北京大学 PEKING UNIVERSITY
全球健康发展研究院
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智慧手术季刊
SMART Surgical Quarterly

Issue 2 June 2024

Cohort Study

Parallel Studies

Global News

（An Internal Journal）

智慧手术季刊

SMART Surgical Quarterly

On May 19, 2023, PKU Institute for Globe Health and Development has launched the Survey of Medical Assessment for Robotic Technology (SMART), a longitudinal multi-center study in China. In order to ensure the SMART study progress to be updated timely and effectively among all the participants, The SMART Surgical Quarterly is launched accordingly as an internal journal. This quarterly journal will serve as a comprehensive platform to update the key information on the SMART progress as well as the progress for the parallel studies.

智慧手术季刊

SMART Surgical Quarterly

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目　　录

（内部交流季刊）

Health Technology Assessment of Robot-assisted Versus Laparoscopic Low Anterior Resection for Middle and Low Rectal Cancer: a prospective cohort study Progress Report

By Xuefeng Hu Zerong Cai Qingbo Wang

Ziting Wu AND Beini Lyu *

Background: Robot-assisted surgery shows promising applications in the treatment of rectal cancer. Despite its numerous advantages, controversy surrounds its use due to inconsistent research findings and high costs.Objective: 1) This study aims to establish a nationwide multicenter observational cohort to evaluate the efficacy, health outcomes, and costs associated with robot-assisted surgery compared to traditional approaches for rectal cancer. 2) This study also aims to compare the total medical expenses, direct medical costs, and indirect medical costs among rectal cancer patients undergoing robot-assisted, laparoscopic, and open surgeries for low anterior resection. The analysis will assess differences in catastrophic health expenditure and the probability of falling into poverty due to illness among these patient groups, along with identifying influencing factors.Methods: 1) Clinical hospitals will be selected based on factors such as geographic location, economic development level, hospital infrastructure, colorectal surgery expertise, and willingness of collaboration. 2) Data will be collected from the "Health Technology Assessment of Robot versus Traditional Laparoscopic-Assisted Low Anterior Resection in Mid to Low Rectal Cancer" project. One-way ANOVA will be used to compare total

* Hu: Institute for Global Health and Development, Peking University, huxuefengDSG@outlook.com. Cai : Colorectal Surgery, the Sixth Affiliated Hospital of Sun Yat-sen University; Guangdong Provincial Institute of Gastroenterology; Guangdong Provincial Key Laboratory of Colorectal and Pelvic Floor Diseases. Wang: Institute for Global Health and Development, Peking University, wangqingbo89@163.com. Wu: Institute for Global Health and Development, Peking University, wuziting@pku.edu.cn. Lyu (Corresponding Author):Institute for Global Health and Development, Peking University, blyu@pku.edu.cn.

medical expenses, direct medical costs, and indirect medical costs among the three patient groups. A Probit model will be employed to analyze the factors associated with catastrophic health expenditure/poverty due to illness. And a Cox regression model will be used to assess the influencing factors of catastrophic health expenditure/poverty due to illness.Results: At present, 16 hospitals were selected based on regional and technological criteria in this study, representing the real-world application of robot-assisted surgery in rectal cancer treatment. Analysis of the differences in catastrophic health expenditure/the probability of falling into poverty due to illness among the three types of surgeries is currently ongoing.

I. Background

Colorectal cancer is one of the most common malignant tumors of the digestive system in China, with an increasing incidence in recent years. Rectal cancer constitutes 50%-60% of all colorectal cancers, predominantly occurring below the peritoneal reflection in the mid to low rectum. Surgery for these rectal cancers is technically challenging, demanding clear exposure and meticulous surgical skills to preserve anal function and protect urinary and reproductive nerves.

Low anterior resection of the rectum is the most widely performed procedure aimed at sphincter preservation. Numerous domestic and international studies have investigated the effectiveness and safety of robot-assisted surgery versus traditional laparoscopic surgery in rectal cancer treatment. Due to higher costs associated with robot-assisted surgery compared to traditional methods, there is a need for health economic evaluations of robot-assisted rectal cancer surgery.

Current research in this field primarily focuses on clinical outcomes, with a few studies from abroad considering short-term quality-adjusted life years and cost-effectiveness（Collinson et al. 2012;Jayne et al. 2019）. However, these studies have several limitations: (1) Health economic evaluations of robot-assisted surgery are predominantly model-based studies lacking unified and definitive conclusions. (2) Studies are mostly single-center retrospective studies with small sample sizes, leading to inadequate statistical power. (3) Many health economic evaluations are based on small-scale clinical studies using health outcome measures as cost-effectiveness outcomes, with limited consideration of preoperative and postoperative psychological factors and long-term quality of life. (4) Currently, there is a lack of cost-effectiveness analyses specific to the Chinese population regarding robot-assisted surgery for rectal cancer.

This study aims to establish a prospective, nationwide multicenter observational cohort to compare the clinical effectiveness, health outcomes, and costs among rectal cancer patients undergoing different surgical approaches. This initiative seeks to provide health economic insights into the application of robot-assisted low anterior resection in rectal cancer patients in China.

II. Objectives

This study aims to select nationally representative clinical hospitals, considering factors such as geographic location, economic development level, hospital infrastructure, colorectal surgery expertise, and willingness to collaborate, to ensure the representativeness and reliability of the research findings. Additionally, it seeks to compare the total medical expenses, direct medical costs, and indirect medical costs among rectal cancer patients undergoing low anterior resection using three surgical approaches: robot-assisted surgery, laparoscopic surgery, and open surgery. The analysis will assess the differences in catastrophic health expenditure and the probability of falling into poverty due to illness among these patient groups, along with identifying influencing factors.

III. Methods

In cohort studies, the geographical representativeness of participants is crucial（Healy and Devane 2011）, necessitating the inclusion of hospitals from different geographic locations with varying levels of economic development. This approach ensures a comprehensive sample that encompasses diverse healthcare settings. Economically developed regions are chosen to evaluate rectal cancer treatment outcomes under conditions of strong technical capabilities and abundant medical resources. Conversely, less developed regions are selected to assess outcomes under conditions of relatively constrained medical resources（Willett and Colditz 1998）.

Selected hospitals must meet established standards in terms of technology and experience（Wang and Kattan 2020）. Given the need to compare clinical effectiveness, health outcomes, and costs among rectal cancer patients undergoing different surgical approaches, hospitals selected for this study must demonstrate proficiency across these surgical modalities to ensure research accuracy（Keung et al. 2020）.

Based on the above requirements, the following approach was adopted to select representative hospitals with adequate technical proficiency. Firstly, potential hospitals nationwide were screened based on factors such as geographical location and economic development level, thus ensuring the regional representativeness of the participants. Secondly, the technical status of the hospitals was analyzed, assessing their technical and experiential adequacy via medical infrastructure, physician composition, and surgical volume. Subsequently, connections were established with the selected hospitals for cooperation. Finally, comprehensive consideration of various factors led to the selection of the hospitals.

Data will be collected from the "Health Technology Assessment of Robot versus Traditional Laparoscopic-Assisted Low Anterior Resection in Mid to Low Rectal Cancer" project. One-way ANOVA will be used to compare total medical expenses, direct medical costs, and indirect medical costs among the three patient groups. A Probit model will be employed to analyze the factors associated with catastrophic health expenditure/poverty due to illness. And a Cox regression model will be used to assess the influencing factors of catastrophic health expenditure/poverty due to illness.

