Application of fuzzy mathematics models in hospital management evaluation

Mei Sun[1,2], Hui Feng[2], Siyuan Tang[2*], Ziqiang Luo[3]

[1]*Postdoctoral research station of school of basic medicine, Central south university, Changsha City, Hunan Province, China, 410013*

[2]*Nursing School of central south university, Changsha City, Hunan Province, China, 410013*

[3]*School of basic medicine, central south university, Changsha City, Hunan Province, China, 410013*

Abstract

To formulate a hospital management evaluation system and conduct empirical research, Delphi, analytic hierarchy process, and fuzzy comprehensive evaluation are used to build a hospital management evaluation system and conduct hospital management empirical research. And then a hospital management evaluation system is built. This system contains five first-level indices, namely, administrative management, human resource management, medical management, financial management and logistical support, and 23 second-level indices. Empirical research shows that the comprehensive evaluation of hospital management is above average and that service quality and infrastructure construction have the highest and lowest evaluation scores, respectively. This evaluation system is an effective tool for studying hospital management. Chinese hospital management requires further improvement, especially in terms of infrastructure construction.

Keywords: fuzzy mathematics, hospital management, evaluation system, analytic hierarchy process

1 Introduction

Hospital is a health and medical institution that treats and prevents diseases and protects people's health. Thus, hospital development and management are important concerns of all social sectors [1]. At present, hospital functions change from simple diagnosis and treatment into prevention, heath care, diagnosis and treatment, and rehabilitation, making services within hospitals extend forward and backward hospitals [2]. Hospital management shall adapt to such changes, adjust service structure and mode, and optimize and reorganize hospital resources. The increasingly fierce competitions in the medical market and the increasing medical service demands have brought new problems, changes, and challenges to hospital management. Hospital management innovation is an inevitable requirement of constantly changing objective hospital conditions and is an eternal theme of sustainable development of health cause. Hospitals should continuously innovate and improve management concept to remain invincible in the fierce market competition [3]. Therefore, hospital administrators need to actively innovate hospital management concept.

WHO introduces a new framework to analyze the performance of health systems in different countries and believes that the health system shall have three objectives [4], namely, promote good health, strengthen reaction capacity that people expect, and ensure financing fair-ness. It also proposes that a health system should possess four main functions, namely, management, financing, service provision, and raising resources. Hospital management quality can reflect the comprehensive strength and level of a hospital. The actual situation of Chinese hospital management reflects the urgent need for the guidance of hospital management innovation theory. Currently, all levels and categories of Chinese hospitals have inaccurate market and functional positioning, outdated operation and management concepts, low operating efficiency, and weak driving force and capital support for sustainable development [5]. Practical exploration and theoretical research of hospital management innovation should be vigorously conducted to make modern Chinese hospitals truly become subjects of market economy with independent management, self-discipline, and self-development. Changes in social medical and health demands urgently require hospitals to study management system innovation, management operation innovation, and management technological innovation, among others [6].

A few domestic and international studies have evaluated hospital management quality. Hospital management quality has its own features, and the particularity of comprehensive evaluation of hospital management quality is worthy of exploration and research. This study builds a hospital management evaluation index system by analytic hierarchy process (AHP). This process can scien-

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[*]*Corresponding author's* e-mail: sunmei1111@yeah.net

tifically, objectively, and accurately evaluate hospital management performance and promote hospitals to strengthen connotation construction. Then, fuzzy comprehensive evaluation is used to assess the management quality of six hospitals in a city. The evaluation results on hospital management quality are discussed for administrators to compare work quality and work development among hospitals in different times. This study may serve as a basis for evaluating hospital management quality.

2 Methods

2.1 EXPERT INTERVIEW

On the basis of literature reading, experience reference, and individual visit, this study begins with important and key contents that reflect hospital management, preliminarily selects hospital management evaluation indices, and initially builds a hospital management evaluation index system that contains 5 first-level indices and 37 second-level indices.

2.2 DELPHI

A qualified expert group and screen indices are selected from studies on social indices through Delphi, a scientific, relatively objective, and strongly operational method [7]. We seek advices of experts on selected hospital management evaluation index systems by distributing questionnaires and finally determine an evaluation system that contains 5 first-level indices and 23 second-level indices according to the advices and suggestions of experts.

