and use of three generations of cephalospores.

Table 5 Factors and codes of susceptible to hospital-acquired infection

Code	Factors
01	Diabetes
02	Cerebral vascular disease
03	Hepatopathy
04	Chronic obstructive pulmonary disease
05	Malignant tumor
06	Nephropathy
07	Hematopathy
08	Severe pancreatitis
09	Enterobrosis
10	Open injury
11	Coma
12	Long-term bed
13	Smoking history $\geq$ 10 years
14	Hormone
15	Radiotherapy
16	Chemotherapy
17	Immunosuppressor
18	Anemia (hemoglobin $<$ 90 g/L)
19	Hypoalbuminemia (serum albumin $<$ 30 g/L)
20	White blood cell count $< 1.5 \times 10^9$/L
21	Urinary catheterization
22	Arteriovenous catheterization
23	Tracheal intubation or tracheostomy
24	Ventilator
25	Endoscopic operation (endoscopic endoscope and bronchoscope)
26	Hemodialysis and peritoneal dialysis
27	Operation
28	Vasectomy
29	Organ transplant
30	Implant
31	Operation time $>$3 h
32	Surgical incision for contamination (III, IV)
33	Use of third-generation cephalospores
34	Use of antifungal drug
35	The time of using antimicrobial agents $>$ 2 weeks
36	Use of three or more antimicrobial agents

The empirical CDFs graph is usually used to evaluate the fit of a distribution to data and compare different sample distribution, including an empirical cumulative distribution function of sample data and a fitted normal cumulative distribution function.

Table 6 Influencing factors to HAI and their numbers

Influencing factors to HAI	Numbers
Use of three or more antimicrobial agents	240
Hypoalbuminemia (serum albumin < 30 g/L)	222
Use of third-generation cephalospores	212
The time of using antimicrobial agents > 2 weeks	210
Arteriovenous catheterization	191
Urinary catheterization	190
Operation	187
Anemia (hemoglobin < 90 g/L)	162
Tracheal intubation or tracheostomy	122
Malignant tumor	120
Ventilator	111
Operation time > 3 h	82
Diabetes	74
Use of antifungal drug	64
Cerebral vascular disease	59
Coma	46
Endoscopic operation (endoscopic endoscope and bronchoscope)	42
Smoking history ≥ 10 years	40
Implant	24
Chronic obstructive pulmonary disease	22
Vasectomy	19
Long-term bed	18
Nephropathy	17
Chemotherapy	17
Surgical incision for contamination (III, IV)	17
Enterobrosis	11
Open injury	10
White blood cell count $< 1.5 \times 10^9$/L	10
Hepatopathy	8
Hemodialysis and peritoneal dialysis	7
Hormone	4
Hematopathy	3
Severe pancreatitis	2
Radiotherapy	1

In Fig. 5, the x-axis are the numbers of influencing factors to HAI and the y-axis are percentage of numbers in the cases. From Fig. 5, we found that the mean numbers of the influencing factors to HAI is 75.41 and SD is 79.07. From Table 6 and Fig. 5, we found that about 50% of the HAIs occurred by the six influencing factors, which are use of three or more antimicrobial agents, hypoalbuminemia < 30 g/L, use of

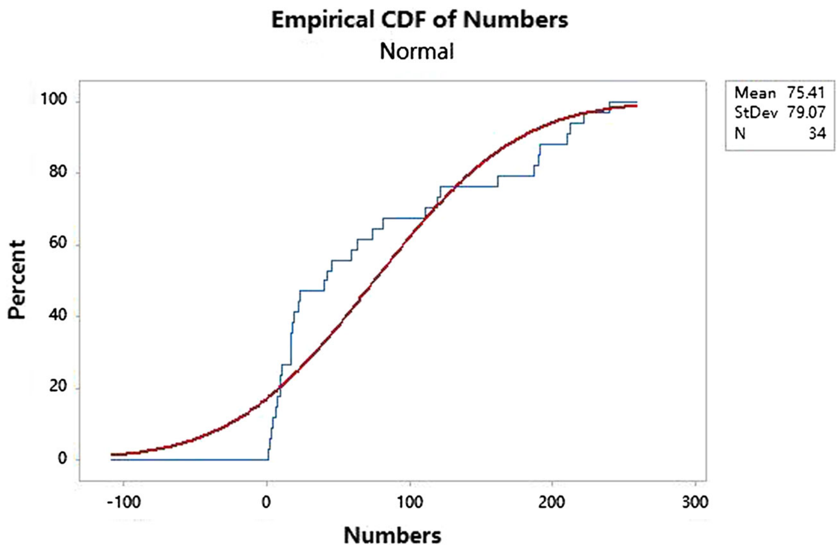

Fig. 5 The empirical CDF of numbers of influencing factors to HAI

third-generation cephalospores, the time of using antimicrobial agents > 2 weeks, arteriovenous catheterization, urinary catheterization. It reminds us these six influencing factors should be the key control objects of HAI.