These methodologies aim to provide robust insights into the economic implications of robot-assisted surgery for rectal cancer patients, addressing both clinical and health economic considerations effectively.

IV. Results

In this paper, only the selected hospitals are reported. We selected 16 hospitals for this cohort study, including the Sixth Affiliated Hospital of Sun Yat-sen University, Shenzhen People's Hospital, Fudan University Shanghai Cancer Center, the First Affiliated Hospital of Nanchang University, Union Hospital Affiliated to Fujian Medical University, Peking University People's Hospital, Shengjing Hospital of China Medical University, Xinjiang Uygur Autonomous Region People's Hospital, Southwest Hospital of Army Medical University, Lanzhou University First Hospital, Chengdu Third People's Hospital, the First Affiliated Hospital of Zhengzhou University, the Affiliated Hospital of Qingdao University, the Second Affiliated Hospital of Harbin Medical University under the People's Liberation Army General Hospital, and the Second Affiliated Hospital of Harbin Medical University.

FIGURE1. DISTRIBUTION OF THE SELECTED HOSPITALS IN THE COHORT STUDY

Figure 1 illustrates the distribution of these hospitals, which exhibits excellent regional representativeness, covering both the eastern and mid-western regions. Specifically, the Sixth Affiliated Hospital of Sun Yat-sen University and Shenzhen People's Hospital are representative hospitals in South China, renowned for their advanced medical equipment and vast clinical experience. Fudan University Shanghai Cancer Center holds a strong technical influence in East China. The First Affiliated Hospital of Nanchang University, located in the central region, also boasts advanced technology and significant influence. Meanwhile, Union Hospital Affiliated to Fujian Medical University reflects the high medical standard of the southeastern coastal area.

Furthermore, hospitals such as Peking University People's Hospital, Shengjing Hospital of China Medical University, Xinjiang Uygur Autonomous Region People's Hospital, Southwest Hospital of Army Medical University, Lanzhou University First Hospital, Chengdu Third People's Hospital, The First Affiliated Hospital of Zhengzhou University, and The Affiliated Hospital of Qingdao University, represent the medical standards of northern, northeastern, northwestern, and southwestern China, respectively. This geographical distribution of the cohort study thus exhibits typical characteristics.

In terms of technical proficiency and experiential adequacy, these hospitals exhibit a high degree of expertise and strong technical capabilities in the field of rectal cancer surgery. Hospitals like the Sixth Affiliated Hospital of Sun Yat-sen University, Shenzhen

People's Hospital, Fudan University Shanghai Cancer Center, and the First Affiliated Hospital of Nanchang University possess robust technical strengths in robotic surgery, laparoscopic surgery, and open surgery, and have accumulated extensive experience in these surgical procedures. Additionally, hospitals such as Union Hospital Affiliated to Fujian Medical University and Peking University People's Hospital possess high technical proficiency and rich clinical experience in comprehensive treatment, early diagnosis, and individualized therapy for rectal cancer. These hospitals' technology and experience fully meet the requirements for comparing robotic, laparoscopic, and open surgeries, and are capable of providing high-quality data for the study.

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How Will Medical Robot Effect the Risk and Uncertainty of Surgery

By Ermo Chen*

A retrospective research is done to analysis the effect on death rate of robotic surgeries, investigating the changes of death rate with introducing medical robots into healthcare systems. This is part of the project of researches on medical errors. The analysis is done with two data sources, one is the service record from a market-dominating medical robot provider, and the other is a sta- tistical result data from a info-tech provider covering thousands of hospitals in China. Results show that the medical robot can lead significantly reduce on death rate of surgery, which might mean medical robots could reduce medical errors. And that will be investigated further.

Prior works does not show coherent significantly benefit on surgeries with introducing medical robots, see Borden et al. (2007) and Alemzadeh et al. (2016), while in real world it does become more and more popular. More driving factors need to be excavated. Too few samples to draw reliable result beyond expectation, such as risk and uncertainty, in cohort studies. This force us to use larger data sets in a retrospective way.

Prior works does not show coherent significantly benefit on surgeries with intro- ducing medical robots (Borden et al., 2007). while in real world it does become more and more popular. More driving factors need to be excavated. Too few samples to draw reliable result beyond expectation, such as risk and uncertainty, in cohort studies. This force us to use larger data sets in a retrospective way.

We investigate the effect on death rate changes by introducing medical robots. Results show that the medical robot can lead significantly reduce on death rate of surgery. This is part of the project of researches on medical errors.

I. Data

Service record from a market-dominating medical robot provider, with all its service

* School of Mathematical Sciences and PKU China Center for Health Economic Research, Peking University, No.5 Yiheyuan Road, Haidian District, Beijing, 100871 (email: chenermo@stu.pku.edu.cn).

records in mainland China. It recorded the name of hospital, surgery date and category of surgery of each case.

Statistical records from a info-tech provider are provided by a inner statistical report, with samples covering 2007-2022 calendar years and 6252 hospitals in mainland china. Number of Samples, Death rate, Average Cost, Variance of Cost and In-hospital Days are reported for each hospital each month and each category of surgery or division. The location, level and grade of the hospitals are also accessible.

These two sources could be merged with hospital and date, making the analysis feasible. 6252 hospitals are covered in the analysis, containing 97 hospitals with medical robots using records, covering 28328/314152 = 9% of all the service record in robot provider. With a data filter, 4231 hospitals with 30936 hospital-quarters are finally used in drawing statistical conclusions.

II. Effect on death rate

The regression model in this section is

$$(1)\ \mathrm{DeathRate}_{i,t} \sim \mathrm{Robot}_{i,t} + \mathrm{X}_i + \mathrm{I}_t,\ \omega = \mathrm{SampleSize}_{i,t} \quad ,$$

where we use two kinds of variables measuring the level of introducing robots, the number of cases down with robots, and the rate of cases down with robots w.r.t. the sample size (robot rate). This is because that the statistical record data are drawn on samples but not fully records, making the evaluation of robot rate not accurate enough. However, the robot rate is necessary to evaluate the level of effect beyond a signature judgement. So both of them are considered in the process of analysis.

Two kinds of fix effected for hospitals are considered. One is to use the unique ID of hospital directly, which is simple by constrained by some missing result in statistical result data. The other one is to use the province, level and grade instead, with may loss some information but more reliable. We check the result of both options, for robustness and reducing endogeneity.

Results of accounting amount of surgery cases done with robots are shown as below in Table II.

	Hospital Level, Robot Count			
Num_of_Robot	1.65E-06	1.12E-06	**-6.19E-06**	**-2.12E-06**
p-Value: Num_of_Robot	0.0838	0.2436	**0.0000**	**0.0094**
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,936	30,936	30,936	30,936
F-stats	2.9890	5.1351	100.2786	17.8164
R-squared	0.0001	0.0104	0.2454	0.7417

The result showed significantly negative relationship between robot surgery count and death rate, under the control of fix effect of time and hospital (both directly and indirectly). Without the control of fix effect, especially the hospital effect, the result becomes complex. This is caused by the selection bias on introducing robots among hospitals, which is common as it is very expensive.

Results of accounting amount of proportion of surgery cases done with robots w.r.t. sample cases in model points are shown as below in TableII.