2.3 AHP

Weight coefficients of all levels of indices can be calculated by AHP [8].

2.4 FUZZY COMPREHENSIVE EVALUATION

Hospital management involves a wide scope. Hospital management evaluation is a multifactor and multilevel process with highly complex influencing factors. Evaluation indices are both qualitative and quantitative. In addition, medical staff evaluates hospital management on the basis of subjective factors, fuzzy index factors, and asymmetric information. The introduction of the hybrid multi-attribute evaluation model can efficiently solve this problem. Triangular fuzzy numbers in fuzzy multi-attribute decision making can effectively handle index quantification and evaluators' subjective preference values [9,10]. Fuzzy comprehensive evaluation is realized by MATLAB7.0 program package.

3 Building of hospital management evaluation system

3.1 BUILDING OF INDEX SYSTEM

In accordance with the basic principles of SERVQUAL [11], a large number of hospital management indices are collected through literature and semi-structured interviews, and then Delphi is used to preliminarily select 37 indices and determine hospital management evaluation indices, including 5 first-level indices (i.e., administrative management, human resource management, medical management, financial management, and logistical support) and 23 second-level indices. An evaluation system is established through experts' scores of indices by pairwise comparison combined with AHP. A questionnaire is designed according to the established system, and the questionnaire is scored by the Likert five-level scale. Finally, a model is established by fuzzy mathematical modeling combined with exploratory and confirmatory analyses.

3.2 DETERMINE INDEX WEIGHT

The weight of hospital management evaluation indices plays an important role in the evaluation system. It is related to the importance degree of hospitals' management of influencing factors. In terms of social evaluation, the weights of evaluation indices are currently directly determined by a few experts according to experience, which is an insufficient basis for data analysis [12]. In addition, their experience may significantly deviate from the actual situation, thereby affecting the accuracy of evaluation results. Thus, this study uses AHP to determine index weights. The index weight of the hospital management evaluation system is calculated by AHP according to the following steps:

Step 1: establish a hierarchical index system structure, i.e., build index hierarchy according to the basic relations of the evaluation index system.

Step 2: build a pair-wise comparison matrix.

Step 3: check consistency.

$$C.I. = \frac{\lambda_{max} - n}{n - 1},$$
$$C.R. = \frac{C.I.}{R.I.}. \tag{1}$$

In this study, CR = 0.017 < 0.10, indicating that weight coefficients are available.

The index weight coefficients of the evaluation index system can be determined according to the above three steps. The weight of all levels of indices can be finally determined as shown in Table 1 on the basis of the scores provided by 10 experts on 5 first-level indices and 23 second-level indices.

TABLE 1 Evaluation index system and weight

First-level index (U_i)	Weight (W_i)	Second-level index (U_{ii})	Weight (W_{ii})	Index connotation
Administrative management U1	0.18	Organizational structure U11	0.22	Rational hospital management organizational structure
		Leaders' management responsibilities U12	0.31	Leaders devote themselves to hospital management
		Management accountability U13	0.21	Management accountability, to implement reward and punishment system
		Development planning U14	0.26	Formulate and implement development planning and annual working plan
Human resource management U2	0.21	Human resource allocation U21	0.23	Rational allocation of department human resources
		Talent echelon construction U22	0.22	Talent echelon construction system, continuing education system
		Physician structure U23	0.18	Rational three-level physician employment structure
		Nursing staff U24	0.19	Rational amount and echelon structure of nursing staff
		Educational background and professional knowledge U25	0.18	Rational educational background and professional knowledge structure of medical staff
Medical management U3	0.32	Medical quality U31	0.21	Medical treatment, medical matters and other management organizations, and working system
		Department supervision U32	0.19	Manage and supervise the quality of clinical and medicine departments
		Medical risk warning U33	0.09	Medical risk warning system, response and handling capacities
		Doctor–patient relationship U34	0.19	Deal with medical disputes timely and properly, and coordinate doctor–patient relationship
		Emergency management U35	0.15	Deal with emergencies and public disasters
		Medical attitude U36	0.17	Attitude of medical staff toward patients
Financial management U4	0.13	Accounting posts U41	0.24	Set accounting posts scientifically according to needs
		Accounting U42	0.27	Set accounting items for financial accounting according to provisions
		Budgeting U43	0.22	Formulate and implement budget for revenues and expenditures scientifically and rationally
		Financial control U44	0.27	Strengthen cost accounting and control, and reduce operating costs
Logistical support U5	0.16	Basic facility construction U51	0.28	Carry out basic construction items according to national laws and regulations
		Equipment management U52	0.26	Manage equipment scientifically
		Equipment renewal U53	0.19	Perfect medical equipment purchasing, maintenance and renewal system
		Logistical work U54	0.27	Meet needs of clinical work and patients' treatment