3.2 The mathematical model of influencing factors to HAI

This section we use the five-step method to build the hospital-acquired infection influencing factors.

Step 1 is to ask a question. The question must be phrased in mathematical terms. In the process we are required to make a number of assumptions or suppositions about the way things really are. We should not be afraid to make a guess at this stage. We can always come back and make a better guess later on. Before we can ask a question in mathematical terms we need to define our terms. Go through the problem and make a list of variables. Include appropriate units. Next make a list of assumptions about these variables. Include any relations between variables (equations and inequalities) that are known or assumed. Having done all of this, we are ready to ask a question. Write down in explicit mathematical language the objective of this problem. Notice that the preliminary steps of listing variables, units, equations and inequalities, and other assumptions are really a part of the question. They frame the question.

From the data we collect from January 2015 to June 2017 in the hospital, we extract the independent variables including diabetes, cerebral vascular disease, hepatopathy, chronic obstructive pulmonary disease, malignant tumor, nephropathy as x_1, x_2, x_3 and the variable ($x_i = 0, 1$) was used to analyze the related factors of HAI by single factor and multifactor logistic regression. We extract the variables including lower respiratory tract (unrelated to catheter), surgical site infection (SSI), ventilator associated pneumonia (VAP) as y_1, y_2, y_3 and the variable ($y_i = 0, 1$) was used to analyze the infective types of HAI by single factor and multifactor logistic regression. The values of the independent variables are shown in the Table 7 and the values of the variables are shown in the Table 8.

Step 2 is to select the modeling approach. Now that we have a problem stated in mathematical language, we need to select a mathematical approach to use to get an answer. Many types of problems can be stated in a standard form for which an effective general solution procedure exists. Most research in applied mathematics consists of identifying these general categories of problems and inventing efficient ways to solve them. There is a considerable body of literature in this area, and many new advances continue to be made.

As statistical scientists studied and found, logistic multivariate nonlinear regression equation is the most suitable for multivariate regression equations. In the analysis of elderly patients hospital-acquired infection, we choose logistic multivariate nonlinear regression. Logistic multivariate nonlinear regression is one of the most widely used statistical techniques for analyzing observational data. The analysis of observational data typically requires a structural and multivariate approach. We use regression models to uncover the relationships between the Infective Types and other variables, especially the influencing factors to HAI.

Step 3 is to formulate the model. We need to take the question exhibited in step 1 and reformulate it in the standard form selected in step 2, so that we can apply the standard general solution procedure. It is often convenient to change variable names if we will refer to a modeling approach that has been described using specific variable names.

In this research, we handle the categorical variables and create dummy variables to represent the different groups. Then we use these dummy variables just like other explanatory variables in a regression model. And the following is the regression analysis of infective types versus influencing factors to HAI. We suppose that the probability of any one of the elderly patients being infected in the hospital is p, and the susceptibility factor (independent variable) has 36 linear combinations of 36 influencing factors.

$$y = a + \sum_{j=1}^{m} b_j x_j \tag{1}$$

Then, logistics multivariate nonlinear regression equation is

$$p = \frac{\exp y}{1 + \exp y} = \frac{1}{1 + \exp(-y)} \tag{2}$$

By (2), we can get:

$$\frac{p}{1-p} = \exp y \quad y = \ln \frac{p}{1-p} \tag{3}$$

$$\text{Define: } \log it p = \ln \frac{p}{1-p} \tag{4}$$

Table 7 Susceptibility factors and assignment methods

Variables	Susceptibility factors	Assignment methods
x_1	Diabetes	$x_1 = 0$, no; $x_1 = 1$, yes
x_2	Cerebral vascular disease	$x_2 = 0$, no; $x_2 = 1$, yes
x_3	Hepatopathy	$x_3 = 0$, no; $x_3 = 1$, yes
x_4	Chronic obstructive pulmonary disease	$x_4 = 0$, no; $x_4 = 1$, yes
x_5	Malignant tumor	$x_5 = 0$, no; $x_5 = 1$, yes
x_6	Nephropathy	$x_6 = 0$, no; $x_6 = 1$, yes
x_7	Hematopathy	$x_7 = 0$, no; $x_7 = 1$, yes
x_8	Severe pancreatitis	$x_8 = 0$, no; $x_8 = 1$, yes
x_9	Enterobrosis	$x_9 = 0$, no; $x_9 = 1$, yes
x_{10}	Open injury	$x_{10} = 0$, no; $x_{10} = 1$, yes
x_{11}	Coma	$x_{10} = 0$, no; $x_{10} = 1$, yes
x_{12}	Long-term bed	$x_{12} = 0$, no; $x_{12} = 1$, yes
x_{13}	Smoking history $\geq$ 10 years	$x_{13} = 0$, no; $x_{13} = 1$, yes
x_{14}	Hormone	$x_{14} = 0$, no; $x_{14} = 1$, yes
x_{15}	Radiotherapy	$x_{15} = 0$, no; $x_{15} = 1$, yes
x_{16}	Chemotherapy	$x_{16} = 0$, no; $x_{16} = 1$, yes
x_{17}	Immunosuppressor	$x_{17} = 0$, no; $x_{17} = 1$, yes
x_{18}	Anemia (hemoglobin $<$ 90g/L)	$x_{18} = 0$, no; $x_{18} = 1$, yes
x_{19}	Hypoalbuminemia (serum albumin $<$ 30 g/L)	$x_{19} = 0$, no; $x_{19} = 1$, yes
x_{20}	White blood cell count $< 1.5 \times 10^9$/L	$x_{20} = 0$, no; $x_{20} = 1$, yes
x_{21}	Urinary catheterization	$x_{21} = 0$, no; $x_{21} = 1$, yes
x_{22}	Arteriovenous catheterization	$x_{22} = 0$, no; $x_{22} = 1$, yes
x_{23}	Tracheal intubation or tracheostomy	$x_{23} = 0$, no; $x_{23} = 1$, yes
x_{24}	Ventilator	$x_{24} = 0$, no; $x_{24} = 1$, yes
x_{25}	Endoscopic operation (endoscopic endoscope and bronchoscope)	$x_{25} = 0$, no; $x_{25} = 1$, yes
x_{26}	Hemodialysis and peritoneal dialysis	$x_{26} = 0$, no; $x_{26} = 1$, yes
x_{27}	Operation	$x_{27} = 0$, no; $x_{27} = 1$, yes
x_{28}	Vasectomy	$x_{28} = 0$, no; $x_{28} = 1$, yes
x_{29}	Organ transplant	$x_{29} = 0$, no; $x_{29} = 1$, yes
x_{30}	Implant	$x_{30} = 0$, no; $x_{30} = 1$, yes
x_{31}	Operation time $>$ 3 h	$x_{31} = 0$, no; $x_{31} = 1$, yes
x_{32}	Surgical incision for contamination (III, IV)	$x_{32} = 0$, no; $x_{32} = 1$, yes
x_{33}	Use of third-generation cephalospores	$x_{33} = 0$, no; $x_{33} = 1$, yes
x_{34}	Use of antifungal drug	$x_{34} = 0$, no; $x_{34} = 1$, yes
x_{35}	The time of using antimicrobial agents $>$ 2 weeks	$x_{35} = 0$, no; $x_{35} = 1$, yes
x_{36}	Use of three or more antimicrobial agents	$x_{36} = 0$, no; $x_{36} = 1$, yes

Table 8 Infective types and assignment methods

Variables	Susceptibility factors	Assignment methods
y_1	Lower respiratory tract (unrelated to catheter) infection	$y_1 = 0$, no; $y_1 = 1$, yes
y_2	Surgical site infection (SSI)	$y_2 = 0$, no; $y_2 = 1$, yes
y_3	Ventilator associated pneumonia (VAP)	$y_3 = 0$, no; $y_3 = 1$, yes
y_4	Catheter associated urinary tract infection (CAUTI)	$y_4 = 0$, no; $y_4 = 1$, yes
y_5	Bloodstream infection (unrelated to catheter)	$y_5 = 0$, no; $y_5 = 1$, yes
y_6	Intraabdominal tissue infection	$y_6 = 0$, no; $y_6 = 1$, yes
y_7	Urinary tract (unrelated to catheter) infection	$y_7 = 0$, no; $y_7 = 1$, yes
y_8	Upper respiratory tract (except for colds) infection	$y_8 = 0$, no; $y_8 = 1$, yes
y_9	Central line-associated bloodstream infections (CLABSI)	$y_9 = 0$, no; $y_9 = 1$, yes
y_{10}	Skin and soft tissue infection	$y_{10} = 0$, no; $y_{10} = 1$, yes
y_{11}	Gastrointestinal infection (except gastroenteritis and appendicitis)	$y_{10} = 0$, no; $y_{10} = 1$, yes
y_{12}	Other site infection	$y_{12} = 0$, no; $y_{12} = 1$, yes
y_{13}	Disseminated infection	$y_{13} = 0$, no; $y_{13} = 1$, yes
y_{14}	Infectious diarrhea	$y_{14} = 0$, no; $y_{14} = 1$, yes
y_{15}	Antibiotic associated diarrhea	$y_{15} = 0$, no; $y_{15} = 1$, yes
y_{16}	Oral infection	$y_{16} = 0$, no; $y_{16} = 1$, yes