	Hospital Level, Robot Rate			
Robot_Rate	2.27E-02	1.79E-02	**-2.88E-02**	**3.10E-02**
p-Value: Robot_Rate	0.1020	0.1960	**0.0184**	**0.0057**
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,936	30,936	30,936	30,936
F-stats	2.6734	5.1401	99.6580	17.8172
R-squared	0.0001	0.0104	0.2443	0.7417

Similar results could be drawn from this analysis about proportion, while things changes as the fixed effect is chosen directly using hospital ID. This is because that the data of robot service is full covered, but the statistical results are sampled. It then will disturb the evaluate of measuring real robot rate, as the denominator is not reliable. So the result on the robot surgery count is more reliable in judging the direction of robot effect.

Similar analysis are done with the statistical results data separating divisions for different surgeries. The results are shown as Table II for robot counts below.

	Division Level, Robot Count			
Num_of_Robot	-9.06E-07	-5.88E-07	**-4.07E-06**	**-1.97E-05**
p-Value: Num_of_Robot	0.5228	0.6820	**0.0105**	**0.0000**
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin	Yes	Yes	Yes	Yes
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	12,849	12,849	12,849	12,849
F-stats	109.2986	12.6725	13.3416	8.6823
R-squared	0.0638	0.0649	0.0999	0.6055

And Table II for robot rates.

Coherent conclusions with former regression results.

	Division Level, Robot Rate			
Robot_Rate	-1.39E-03	-8.91E-04	**-5.97E-03**	**-1.38E-02**
p-Value: Robot_Rate	0.5963	0.7368	**0.0351**	**0.0000**
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin	Yes	Yes	Yes	Yes
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	12,849	12,849	12,849	12,849
F-stats	109.2816	12.6717	13.3194	8.6144
R-squared	0.0637	0.0649	0.0998	0.6036

III. Effect on in-hospital days

The regression model in this section is

$$(2) \qquad \mathrm{InHospitalDays}_{i,t} \sim \mathrm{Robot}_{i,t} + \mathrm{X}_i + \mathrm{I}_t, \quad \omega = \mathrm{SampleSize}_{i,t},$$

where modelling the length of stay in hospital. Other settings are similar with the former section.

Results are displayed as below, firstly is the result with hospital level statistics on robot case counts.

	Effect on in-hospital days			
Num_of_Robot	-1.33E-01	-9.52E-02	-2.99E-02	7.37E-01
p-Value: Num_of_Robot	0.8756	0.9121	0.9729	0.5969
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,904	30,904	30,904	30,904
F-stats	0.0245	0.2178	0.9134	0.3736
R-squared	0.0000	0.0004	0.0030	0.0568

Secondly, there is the result with hospital level statistics on robot case proportions.

	Effect on in-hospital days			
Robot_Rate	-1.13E+03	-7.70E+02	-2.00E+02	3.91E+03
p-Value: Robot_Rate	0.9277	0.9508	0.9873	0.8382
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,904	30,904	30,904	30,904
F-stats	0.0082	0.2177	0.9134	0.3735
R-squared	0.0000	0.0004	0.0030	0.0568

And similar results with division level shown as below two tables.

It shows that, no significant changes are shown in the results, means that the length in hospital will not be effected heavily with introducing the robot for surgeries. This is coherent with the conclusions of other researches.

	Effect on in-hospital days			
Num_of_Robot	-4.04E-03	5.79E-02	1.57E-01	5.42E-01
p-Value: Num_of_Robot	0.9969	0.9561	0.8945	0.8309
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin	Yes	Yes	Yes	Yes
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	12,847	12,847	12,847	12,847
F-stats	2.0274	0.2798	0.3284	0.1813
R-squared	0.0013	0.0015	0.0027	0.0311

	Effect on in-hospital days			
Robot_Rate	-8.98E+00	9.68E+01	2.20E+02	5.22E+02
p-Value: Robot_Rate	0.9963	0.9602	0.9169	0.8716
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin	Yes	Yes	Yes	Yes
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	12,847	12,847	12,847	12,847
F-stats	2.0274	0.2798	0.3283	0.1813
R-squared	0.0013	0.0015	0.0027	0.0311

IV. Effect on cost expectation

The regression model in this section is

(3) $$\text{ExpectedCost}_{i,t} \sim \text{Robot}_{i,t} + \text{X}_i + \text{I}_t, \quad \omega = \text{SampleSize}_{i,t},$$

where modelling the expected cost. Other settings are similar with the former section. Results are shown as below.First is the results on robot surgery case numbers.

	Effect on cost expectation			
Num_of_Robot	2.72E+01	2.63E+01	1.93E+01	3.34E+00
p-Value: Num_of_Robot	0.0000	0.0000	0.0000	0.0017
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,936	30,936	30,936	30,936
F-stats	744.2504	17.9099	113.2246	9.5432
R-squared	0.0235	0.0353	0.2686	0.6060

Second is the the results on robot surgery case proportions.

	Effect on cost expectation			
Robot_Rate	3.47E+05	3.37E+05	2.67E+05	1.18E+05
p-Value: Robot_Rate	0.0000	0.0000	0.0000	0.0000
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,936	30,936	30,936	30,936
F-stats	564.6737	15.4653	112.8116	9.5755
R-squared	0.0179	0.0306	0.2679	0.6068

Both groups of results show significant increment in cost when introducing the robot. This is common as it does take some more cost using the machine, such as start-up fee, equipment fee, maintenance fee.

V. Effect on cost uncertainty

The regression model in this section is

(4)

$$\mathrm{VarianceCost}_{i,t} \sim \mathrm{Robot}_{i,t} + \mathrm{Robot}_{i,t}(1-\mathrm{Robot}_{i,t}) + \mathrm{X}_i + \mathrm{I}_t, \quad \omega = \mathrm{SampleSize}_{i,t},$$

where modelling the variance of cost. Other settings are similar with the former section. The term of Roboti,t(1 − Roboti,t) is used to separate the Within-group variance from the total variance. We proof the reason of this method in appendix.

In this section, only proportion of robot is available, as the number of robot could not face the constrains of variance regression theory.

The results are shown as below. First is the result on hospital level statistics.

	Effect on cost uncertainty			
Robot_Rate	3.71E+12	1.85E+12	-1.34E+12	-6.30E+12
p-Value: Robot_Rate	0.9400	0.9702	0.9784	0.9318
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin				
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	30,936	30,936	30,936	30,936
F-stats	0.0185	0.4753	0.6423	0.7605
R-squared	0.0000	0.0010	0.0021	0.1092

Second is the result on division level statistics.

	Effect on cost uncertainty			
Robot_Rate	-1.43E+13	-1.07E+13	-3.34E+12	3.72E+12
p-Value: Robot_Rate	0.9398	0.9553	0.9869	0.9919
Fix Effect: Time		Yes	Yes	Yes
Fix Effect: Hospital				Yes
Fix Effect: Divisioin	Yes	Yes	Yes	Yes
Fix Effect: Province			Yes	
Fix Effect: Hospital_Lv			Yes	
Fix Effect: Hospital_Grade			Yes	
Num of Model Points	12,849	12,849	12,849	12,849
F-stats	0.0825	0.0397	0.0445	0.0589
R-squared	0.0001	0.0002	0.0004	0.0103

We can claim that there is no significant difference between robot surgeries and traditional ones.

VI. Discussion on cost-effectiveness

We may measure the cost-effectiveness with the estimated incremental cost and the decrements in death, with the help of monetary life value. This may suggest a lower bound of the HTA result on robot surgeries.