3.3 EVALUATION METHODS

Fuzzy comprehensive evaluation mathematical models can be divided into one-level models and multilevel models. Analysis of evaluation factors shows that some factors are coordinating while some are causal. In other words, evaluation factors have different levels, causing a practical issue that objectively exists.

Multilevel fuzzy comprehensive evaluation model: low-level factors are initially comprehensively evaluated, and then results are subjected to high-level comprehensive evaluation by the following specific steps:

1) Confirm the factor set of evaluation object $F=\{f_1, f_2,\ldots,f_n\}$. For hospital management evaluation indices, first-level evaluation factors include f_1 (administrative management), f_2 (human resources), f_3 (medical management), f_4 (financial management), and f_5 (logistical support) while second-level evaluation sub-factors include those of the indices in Table 1.

2) Confirm evaluation category set $E=\{e_1, e_2,\ldots,e_n\}$. Hospital management evaluation grades are determined as E= {very high, quite high, general, quite low, very low} grades, which correspond to scores of 90, 80, 70, 60, and 50, respectively.

3) Determine weight set W_f.

4) Perform single-factor evaluation. Establish fuzzy mapping f from factor set F to comment set E, derive a fuzzy relation R_f from f, and its matrix representation can be denoted as $R_i = R_f = (\gamma_{ikj}\ m \times n)$.

5) Comprehensive evaluation. Calculate comprehendsive evaluation vector S and comprehensive evaluation value μ according to the following formulas. $S = W_f R$, $\mu = W_e S^T$.

4 Empirical research of hospital management based on fuzzy mathematics

A questionnaire is formulated in accordance with a hospital management evaluation system to investigate hospital management quality, and the questionnaire is scored by the Likert five-level scale with "1" representing "dissatisfied" and "5" representing "very satisfied." Medical staff members select according to perceived actual situation and thus complete the test of hospital management quality. A total of 600 questionnaires are sent out, and 586 valid ones are recovered with an effective recovery rate of 97.67%.

With different emphasis on factors in U, each factor shall be given different weights, which can be expressed as a fuzzy subset $\underset{\sim}{A}(a_1, a_2, \cdots, a_n)$ of U, and stipulate

$$\sum_{i=1}^{n} a_i = 1 .$$

With $\underset{\sim}{R}$ and $\underset{\sim}{A}$, comprehensive evaluation is $\underset{\sim}{B} = \underset{\sim}{A} \cdot \underset{\sim}{R}$, $\underset{\sim}{B} = (b_1, b_2, \cdots, b_m)$ is a fuzzy subset of V, where

$$b_j = \overset{n}{\underset{i=1}{V}}(a_i \wedge r_{ij})(j = 1, 2, \cdots, m) . \tag{2}$$

The statistical data from the sample survey are substituted into the established model, and the vectors of all levels of fuzzy comprehensive evaluation are calculated.

4.1 ESTABLISH AN EVALUATION SET

An evaluation set consists the evaluation of all indices and all possible results of total evaluation. Hospital management evaluation may have five possible results. The evaluation set can be denoted as $R = \{r_1, r_2, r_3, r_4, r_5\}$ = {very low, quite low, general, quite high, very high}.

The index "organizational structure U11" is "very high" for 48 people, "quite high" for 169 people, "general" for 228 people, "quite low" for 37 people, and "very low" for 104 people. On the basis of normalization calculation, the evaluation set of organizational structure U11 is r1 = (0.178, 0.063, 0.389, 0.289, 0.081).