By (4), (3) and (1), we can get:

$$\log it\, p = \ln \frac{p}{1-p} = a + \sum_{j=1}^{m} b_j x_j \tag{5}$$

By (5), we can get:

$$a = \ln \frac{p_0}{1-p_0}. \tag{6}$$

Step 4 is to solve the model. We use the Minitab statistical package to obtain the regression line. To do this, first we entered the samples data into Minitab worksheet and enter the time index numbers t into another column. Then we used the pull-down menus to issue the command Stat > Regression > Regression and specified the data as the response and the time index data as the predictor. To get the prediction interval for, we selected the options button in the regression window and enter in the box labeled Prediction intervals for new observations.

Step 5, we have made conclusion shown as the Sect. 3.3.

3.3 The numerical experiments of influencing factors to HAI

By regression analysis of 16 infective types versus 36 influencing factors to HAI, we could get the influencing factors with significant influence to each infective type. Among the 16 infective types, 11 infective types had influencing factors with P value < 0.05. The results of likelihood ratio tests of these 11 infective types were shown in Table 9. Other five infective types were not found having any influencing factor with significance, such as upper respiratory tract (except for colds) infection, disseminated hyper infection, infectious diarrhea, antibiotic associated diarrhea, oral infection.

From the results of likelihood ratio tests in Table 9, for lower respiratory tract (unrelated to catheter), six influencing factors had significant influence, which were cerebral vascular disease, smoking history $\geq$10 years, hormone, endoscopic operation (endoscopic endoscope and bronchoscope), surgical incision for contamination (III, IV) and use of antifungal drug. The estimates of regression coefficient and marginal coefficient of these six variables were significant at the test level 0.05.

For SSI, five influencing factors had significant influence, which were hepatopathy, Coma, arteriovenous catheterization, operation and surgical incision for contamination (III, IV). The estimates of regression coefficient and marginal coefficient of these six variables were significant at the test level 0.05.

For VAP, three influencing factors had significant influence, which were malignant tumor, ventilator and use of three or more antimicrobial agents. The estimates of regression coefficient and marginal coefficient of these six variables were significant at the test level 0.05.

For CAUTI, four influencing factors had significant influence, which were diabetes, smoking history $\geq$ 10 years, urinary catheterization and implant. For Bloodstream infection (unrelated to catheter), six influencing factors had significant influence, which were cerebral vascular disease, chronic obstructive pulmonary disease, hematopathy, white blood cell (WBC) $< 1.5 \times 10^9$/L, endoscopic operation (endoscopic endoscope and bronchoscope) and operation. For intraabdominal tissue infection, seven influencing factors had significant influence, which were hepatopathy, malignant tumor, anemia $<$ 90 g/L, hypoalbuminemia $<$ 30 g/L, hemodialysis and peritoneal dialysis, use antimicrobials time $>$ 2 weeks and use of three or more antimicrobial agents. For urinary tract (unrelated to catheter), smoking history $\geq$ 10 years and use of three generations of cephalosporins had significant influence. For central line-associated bloodstream infections (CLABSI), arteriovenous catheterization and use of antifungal drug had significant influence.

For skin and soft tissue, long-term bed had significant influence. For gastrointestinal infections (except gastroenteritis and appendicitis), nine influencing factors had significant influence, which were diabetes, chronic obstructive pulmonary disease, open injury, coma, long-term bed, hypoalbuminemia $<$ 30 g/L, arteriovenous catheterization, tracheal intubation or tracheostomy, implant. For other site infection, vasectomy had significant influence.