VII. Conclusions

- Surgery Robots will help reducing the death rate in hospital significantly.
- Although the average cost has a significant increment, the variance does not change much.
- The length in hospital is not significantly effected.

Filter Settings and Reasons

The regression will not get stable result unless using the statistics of model points with sample sizes larger than a hurdle level.

We use a common regression

$$\text{ExpecedCost}_{i,t} \sim \text{X}_i + \text{I}_t + \text{SampleSize}_{i,t}, \quad \text{(A1)}$$

which modeling the cost effect in areas and periods. A reasonable result should shows that the cost increasing along time, and positive diffs from large city to low-income areas. The Figure below shows the estimation of coefficients, using different hurdle level on sample sizes.

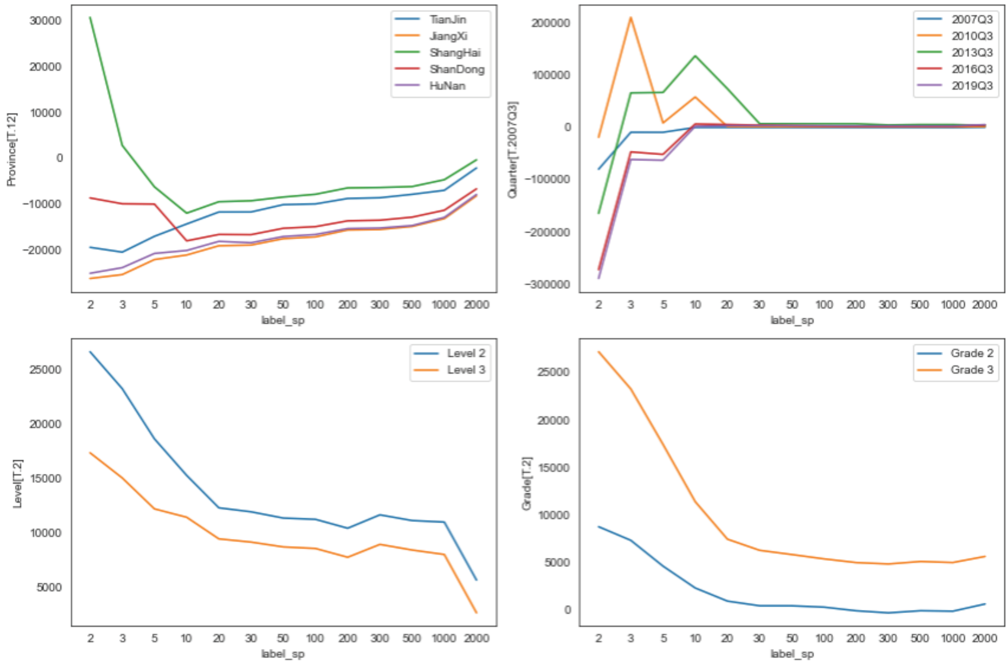

FIGURE A1. ESTIMATION OF COEFFICIENTS

Stable and reasonable results generate for estimations with model points larger than 30 samples. In our paper, we use model points larger than 50 samples for reliable results.

Proof of Variance Regression Theory

One could not directly use the regression on proportion to estimate the effect on total variance, if there is difference both on expectations and variances. So we propose this specially designed regression for this propose.

We have

(B1) $$X_i \sim \mathbb{E}[X_i] = \mu_1, \quad \mathrm{Var}[X_i] = \sigma_1^2, \forall i$$

and

(B2) $$Y_j \sim \mathbb{E}[Y_j] = \mu_2, \quad \mathrm{Var}[Y_j] = \sigma_2^2, \forall j,$$

say X for other surgeries and Y for robot ones for example. We have model points' result of variance, with N_1 cases of X and N_2 cases of Y in some unique model point. We know the variance is indeed evaluated as the following equation, although we could not get the detailed data.

(B3)
$$\mathrm{Var}[Z] = \frac{1}{N-1}\left[\sum_{i=1}^{N_1}\left(X_i - \frac{\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j}{N}\right) + \sum_{j=1}^{N_2}\left(Y_j - \frac{\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j}{N}\right)\right]$$
$$= \frac{1}{N-1}\left(\sum_{i=1}^{N_1} X_i^2 + \sum_{j=1}^{N_2} Y_j^2 - \frac{1}{N}(\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j)^2\right),$$

where $N = N_1 + N_2$.

Then we can get

(B4)
$$\mathbb{E}[\mathrm{Var}[Z]] = \frac{1}{N-1}\left[N_1(\mu_1^2+\sigma_1^2) + N_2(\mu_2^2+\sigma_2^2) - \frac{1}{N}\mathbb{E}[(\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j)^2]\right]$$
$$= \frac{1}{N-1}\left[N_1(\mu_1^2+\sigma_1^2) + N_2(\mu_2^2+\sigma_2^2) - \frac{1}{N}\left(N_1(\mu_1^2+\sigma_1^2) + N_2(\mu_2^2+\sigma_2^2)\right)\right]$$
$$+ \frac{1}{N-1}\left[\frac{1}{N}\left(N_1(N_1-1)\mu_1^2 + N_2(N_2-1)\mu_2^2 + 2N_1N_2\mu_1\mu_2\right)\right]$$
$$= \frac{N_1}{N}(\mu_1^2+\sigma_1^2) + \frac{N_2}{N}(\mu_2^2+\sigma_2^2) - \frac{N_1}{N}\frac{N_1-1}{N-1}\mu_1^2 - \frac{N_2}{N}\frac{N_2-1}{N-2}\mu_2^2 - 2\frac{N_1}{N}\frac{N_2}{N}\mu_1\mu_2.$$

Use $\frac{N_2}{N} = \lambda$ for simplification, and under the assumption that

(B5)
$$N_1 \ll N_2 \ll 1,$$

which is suitable for our case, we can get

(B6)
$$\frac{N_1}{N} = 1-\lambda,\ \frac{N_2-1}{N-1} \approx \lambda,\ \frac{N_1-1}{N-1} \approx 1-\lambda.$$

Then we can finally get

(B7)
$$\mathbb{E}[\mathrm{Var}[Z]] = [\sigma_2^2 - \sigma_1^2 + (\mu_2-\mu_1)^2]\lambda - (\mu_2-\mu_1)^2\lambda^2 + c$$
$$= (\sigma_2^2 - \sigma_1^2)\lambda + (\mu_2-\mu_1)^2[\lambda(1-\lambda)] + c$$

where c is independent with λ.

This means that we can regression $\mathbb{E}[\mathrm{Var}[Z]]$ with λ and λ(1 − λ) to get the estimation and test result of $\sigma_2^2 - \sigma_1^2$.

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Robot Adoption in Chinese Hospitals: Analysis Plan

By Kwanting Leung   Yuhang Pan*

We empirically examine the impact of the first-time using of medical robots on department level performance in China. Employing a robust analytical framework combining Two-Way Fixed-Effect (TWFE) and Event Study methodologies, we analyze daily department data spanning from Jan 2013 to Dec 2022. Our focus is on quantifying the shifts in ln total revenue following the first-time using of this advanced surgical technology.

Due to its unprecedent economic development and increasingly growing demands, China has become one of the fastest-growing markets for the surgical robotics developer. This short article briefly reviews the technology adoption of da Vinci surgical system (da Vinci RAS) in Chinese hospitals, especially at the hospital department level. As of 2022, da Vinci RAS was recognized as the largest provider of robotic-assisted surgical (RAS) technology training to be accredited, and nearly 7000 da Vinci RAS have been installed in more than 70 countries, with more than 10 million minimally invasive robotic surgical procedures performed (Xue et.al, 2021).