Similarly, the single-factor evaluation matrix of administrative management obtained by combining the evaluation grades of the sub-indices of administrative management is as follow:

$$R_1 = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix} =$$

$$\begin{pmatrix} 0.17848 & 0.063194 & 0.388557 & 0.288642 & 0.081127 \\ 0.099915 & 0.098207 & 0.447481 & 0.268147 & 0.086251 \\ 0.24509 & 0.020495 & 0.378309 & 0.288642 & 0.067464 \\ 0.207515 & 0.076003 & 0.41076 & 0.293766 & 0.011956 \end{pmatrix}$$

TABLE 2 Index evaluation scores

First-level index	Second-level index	Evaluation scores
Administrative management U1	Organizational structure U11	70.30743
	Leaders' management responsibilities U12	71.42613
	Management accountability U13	69.12895
	Development planning and management U14	68.26644
Human resource management U2	Human resource allocation U21	77.42101
	Talent echelon construction U22	76.13151
	Physician structure U23	78.94962
	Nursing staffs U24	78.65073
	Educational background and professional knowledge U25	69.12041
Medical management U3	Medical quality U31	76.65243
	Department supervision U32	78.924
	Medical risk warning U33	68.93254
	Doctor–patient relationship U34	68.94108
	Emergency management U35	68.7105
	Medical attitude U36	62.50213
Financial management U4	Accounting posts U41	68.77882
	Accounting U42	68.33476
	Budgeting U43	70.40137
	Financial control U44	63.57814
Logistical support U5	Basic facility construction U51	77.30999
	Equipment management U52	71.04184
	Equipment renewal U53	68.51409
	Logistical work U54	66.191289

According to fuzzy membership degree, the evaluation matrix shows that the organizational structure and leader management responsibilities are general while the management accountability and development planning are low. In terms of comprehensive evaluation scores, physician structure evaluation has the highest scores; whereas medical attitude evaluation has the lowest scores (Table 2).

Similarly, the single-factor evaluation matrix of human resource management obtained by combining the evaluation grades of sub-indices of human resource management is shown as follow:

r1	0.17848	0.043553	0.050384	0.312553	0.41503
r2	0.172502	0.072588	0.081981	0.315115	0.357814
r3	0.013664	0.003416	0.326217	0.387703	0.269001
r4	0.032451	0.051238	0.228864	0.393681	0.293766
r5	0.187874	0.097353	0.389411	0.265585	0.059778

In terms of fuzzy membership degree, the evaluation of human resource allocation, talent echelon construction, physician structure, and nursing staff is general, whereas the evaluation of educational background and professional knowledge is low. In terms of evaluation scores, human resource allocation has the highest scores, whereas educational background and professional knowledge have the lowest scores.

Similarly, the single-factor evaluation matrix of medical management obtained by combining the evaluation grades of sub-indices of medical management is shown as follow:

r1	0.184458	0.071734	0.052946	0.275833	0.415030
r2	0.028181	0.071734	0.169086	0.441503	0.289496
r3	0.220325	0.000854	0.482494	0.257899	0.038429
r4	0.189582	0.057216	0.458582	0.258753	0.035867
r5	0.247652	0.008540	0.429547	0.253629	0.060632
r6	0.232280	0.436379	0.252775	0.005978	0.072588

In terms of fuzzy membership degree, medical quality and department supervision have general evaluation, whereas medical risk warning, doctor–patient relationship, emergency management, and medical attitude have low evaluation. In terms of evaluation scores, medical quality has the highest scores, whereas medical attitude has the lowest scores.

Similarly, the single-factor evaluation matrix of financial management obtained by combining the evaluation grades of the sub-indices of financial management is shown as follow:

r1	0.222886	0.042699	0.40222	0.298036	0.034159
r2	0.245090	0.047822	0.360376	0.321947	0.024765
r3	0.168232	0.035013	0.455167	0.271563	0.070026
r4	0.203245	0.400512	0.273271	0.081127	0.041845

In terms of fuzzy membership degree, accounting posts, accounting, and financial control have low evaluation, whereas budgeting has general evaluation. In terms of evaluation scores, budgeting has general scores, the other aspects of financial management have low scores, and financial control has the lowest scores.

Similarly, the single-factor evaluation matrix of logistical support obtained by combining the evaluation grades of sub-indices of logistical support is shown as follow:

r1	0.222886	0.042699	0.402220	0.298036	0.034159
r2	0.245090	0.047822	0.360376	0.321947	0.024765
r3	0.168232	0.035013	0.455167	0.271563	0.070026
r4	0.203245	0.400512	0.273271	0.081127	0.041845

In terms of fuzzy membership degree, basic facility construction and equipment management have general eva-

luation, and equipment renewal and logistical work have low evaluation. Basic facility construction has the highest scores, whereas logistical work has the lowest scores.