Table 9 Some likelihood ratio tests of all infective types

Infective type	Susceptibility factors and assignment methods	Model fitting criteria	Likelihood ratio tests		
		−2 Log likelihood of reduced model	Chi-square	*df*	Sig.
01 Lower respiratory tract (unrelated to catheter)	02 Cerebral vascular disease	332.683	5.325	1	0.021
	13 Smoking history $\geq$ 10 years	335.213	7.855	1	0.005
	14 Hormone	333.159	5.801	1	0.016
	25 Endoscopic operation (endoscopic endoscope and bronchoscope)	334.501	7.143	1	0.008
	32 Surgical incision for contamination (III, IV)	334.276	6.918	1	0.009
	34 Use of antifungal drug	332.063	4.705	1	0.030
02 Surgical site infection (SSI)	03 Hepatopathy	204.000	7.332	1	0.007
	11 Coma	201.209	4.541	1	0.033
	22 Arteriovenous catheterization	203.561	6.893	1	0.009
	27 Operation	228.002	31.334	1	0.000
	32 Surgical incision for contamination (III, IV)	204.481	7.813	1	0.005
03 Ventilator associated pneumonia (VAP)	05 Malignant tumor	123.939b	5.152	1	0.023
	24 Ventilator	136.217b	17.430	1	0.000
	36 Use of three or more antimicrobial agents	122.813b	4.026	1	0.045

Table 9 continued

Infective type	Susceptibility factors and assignment methods	Model fitting criteria	Likelihood ratio tests		
		−2 Log likelihood of reduced model	Chi-square	*df*	Sig.
04 Catheter associated urinary tract infection (CAUTI)	01 Diabetes	107.561b	6.937	1	0.008
	13 Smoking history ≥ 10 years	109.171b	8.547	1	0.003
	21 Urinary catheterization	119.428b	18.803	1	0.000
	30 Implant	105.640b	5.016	1	0.025
05 Bloodstream infection (unrelated to catheter)	02 Cerebral vascular disease	109.617b	4.907	1	0.027
	04 Chronic obstructive pulmonary disease	109.604b	4.894	1	0.027
	07 Hematopathy	110.662	5.952	1	0.015
	20 White blood cell (WBC) < 1.5*10^9/L	112.526	7.817	1	0.005
	25 Endoscopic operation (endoscopic endoscope and bronchoscope)	108.772b	4.062	1	0.044
	27 Operation	109.632b	4.922	1	0.027
06 Intraabdominal tissue	03 Hepatopathy	75.405b	7.183	1	0.007
	05 Malignant tumor	73.376b	5.155	1	0.023
	18 Anemia < 90 g/L	72.531b	4.310	1	0.038
	19 Hypoalbuminemia < 30 g/L	72.070b	3.848	1	0.050
	26 Hemodialysis and peritoneal dialysis	72.490b	4.269	1	0.039
	35 Use antimicrobials time > 2 weeks	73.602b	5.381	1	0.020
	36 Use of three or more antimicrobial agents	73.279b	5.058	1	0.025

Table 9 continued

Infective type	Susceptibility factors and assignment methods	Model fitting criteria	Likelihood ratio tests		
		−2 Log likelihood of reduced model	Chi-square	*df*	Sig.
07 Urinary tract (unrelated to catheter)	13 Smoking history $\geq$ 10 years	85.669b	4.872	1	0.027
	33 Use of third-generation cephalospores	85.591b	4.795	1	0.029
09 Central line-associated bloodstream infections (CLABSI)	22 Arteriovenous catheterization	50.410b	4.845	1	0.028
	34 Use of antifungal drug	50.376b	4.811	1	0.028
10 Skin and soft tissue	12 Long-term bed	29.848b	19.509	1	0.000
11 Gastrointestinal infections (except gastroenteritis and appendicitis)	01 Diabetes	12.922b	6.801	1	0.009
	04 Chronic obstructive pulmonary disease	127.966b	121.845	1	0.000
	10 Open injury	12.465b	6.344	1	0.012
	11 Coma	14.529b	8.408	1	0.004
	12 Long-term bed	10.407b	4.286	1	0.038
	19 Hypoalbuminemia $<$ 30 g/L	10.623b	4.502	1	0.034
	22 Arteriovenous catheterization	12.596b	6.475	1	0.011
	23 Tracheal intubation or tracheostomy	97.704b	91.583	1	0.000
	30 Implant	29.614c	23.493	1	0.000
12 Other site infection	28 Vasectomy	17.679c	17.679	1	0.000

4 Discussion

In this study, we found that the top 10 factors causing HAI are use of three or more antimicrobial agents, hypoalbuminemia (serum albumin < 30 g/L), use of third-generation cephalospores, the time of using antimicrobial agents > 2 weeks, arteriovenous catheterization, urinary catheterization, operation, anemia (hemoglobin < 90 g/L), tracheal intubation or tracheostomy and ventilator. These influencing factors can be summarized in the following three aspects: antibacterial use, relevant clinical test, invasive surgery and operation.