The da Vinci surgical system was first introduced in China in 2006, where it was adopted at Chinese PLA General Hospital. Over the period from 2006 to 2023, a total of 284 Chinese hospitals have implemented the da Vinci RAS system. This technology has then been utilized by approximately 2,300 surgeons among a diverse range of surgical procedures. These surgeons have performed over 180 kinds of procedures, with the highest volume observed in Urology at around 150 thousand procedures.

* Leung: Institute for Global Health and Development, Peking University (e-mail: kwanting@stu.pku.edu.cn); Pan (Corresponding Author): Institute for Global Health and Development, Peking University (e-mail: yhpan@pku.edu.cn).

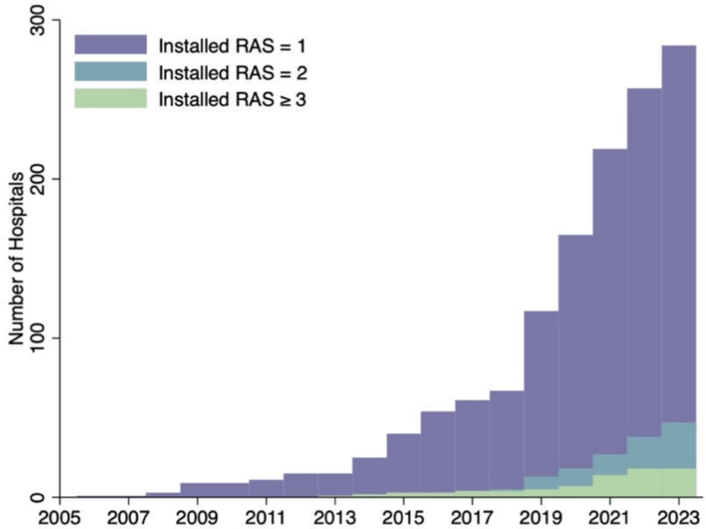

FIGURE 1. NUMBER OF CHINESE HOSPITALS WITH DA VINCI RAS

The adoption of da Vinci systems in Chinese hospitals encompasses four distinct models: DaVinci SP, DaVinci S, DaVinci Si, and DaVinci Xi. Our focus lies in examining the inaugural procedures performed using the da Vinci system within each category and across various hospital-department pairings. Figure 1 depicts the prevalence of da Vinci RAS systems across Chinese hospitals. Two notable periods of growth are observed. The first eye-catching growth occurred in 2014, where the number of hospitals with the da Vinci system nearly doubled. The second substantial growth took place around 2019, resulting in a rise from 69 hospitals to 119 hospitals with da Vinci systems.

Figure 2 illustrates the time lag between the installation of the da Vinci RAS system and its initial application across various surgical departments. The data suggest that General Surgery and Urology departments show a short interval from system installation to operation, possibly due to the high demands and immediate applicability of the da Vinci RAS for procedures common to these fields. The da Vinci RAS system is leveraged for an extensive array of procedures. For Urology, it can perform oncological management of prostate, kidney, and bladder cancers. In the sphere of General Surgery, the RAS system is for intricate removal of gastrointestinal malignancies, including gastric and colorectal cancers. Thoracic Surgery harnesses the advanced capabilities of the RAS for conditions like lung and esophageal cancers. For Gynecology, the da Vinci can be used to hysterectomies and managing gynecologic cancers. Building upon the classification initiated in Figure 2, the analysis extends to the level of hospital departments, incorporating additional specialties such as Pediatrics, Gastroenterology, Hepatobiliary Pancreatic, and Thyroid. As presented in Figure 3, only the Thyroid department exhibited a notable delay between the installation of RAS systems and their operational use, suggesting a latent phase of adoption for certain specialties.

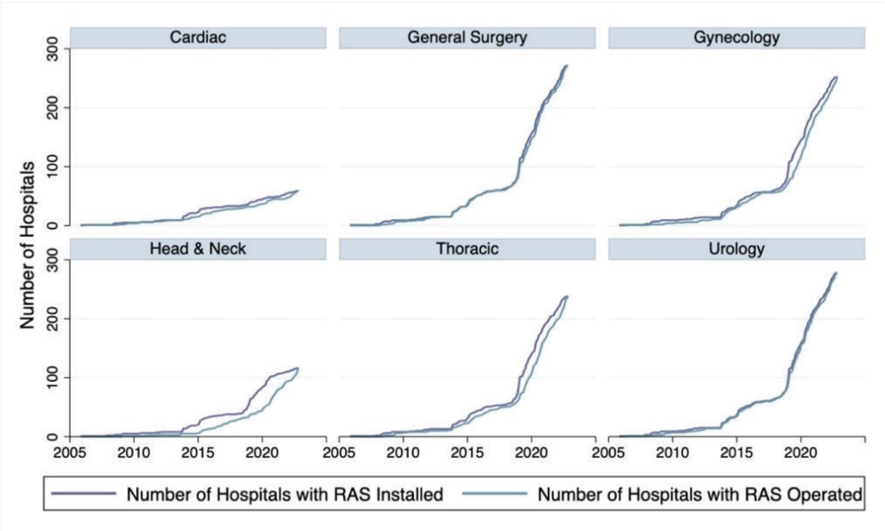

FIGURE 2. INSTALLATION AND OPERATION OF RAS BY CATEGORY

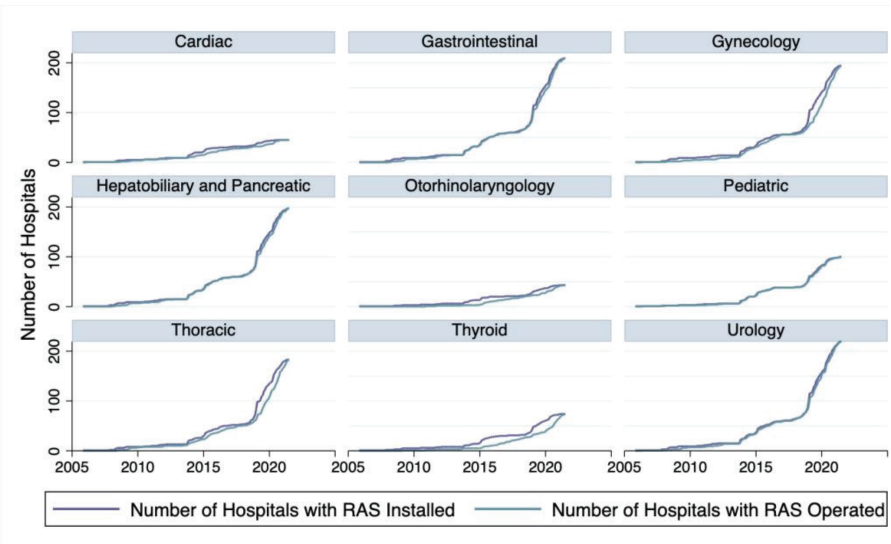

FIGURE 3. INSTALLATION AND OPERATION OF RAS BY HOSPITAL DEPARTMENTS

Data

The patient-level data, with each observation representing information for a single patient's entire stay, is aggregated at the department level daily. The data includes patient characteristics, spending, length of stay, and dates of admission and discharge.