4.2 ESTABLISH A WEIGHT SET

Weight set of second-level index layer: The corresponding weight of each index is provided according to the above expert scoring and AHP analysis results.

Weights of administrative management indices:
$A_1 = c$ **(0.22, 0.31, 0.21, 0.26)**
Weights of human resource management indices:
$A_2 = c$ **(0.23, 0.22, 0.18, 0.19, 0.18)**
Weights of medical management indices:
$A_3 = c$ **(0.21, 0.19, 0.09, 0.19, 0.15, 0.17)**
Weights of financial management indices:
$A_4 = c$ **(0.24, 0.27, 0.22, 0.27)**
Weights of logistical support indices:
$A_5 = c$ **(0.28, 0.26, 0.19, 0.27)**

Weight set of first-level index layer: The corresponding weight of each index is provided according to the AHP analysis results: $W = c$ (0.18, 0.21, 0.32, 0.13, 0.16).

4.3 COMPREHENSIVE EVALUATION

With the above weight sets and single factor evaluation sets, we can calculate the following:

The comprehensive evaluation vector of administrative management is:

$$B_1 = A_1 \times R_1 = \begin{pmatrix} 0.22 & 0.31 & 0.21 & 0.26 \end{pmatrix}$$

$$\begin{pmatrix} 0.17848 & 0.063194 & 0.388557 & 0.288642 & 0.081127 \\ 0.099915 & 0.098207 & 0.447481 & 0.268147 & 0.086251 \\ 0.24509 & 0.020495 & 0.378309 & 0.288642 & 0.067464 \\ 0.207515 & 0.076003 & 0.41076 & 0.293766 & 0.011956 \end{pmatrix} =$$

$$\begin{pmatrix} 0.175662 & 0.068412 & 0.410444 & 0.283621 & 0.061862 \end{pmatrix}.$$

In terms of fuzzy membership degree, at administrative management has low evaluation, and its comprehensive evaluation scores are:

$0.1756618 \times 50 + 0.06841161 \times 60 + 0.4104441 \times 70 +$
$0.2836208 \times 80 + 0.06186166 \times 90 = 69.87609.$

Similarly, the comprehensive evaluation vector of human resource management is:

$$B_2 = \begin{pmatrix} 0.121443 & 0.05386 & 0.201921 & 0.333604 & 0.289172 \end{pmatrix}.$$

In terms of fuzzy membership degree, human resource management has general evaluation, and its comprehendsive evaluation scores are:

$0.1214432 \times 50 + 0.05385995 \times 60 + 0.2019214 \times 70 +$
$0.3336038 \times 80 + 0.2891716 \times 90 = 76.15201.$

Similarly, the comprehensive evaluation vector of medical management is:

$$B_3 = \begin{pmatrix} 0.176576 & 0.115107 & 0.281204 & 0.253245 & 0.173869 \end{pmatrix}.$$

In terms of fuzzy membership degree, medical management has general comprehensive evaluation, and its evaluation scores are:

$0.1765756 \times 50 + 0.1151067 \times 60 + 0.2812041 \times 70$
$+0.2532451 \times 80 + 0.1738685 \times 90 = 71.32724.$

Similarly, the comprehensive evaluation sector of financial management is:

$$B_4 = \begin{pmatrix} 0.211554 & 0.139001 & 0.367754 & 0.240103 & 0.041588 \end{pmatrix}.$$

In terms of fuzzy membership degree, financial management has quite low comprehensive evaluation, and its comprehensive evaluation scores are:

$0.2115542 \times 50 + 0.1390009 \times 60 + 0.3677541 \times 70 +$
$0.2401025 \times 80 + 0.04158839 \times 90 = 67.6117.$

Similarly, the comprehensive evaluation sector of logistical support is:

$$B_5 = \begin{pmatrix} 0.197874 & 0.050325 & 0.324355 & 0.308121 & 0.119325 \end{pmatrix}.$$