Firstly, this study finds that in the rank of the influencing factors of elderly patients hospital-acquired infection, use of three or more antimicrobial agents, use of third-generation cephalospores and the time of using antimicrobial agents > 2 weeks respectively rank the first, third and fourth. It shows that the long-term exposure of antibiotics, frequent replacement of antibiotics and the unreasonable use of antibiotics are the high risk factors that lead to hospital infection. Long-term abuse of antimicrobial agents can lead to increased bacterial resistance, increased risk of secondary infections such as fungi, and damage to liver and kidney function. All of these factors will make the patient's infection worsen, the cure rate drop, and also make the patients more exposed to the environment of the more advanced antimicrobials. These infection will increase the patient's hospital stay, the hospitalization expenses of the patients, and the human cost of medical treatment and nursing and will lead to a vicious cycle of treatment.

Secondly, this study finds that in the rank of the influencing factors of elderly patients HAI, hypoalbuminemia (serum albumin < 30 g/L) and anemia (hemoglobin < 90 g/L) respectively rank the second and eighth. It hints that during the elderly patient's hospitalization, the nutritional status of patients was correlated with subsequent hospital infection. When elderly patients blood albumin is low than normal, the defense barrier of the patients bodies is easy to be destroyed. This leads to a decrease in immunity and the body may be vulnerable to microbial injury such as surgery or trauma, which leads to infection. When the hemoglobin becomes lower than normal, oxygen in the blood carried by hemoglobin decreases obviously and the ability to resist microorganisms will also be loss or decline in the condition of oxygen deprivation in the body. Therefore, we conclude that the decline of serum albumin and hemoglobin should be monitored during the course of elderly patients hospitalization and intravenous infusion of human albumin and erythrocyte suspension should be applied timely in order to correct its hypoalbuminemia and anemia status. These measures are conducive to reduce the risk factors of HAI and will have realistic guiding significance for the prognosis of elderly patients.

Thirdly, this study finds that in the rank of the influencing factors of elderly patients HAI, arteriovenous catheterization, urinary catheterization, operation, tracheal intubation or tracheostomy and ventilator respectively rank the fifth, sixth, seventh, ninth, and eleventh. This corroborates that both of invasive surgery and the process of operation and all kinds of intubation making the body interlinked with the outside world increase the body's normal mucosa, blood vessels, skin, viscera exposed to the outside world or have the possibility of microorganisms of the internal environment, especially the sterile area damage status which provides a channel and carrier for microbial invasion.

Therefore, sterile technical principles of operation must be strictly abided , the care of the tubes of the intubated and operated patients must be strengthened, VAP, CAUTI, CLABSI core prevention and control strategy must be adhere to and carried out. All of these measures are critical for the prevention and control of nosocomial infections.

By regression analysis of 16 infective types versus 36 influencing factors to HAI, we found 11 infective types had influencing factors with P value < 0.05. The cause analysis of the correlation between each infective type and their influencing factors were as follows.

Lower respiratory tract (unrelated to catheter) was significantly related to six influencing factors have significant influence, which were cerebral vascular disease, smoking history $\geq$ 10 years, hormone, endoscopic operation (endoscopic endoscope and bronchoscope), surgical incision for contamination (III, IV) and use of antifungal drug. Patients with cerebral vascular disease usually had disturbance of consciousness, cough reflex loss or decrease, failure to automatic sputum excretion, which were high risk factors of respiratory infections. The oscillating ability of the lower respiratory mucosal cilia decreased in patients with smoking history $\geq$ 10 years, which could result in decrease of the ability of the respiratory tract to eliminate dust and pathogenic bacteria and lower respiratory tract infection and likely to occur lower respiratory tract infection. The use of hormones can cause decline of the body's own immunity, which may cause various types of infections. Endoscopic operation, especially in the operation of bronchoscopy, if not be taken care of the principles of aseptic operation, can easily lead to the descending of upper respiratory tract infection, which can lead to lower respiratory tract infection. For incision type of contaminated wounds, the surgery itself exists invasion of pathogenic bacteria and the surgical site infection rate is extremely high. But there is no research for the correlation with lower respiratory tract infection, which can be confirmed in further correlation analysis with control group setup. The use of antifungal agents and the lower respiratory tract infections may be cause and effect mutually. The reason for use of antifungal drugs may be either the existing lower respiratory tract fungal infection, or the secondary fungal double infection caused by long-term antibiotics abuse. Both of them can lead to lower respiratory tract infections caused by pathogenic fungi.