Due to the lack of information on daily patient payments, we make three assumptions regarding how hospitals collect these payments. First, the hospital collects an equal amount daily; second, the hospital collects a lump sum on the date of admission; third, the hospital collects a lump sum on the date of discharge.

Assuming that patients spend the same amount of money each day during admission, daily revenue is calculated by using their total spending divided by the length of stay. Assuming that the hospital charges once at admission, total revenue on the admission date is calculated by adding up the total spending of each patient on the date of admission. Assuming that the hospital charges once at discharge, total revenue on the discharge date is calculated by adding up the total spending of each patient on the date of discharge.

The two-digit number Age Gender contains information about the patient's gender and age. Gender includes 1 for male, 2 for female, and 3 for unknown. Six age groups are assigned: 0-15, 16-30, 31-45, 46-60, 61-75, and above 76. Three types of patient characteristics are calculated: first, cumulative for all patients currently in the hospital; second, for patients who have just been admitted; third, for discharged patients.

Empirical Model

To test for parallel trends and study the dynamics of treatment effects of using the Da Vinci machine on hospital departments, we estimate an event-study version of the Two-Way Fixed-Effect model. Specifically, we estimate the following specification (Braghieri et al., 2022):

$$Y_{ijt} = \alpha_{ij} + \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

Our outcome variables Y_{ijt} is a mix of payment variables for hospital in department j at time t. Y_{ijt} includes daily revenue, total revenue for admission, total revenue for discharged, revenue from self-pay, service, operational, Nursing, other, pathological diagnosis, laboratory diagnostics, imaging, clinical diagnosis, non-surgical treatment, surgical treatment, rehabilitation.

The dummy variable D_{ijt} jointly represent the da Vinci first-time using event, define

s_i as the year when hospital i department j first install the da Vinci robotic system. We define $D_{ijt}^{-15} = 1 \text{ if } t - s_i \leq -15$ and 0 otherwise. In the baseline model we control fixed effects α_{ij} at the hospital level i department j and time fixed effect δ_t. Standard errors are clustered at hospital level; in future robustness checks, we will cluster on smaller category level.

For the next three models we run a different combination of fixed effects. In the second model we add a hospital-time effect to capture variance between hospital and time. Note that capturing hospital effect also indicate a location effect since hospital are not likely to move around. In the third model we add a department-time fixed effect to capture variance between department and time. In the last model we add in both fixed effects.

$$Y_{ijt} = \alpha_{ij} + \theta_i \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

$$Y_{ijt} = \alpha_{ij} + \eta_j \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

$$Y_{ijt} = \alpha_{ij} + \theta_i \times \delta_t + \eta_j \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

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Health Economics Study of Robots and Laparoscopy for Hepatocellular Carcinoma Resection

By XIAO LIANG HAIJING GUAN

JUNHAO ZHENG AND CHENYUE YANG*

Background: Compared to laparoscopic liver resection, robotic liver resection can reduce postoperative complication rates and hospital stay, and improve patients' postoperative quality of life. However, the costs of robotic liver resection are relatively high, and there is currently a lack of evidence from China on whether robotic liver resection for hepatocellular carcinoma is cost-effective. Objective: To explore the clinical value and medical costs of robotic liver resection compared to laparoscopic liver resection for hepatocellular carcinoma. Methods: We retrospectively collected data from patients with hepatocellular carcinoma who underwent minimally invasive liver resection by a single medical team at Sir Run Run Shaw Hospital of College of Medicine of Zhejiang University from January 2016 to July 2023. Patients were divided into the study group (robotic liver resection group) and the control group (laparoscopic liver resection group). After propensity score matching, we compared perioperative indicators and medical costs before and after matching and conducted subgroup analyses with surgical difficulty as a covariate to analyze the differences in perioperative outcomes and medical costs between the two surgical methods under different surgical difficulties. Results: A total of 277 patients were included in this study (175 in the laparoscopic liver resection group and 102 in the robotic liver resection group). After controlling for baseline characters using propensity score matching,

* Liang: Sir Run Run Shaw Hospital, Zhejiang University (email: 3190104362@zju.edu.cn); Guan: Beijing Tiantan Hospital, Capital Medical University; Zheng: Sir Run Run Shaw Hospital, Zhejiang University; Yang: Sir Run Run Shaw Hospital, Zhejiang University.

162 patients (81 in each group) were included for further analysis. The results showed that the robotic liver resection group had less intraoperative bleeding, fewer postoperative complications, a lower conversion to open surgery rate, and better surgical safety compared to the laparoscopic liver resection group. The robotic liver resection group had higher medical costs (¥82,885.3 vs. ¥58,643.8, $p<0.001$); however, the non-surgical costs of laparoscopic liver resection group is significantly higher costs higher than robotic liver resection group. The subgroup analysis indicates that there was no significant difference in costs between the two surgical methods in high-difficulty liver resections. Conclusion: For patients with hepatocellular carcinoma, robotic liver resection has better surgical safety and higher medical costs compared to laparoscopic liver resection. Simultaneously, robotic liver resection appears to be more cost-effective for patients with high surgical difficulty.

I. Background

Robotic liver resection (RLR), as a new technology, may offer better surgical safety compared to laparoscopic liver resection (LLR), though it tends to be more costly. Therefore, whether using robotic resection for the treatment of hepatocellular carcinoma (HCC) is economically effective remains to be evidenced due to the current lack of related proof.

Currently, there are few reports on the health economics of robotic liver resection both domestically and internationally. A meta-analysis in 2022, which included four relevant studies, showed that the cost of RLR (USD 20,205.92) is significantly higher than that of LLR (USD 15,789.75). Cost is a major factor restricting the implementation of RLR (Ciria et al., 2022). However, with the development of modern medicine, surgery aims not only to cure but also to improve the quality of life. In 2020, Mejia et al. reported on 214 liver resection patients and indicated that, despite the higher costs, RLR resulted in shorter hospital stays compared to LLR, making it a better choice for patients requiring minor liver resections (Mejia et al., 2020). Nonetheless, in 2016, Chinese researchers, based on data from 39 patients undergoing robotic and laparoscopic left lateral liver lobe resection, pointed out that RLR is more expensive than LLR for left lateral liver lobe resection, but there is no statistically significant difference in efficacy and safety (Yin et al., 2016). Therefore, whether RLR can improve quality of life and be cost-effective remains a debate.

The 2023 International Guidelines for Robotic Liver Resection experts pointed out that, compared to LLR, RLR has unique therapeutic value in liver-related diseases, and its cost-effectiveness merits further research (Liu et al., 2023). In disciplines such as urology and colorectal surgery, studies have suggested that robotic surgery is cost-effective or highlighted the cost reductions needed to improve the adoption rate of robots (Simianu et al., 2020; Song et al., 2022).

II. Methods

Conduct real-world research, retrospectively collecting data on inpatients diagnosed with HCC at Sir Run Run Shaw Hospital affiliated with Zhejiang University from January 2016 to July 2023. Patients were divided into RLR and LLR groups based on the type of surgery they underwent. On the basis of descriptive analysis, confounding factors were controlled through propensity score matching (PSM) to explore the net benefits of different treatment methods on treatment outcomes and medical costs, and to conduct an economic evaluation. Subgroup analyses were carried out to explore the robustness of the research results.