In terms of fuzzy membership degree, logistical support has general comprehensive evaluation, and its comprehensive evaluation scores are:

$0.1978736 \times 50 + 0.05032451 \times 60 + 0.3243553 \times 70 +$
$0.3081213 \times 80 + 0.1193254 \times 90 = 71.007.$

With the above comprehensive evaluation and weights of three first-level indices, the comprehensive evaluation scores of hospital management can be calculated as follow:

$$C = W \times \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{pmatrix} \begin{pmatrix} 0.18 & 0.21 & 0.32 & 0.13 & 0.16 \end{pmatrix}$$

$$\begin{pmatrix} 0.176 & 0.068 & 0.410 & 0.284 & 0.062 \\ 0.121 & 0.054 & 0.202 & 0.334 & 0.289 \\ 0.177 & 0.115 & 0.281 & 0.253 & 0.174 \\ 0.212 & 0.139 & 0.368 & 0.240 & 0.042 \\ 0.198 & 0.050 & 0.324 & 0.308 & 0.119 \end{pmatrix} =$$

$$\begin{pmatrix} 0.173 & 0.087 & 0.306 & 0.283 & 0.152 \end{pmatrix}.$$

In terms of fuzzy membership degree, comprehensive evaluation is general, and the comprehensive evaluation scores of hospital management are:

$0.1779046 \times 50 + 0.06538295 \times 60 + 0.3063106 \times 70 +$
$0.2908957 \times 80 + 0.1595061 \times 90 = 71.89.$

On the basis of the above results, a summary table of first-level indices and comprehensive evaluation scores can be obtained (Table 3).

TABLE 3 First-level indices and comprehensive evaluation

First-level index Ui	Satisfaction membership	Evaluation scores
Administrative management U1	Quite low	69.876
Human resource management U2	General	76.152
Medical management U3	General	71.327
Financial management U4	Quite low	67.612
Logistical support U5	General	71.007
Comprehensive evaluation	General	71.89

5 Conclusions

This study establishes a hospital management evaluation system containing 5 first-level indices (i.e., administrative management, human resource management, medical management, financial management, and logistical support) and 23 second-level indices. It also determines the weights and evaluation methods of indices in this evaluation system.

The hospital management evaluation system in this study can scientifically and rationally solve the problem of irrational evaluation by considering the main quantitative factors in previous evaluation methods.

Empirical analysis of hospital management shows that the comprehensive evaluation score of current hospital management is 71.89 while that of hospital management level needs further improvement. Particularly, administrative and financial managements have low evaluation scores and need to be improved urgently. Meanwhile, human resource management, logistical support, and medical management have general evaluation scores and also need further improvement.

Acknowledgement

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Authors	
	Mei Sun, born in August 1982, Taiyuan City, Shanxi Province, P.R. China. **Current position, grades:** lecturer of Nursing school, Central South University, China. **University studies:** Doctor degree at Central South University in China. **Scientific interests:** nursing quality control, chronic disease management. **Publications:** more than 12 papers. **Experience:** teaching experience of 2 years, 4 scientific research projects.
	Hui Feng, born in June 1973, Changsha City, Hunan Province, P.R. China. **Current position, grades:** Associate Professor of Nursing school, Central South University, PR China. **University studies:** Bachelor, Master and Doctor degree in Medicine at Central South University of Hunan in China. **Scientific interests:** nursing education and chronic disease management. **Publications:** more than 20 papers. **Experience:** teaching experience of 21 years, 7 scientific research projects.
	Siyuan Tang, born in April 1966, Hengyang City, Hunan Province, P.R. China. **Current position, grades:** Professor at Nursing school, Central South University, China. **University studies:** Bachelor, Master and Doctor degree in Medicine at Central South University of Hunan in China. **Scientific interests:** nursing education, chronic disease management. **Publications:** more than 120 papers. **Experience:** teaching experience of 26 years, 12 scientific research projects.
	Ziqiang Luo, born in April 1962, Changsha City, Hunan Province, P.R. China. **Current position, grades:** Professor at the basic medical school, Central South University, China. **University studies:** Bachelor, Master and Doctor degree in Medicine at Central South University of Hunan in China. **Scientific interests:** respiratory physiology. **Publications:** more than 102 papers. **Experience:** teaching experience of 30 years, 18 scientific research projects.

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