SSI was significantly related to hepatopathy, coma, arteriovenous catheterization, operation and surgical incision for contamination (III, IV). Obviously, operation and surgical incision for contamination were undoubtedly high risk factors for surgical site infection. The patient was in a coma, indicating that the patient was in critical condition and the body's ability to defense against infection decreased as well as suffered from surgical traumatic stress response, which were probably risk factors of surgical site infection. Arteriovenous catheterization were invasive operation. The patients using arteriovenous catheterization mainly depend on artificial intravenous channels for long-term hydration, which would easily lead to pathogen infection into bloodstream related to surgical site infection. However, there was no relevant report about the relationship between hepatopathy and surgical site infection, which needs further verification.

VAP was significantly related to malignant tumor, ventilator and use of three or more antimicrobial agents. The use of ventilator is undoubtedly a necessary factor in the occurrence of VAP. Use of three or more antimicrobial agents and upper respiratory tract infection may be cause and effect mutually. In case of VAP happened, use of three or more antimicrobial agents are probably necessary to control infection, which may cause double infection such as fungal infection and exacerbation of VAP. Malignant tumor may be associated with VAP, since the ratio of CD4/CD8 in patients with malignant tumors decreased and was susceptible to infection. However, the correlation with VAP should be further studied.

CAUTI was significantly related to diabetes, smoking history $\geq$ 10 years, urinary catheterization and implant. Obviously, urinary catheterization is undoubtedly a necessary factor in the occurrence of CAUTI. The increase of inflammatory stress factors in patients with diabetes and smoking history can lead to the occurrence of various infections, no exception for CAUTI. Patients after transplantation should stay in bed for a long time and the urinary catheter should be imbedded in large proportion, so the incidence of CAUTI would increase.

Bloodstream infection (unrelated to catheter) was significantly related to cerebral vascular disease, chronic obstructive pulmonary disease, hematopathy, white blood cell (WBC) $< 1.5 \times 10^9$/L, endoscopic operation (endoscopic endoscope and bronchoscope) and operation. The majority of patients with WBC $< 1.5 \times 10^9$/L had blood system diseases such as Leukemia or lymphoma. The absence of white blood cells leads to a decrease in the body's immunity, and is prone to bloodstream infections such as sepsis and septicemia. Endoscopic operation and operation were invasive operations. The human skin mucosa and organ tissues were subjected to mechanical destruction. If the aseptic operation was not notices or its own operation position was infective site, it would facilitate the opportunistic pathogen into blood, and cause bloodstream infection. However, the relationship between cerebral vascular disease, chronic obstructive pulmonary disease, hematopathy and bloodstream infection were not clear.

Intraabdominal tissue infection was significantly related to hepatopathy, malignant tumor, anemia $<$ 90 g/L, hypoalbuminemia $<$ 30 g/L, hemodialysis and peritoneal dialysis, use antimicrobials time $>$2 weeks and use of three or more antimicrobial agents. According to the statistical results, hepatopathy and malignant tumor in patients were risk factors for intraabdominal tissue infection. Decreased liver function and malignant tumors in the abdominal cavity would result in intraabdominal tissue infection. Anemia and hypoalbuminemia were the first found to be associated with intraabdominal tissue infection. It might because that the lack of nutrition and the decline of the nutritional condition of the body caused by gastrointestinal surgery or operation provided the possibility for microbial invasion, which lead to intraabdominal tissue infection. In the case of patients with hemodialysis or peritoneal dialysis, the majority of them were attacked by renal function injury or uremia, and renal failure reduced the ability of toxin excretion. Meanwhile, the patients with peritoneal dialysis had long retained abdominal tubes, which also provided an invasive window for microbes. If the abdominal permeability pipeline was not properly managed and the aseptic operation was not strict, it would also lead to intraabdominal tissue infection. Use of antimicrobials time $>$ 2 weeks, use of three or more antimicrobial agents and intraabdominal tissue infection may be cause and effect mutually.