Continuous variables with a normal distribution are described as mean ± standard deviation, while those with a skewed distribution are described as median (interquartile range), and categorical variables are described as frequency and percentage. Age, BMI, AFP, INR, ALB, AST, TBIL, Child-Pugh classification, vascular invasion, difficulty of operation, and ASA classification were included as covariates in the model for fitting, and propensity scores were calculated for nearest neighbor matching. PSM analysis was conducted using SPSS version 25.0. Patients were divided into four subgroups based on IWATE surgical difficulty grading as “Low”, “Intermediate”, “Advanced”, and “Expert” for subgroup analysis. (Figure 1)

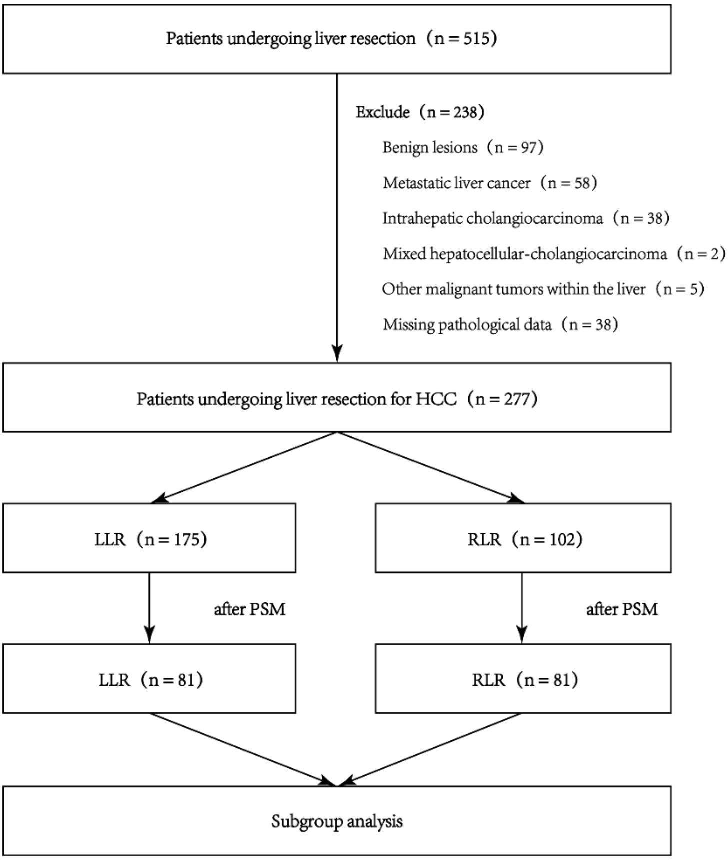

FIGURE 1. INCLUSION AND EXCLUSION CRITERIA AND FLOWCHART

III. Results

After applying the inclusion and exclusion criteria, a total of 277 patients were included in this study. They were divided into the LLR group (175 patients) and the RLR group (102 patients) based on the surgical method. After PSM, 81 patients in each group were further analyzed and compared.

A. baseline characteristics of the patients

Before PSM, the LLR group had significant differences compared to the RLR group in BMI, AFP, PLT, INR, ALB, AST, liver cirrhosis, Child-Pugh classification, portal hypertension, and IWATE surgical difficulty classification (all $p < 0.05$). There were no significant differences in the remaining indicators. After balancing the baseline characteristics through PSM, 162 patients (81 in the LLR group and 81 in the RLR group) were included for further analysis, and there were no significant differences in baseline characteristics between the LLR and RLR groups (Table 1).

TABLE1 — BASELINE CHARACTERISTICS OF THE LLR AND RLR GROUPS BEFORE AND AFTER PSM

Baseline characteristics	before PSM (n=277)			after PSM (n=162)		
	LLR (n = 175)	RLR (n = 102)	p value	LLR (n=81)	RLR (n=81)	p value
Age (SD), year	58.7±12.2	60.6±11.5	0.056	62.9±11.6	61.4±11.2	0.390
BMI (SD), kg/m2	23.2±2.8	24.1±3.6	**0.021**	23.6±3.0	24.0±3.3	0.406
Gender, n(%)		0.309		0.678		
Female	23(13.1)	18(17.6)		13(16.0)	15(18.5)	
Male	152 (86.9)	84(82.4)		68(84.0)	66(81.5)	
Tumor size (IQR), cm	2.6 (1.8-4.3)	3.0 (2.2-4.5)	0.163	2.5(1.8-4.4)	3.2(2.2-4.7)	0.082
AFP (IQR), ng/mL	17.2 (3.4-277.5)	6.6 (2.5-110.2)	**0.048**	10.2(3.2-139.8)	6.6(2.6-110.2)	0.403
PLT (IQR), ×109/L	126.0 (89.0-172.0)	143.5 (111.0-191.2)	**0.005**	124.0(95.5-170.0)	138.0(108.0-190.0)	0.050
PT (IQR), s	13.8 (13.1-14.6)	13.5 (13.0-14.2)	0.068	13.5(12.9-14.1)	13.5(13.1-14.2)	0.437
INR (IQR)	1.0 (1.0-1.2)	1.0 (1.0-1.1)	**＜0.001**	1.0(1.0-1.1)	1.0(1.0-1.0)	0.307
TBIL (IQR), mmol/L	14.9 (11.1-21.1)	14.8 (11.2-19.1)	0.728	14.2(9.6-21.3)	15.3(11.4-18.8)	0.589
ALB (SD), g/L	39.4±4.8	40.9±4..5	**0.013**	40.2±4.4	40.0±3.6	0.794
AST (IQR), U/L	27.0 (18.0-40.0)	30.0 (23.8-38.0)	**0.026**	25.0(17.0-41.0)	29.0(23.5-38.0)	0.100
ALT (IQR), U/L	29.0 (22.0-39.0)	27.0 (19.0-42.3)	0.364	29.0(21.5-39.0)	27.0(19.0-41.5)	0.559
Number of tumors, n(%)			0.819			0.658
Single	151(86.3)	87(85.3)		68(84.0)	70(86.4)	
Multiple	24(13.7)	15(14.7)		13(16.0)	11(13.6)	

Liver cirrhosis, n(%)	96(54.8)	41(40.2)	**0.016**	38(46.9)	32(39.5)	0.341
Child-Pugh classification, n(%)			**0.049**			1
A	159(90.9)	99(93.1)		78(96.3)	78(96.3)	
B or C	16(9.1)	3(2.9)		3(3.7)	3(3.7)	
Portal hypertension, n(%)	11(6.2)	0(0)	**0.028**	5(6.2)	0(0.0)	0.074
History of liver resection, n(%)	22(12.6)	14(13.7)	0.844	12(14.8)	12(14.8)	1
History of laparotomy, n(%)	56(32.0)	35(34.3)	0.693	27(33.3)	31(38.3)	0.512
History of neoadjuvant therapy, n(%)	25(14.2)	10(9.8)	0.279	6(7.4)	9(11.1)	0.416
IWATE tumor location (IQR)	5.0(3.0-5.0)	5.0(3.0-5.0)	0.949	5.0(3.0-5.0)	5.0(3.0-5.0)	0.576
IWATE tumor size (IQR)	0.0(0.0-1.0)	1.0(0.0-1.0)	0.179	0.0(0.0-1.0)	1.0(0.0-1.0)	0.140
IWATE the extent of liver resection (IQR)	0.0(0.0-4.0)	3.0(0.0-4.0)	0.195	0.0(0.0-4.0)	0.0(0.0-4.0)	0.946
IWATE proximity to a major vessel (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	0.541	0.0(0.0-0.0)	0.0(0.0-0.0)	0.135
IWATE liver function (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	**0.049**	0.0(0.0-0.0)	0.0(0.0-0.0)	0.988
IWATE HALS/ hybrid (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	1	0.0(0.0-0.0)	0.0(0.0-0.0)	1
IWATE total score (IQR)	6.0(5.0-9.0)	7.0(5.0-9.0)	0.176	6.0(4.0-9.0)	6.0(4.5-9.0)	0.57
IWATE difficulty level, n(%)			**0.003**			0.916
Low	27(15.4)	19(18.6)		16(19.8)	16(19.8）	
Intermediate	82(46.9)	28(27.5)		29(35.8)	25(30.9)	
Advanced	31(17.7)	35(34.3)		21(25.9)	23(28.4)	
Expert	35(20.0)	20(19.6)		15(18.5)	17(21.0)	