Urinary tract (unrelated to catheter) was significantly related to smoking history $\geq$ 10 years and use of three generations of cephalosporins. The increase of inflammatory stress factors in smoking patients can lead to various infections, including urinary tract infection. Urinary tract infection and use of three generations of cephalosporins might be cause and effect mutually. When urinary tract infection occurred, the three generations of cephalosporins might be used for bacterium infection control, and long-term use of the three generations of cephalosporins would also increase resistance, which would promote the double infection such as drug-resistant or secondary fungus infection, and lead to the urinary tract infection happen or aggravate.

CLABSI was significantly related to arteriovenous catheterization and use of antifungal drug. Obviously, arteriovenous catheterization is undoubtedly a necessary factor in the occurrence of CLABSI. Among CLABSI, some of the pathogens are fungal infections, so it is possible to use antifungal agents against infection. However, use of antifungal agents is not always risk factor of CLABSI.

We have identified some areas of future work. We see the health economics analysis of elderly patients hospital-acquired infection as an interesting and challenging future direction. Additionally, this work can also be extended to a larger scale, such as all public hospitals in Shanghai and can be enhanced by using individual patient data, such as patients of all ages.

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References

Andersen BM, Rasch M (2000) Hospital-acquired infections in Norwegian long-term-care institutions. A three-year survey of hospital-acquired infections and antibiotic treatment in nursing/residential homes, including 4500 residents in Oslo. J Hosp Infect 46(4):288–296

Avci M, Ozgenc O, Coskuner SA, Olut AI (2012) Hospital acquired infections (HAI) in the elderly: comparison with the younger patients. Arch Gerontol Geriatr 54(1):247–250

Boev C, Kiss E (2017) Hospital-acquired infections: current trends and prevention. Crit Care Nurs Clin North Am 29(1):5165

Brusaferroa S, Silvestrob A, Vidottob L (2006) Incidence of hospital-acquired infections in Italian long-term-care facilities: a prospective six-month surveillance. J Hosp Infect 63(2):211–215

Durando P, Bassetti M, Orengo G, Crimi P, Battistini A, Tiberio G, Bellina D, Talamini A, Dodi F, Ansaldi F, Alicino C, Iudici R, Sticchi L, De Florentiis D, Viscoli C, Icardi G (2010) Hospital-acquired infections and leading pathogens detected in a regional university adult acute-care hospital in Genoa, Liguria, Italy: results from a prevalence study. J Prev Med Hyg 51(2):80–86

Ellidokuz H, Ukub R, Uysal Ü, Abacolud H (2003) Hospital-acquired infections in elderly patients: results of a West Anatolian University Hospital surveillance. Arch Gerontol Geriatr 37(3):259–263

Hensley BJ, Monson JRT (2015) Hospital-acquired infections. Surgery (Oxford) 33(11):528–533

Hussain M, Oppenheim BA, ONeill P, Trembath C, Morris J, Horan MA (1996) Prospective survey of the incidence, risk factors and outcome of hospital-acquired infections in the elderly. J Hosp Infect 32:117–126

Klevens RM, Edwards JR, Richards CL, Horan TC, Gaynes RP, Pollock DA, Cardo DM (2007) Estimating Healthcare-associated infections and deaths in U.S. Hospitals, 2002. Public Health Rep 122(2):160–166

Laurent M, NhiBories P, Thuaut AL, Liuu E, Ledudal K, Bastuji-Garin S, Paillaud E (2012) Impact of comorbidities on hospital-acquired infections in a geriatric rehabilitation unit: prospective study of 252 patients. J Am Med Dir Assoc 13(8):760.e7–760.e12

Mayon-White RT et al (1988) An international survey of the prevalence of hospital-acquired infection. J Hosp Infect 11(Suppl A):43–48

Mehta Y, Gupta A, Todi S, Myatra SN, Samaddar DP, Patil V, Bhattacharya PK, Ramasubban S (2014) Guidelines for prevention of hospital acquired infections. Indian J Crit Care Med 18(3):149–163

Plowman R et al (2000) The socio-economic burden of the hospital-acquired infection. Euro Surveill 5(4):49–50

Sangwan Anita Hospital Acquired Infections. http://www.biologydiscussion.com/micro-biology/hospital-acquired-infections/31060

Wolkewitz M, Palomar-Martinezb M, Olaechea-Astigarraga P (2016) A full competing risk analysis of hospital-acquired infections can easily be performed by a case-cohort approach. J Clin Epidemiol 74:187–193