ASA classification, n(%)			0.206			0.692
I	8(4.6)	1(1.0)		2(2.5)	1(1.2)	
II	155(88.6)	94(92.2)		72(88.9)	75(92.6)	
III	12(6.9)	7(6.9)		7(8.6)	5(6.2)	
IV~VI	0(0.0)	0(0.0)		0(0.0)	0(0.0)	
Type of medical insurance, n(%)			0.074			0.070
Basic medical insurance for urban workers	164(93.7)	101(99.0)		74(91.4)	80(98.8)	
The others	11(6.3)	1(1.0)		7(8.6)	1(1.2)	
Place of residence, n(%)			0.803			0.727
Local	47(26.9)	26(25.5)		24(29.6)	22(27.2)	
Nonlocal	128(73.1)	76(74.5)		57(70.4)	59(72.8)	

B. clinical outcomes of the patients

Before PSM, the LLR group had significantly higher intraoperative blood loss (100.0 ml vs. 50.0 ml, $p < 0.001$), intraoperative transfusion rate (33 [18.8%] vs. 10 [9.8%], $p = 0.045$), postoperative complication rate (35 [20.0%] vs. 7 [6.8%], $p = 0.003$), conversion to open surgery rate (20 [11.4%] vs. 0 [0.0%], $p = 0.001$), postoperative hospital stay (6.0 days vs. 5.0 days, $p = 0.001$), and total hospital stay (13.0 days vs. 9.5 days, $p = 0.001$) compared to the RLR group, with no significant differences in the remaining indicators (all $p \geq 0.05$).

After balancing baseline characteristics through PSM, a total of 162 patients (81 in the LLR group and 81 in the RLR group) were included in the study. The LLR group still had significantly higher intraoperative blood loss (100.0 ml vs. 50.0 ml, $p = 0.002$), postoperative complication rate (16 [19.8%] vs. 7 [8.6%], $p = 0.043$), postoperative hospital stay (6.0 days vs. 5.0 days, $p = 0.005$), and total hospital stay (12.0 days vs. 10.0 days, $p < 0.001$) compared to the RLR group, with no significant differences in the remaining indicators (all $p \geq 0.05$) (Table 2).

TABLE2 — OUTCOMES OF THE LLR AND RLR GROUPS BEFORE AND AFTER PSM

Outcomes	before PSM (n=277)	after PSM (n=162)				
	LLR (n = 175)	RLR (n = 102)	p value	LLR (n=81)	RLR (n=81)	p value
Operation time (IQR), min	168.0 (125.0-240.0)	165.0 (110.0-220.0)	0.263	180.0(120.0-250.0)	160.0(107.5-220.0)	0.134
Status of surgical margins, n(%)			0.464			1
R0	172(98.3)	98(96.1)		80(98.8)	79(97.5)	
R1 or R2	3(1.7)	4(3.9)		1(1.2)	2(2.5)	
Intraoperative blood loss (IQR), mL	100.0(50.0-400.0)	50.0 (50.0-112.5)	**<0.001**	100.0(50.0-275.0)	50.0(50.0-125.0)	**0.002**
Intraoperative blood transfusion, n(%)	33(18.8)	10(9.8)	**0.045**	12(14.8)	8(9.8)	0.339
Postoperative complications, n(%)	35(20.0)	7(6.8)	**0.003**	16(19.8)	7(8.6)	**0.043**
ClavienDindo classfication, n(%)			**0.006**			0.062
No	140(80.0)	95(93.1)		65(80.2)	74(91.4)	
I or II	25(14.3)	6(5.9)		10(12.3)	6(7.4)	
III or IV or V	10(5.7)	1(1.0)		6(7.4)	1(1.2)	
Conversion to open surgery during operation, n(%)	20(11.4)	0(0.0)	**0.001**	5(6.2)	0(0.0)	0.069
Reoperation during hospitalization, n(%)	0(0.0)	0(0.0)	/	0(0.0)	0(0.0)	/
Perioperative mortality, n(%)	0(0.0)	0(0.0)	/	0(0.0)	0(0.0)	/
Postoperative hospital stay (IQR), day	6.0(4.0-7.0)	5.0(3.8-6.2)	**0.001**	6.0(4.0-7.0)	5.0(3.5-6.0)	**0.005**
Readmission within 30 days postoperatively due to complications, n(%)	3(1.7)	1(1.0)	1	2(2.5)	1(1.2)	1

Total hospital stay (IQR), day	13.0(10.0-16.0)	9.5(7.0-13.0)	**<0.001**	12.0(10.0-16.0)	10.0(8.0-12.0)	**<0.001**
Total hospitalization cost (IQR), ¥	57150.9 (44313.0-76302.3)	81432.5 (74644.9-90934.2)	**<0.001**	58643.8 (45171.2-75899.8)	82885.3 (75617.3-90501.2)	**<0.001**
Out-of-pocket cost (IQR), ¥	16875.0 (9911.2-23013.9)	50333.4 (46274.6-57632.8)	**<0.001**	15972.7 (8999.7-23056.8)	50706.2 (46796.8-57640.6)	**<0.001**
Drug cost (IQR), ¥	15879.4 (11219.3-23459.2)	9955.6 (7687.4-14007.0)	**<0.001**	16517.6 (11994.0-24028.5)	9975.0(7861.8-14117.4)	**<0.001**
Surgical cost (IQR), ¥	6916.0 (6302.0-7834.3)	43424.9 (42808.6-43897.9)	**<0.001**	6616.0 (6165.0-7481.4)	43424.9(42754.1-43994.5)	**<0.001**
Examination cost (IQR), ¥	1260.0(930.0-2153.0)	1160.0(673.0-1752.8)	**0.010**	1365.0 (1075.0-2340.0)	1115.0(659.0-1602.0)	**0.001**
Nursing cost (IQR), ¥	1164.0(879.0-1521.0)	989.6(784.0-1291.3)	**0.004**	1174.0 (832.5-1555.0)	988.6(779.9-1255.1)	**0.012**
Consumables cost (IQR), ¥	21113.4 (15486.0-31411.4)	12094.4 (10839.8-18034.8)	**<0.001**	21565.4 (15899.2-32842.0)	12069.4(10898.8-19094.2)	**<0.001**
Other cost (IQR), ¥	386.0(182.0-722.0)	486.5(246.5-851.8)	0.054	341.0(182.0-683.4)	535.0(276.5-863.0)	**0.004**

C. cost outcomes of the patients

Before PSM, the LLR group had significantly lower total hospitalization cost (57,150.9 ¥ vs. 81,432.5¥, $p < 0.001$), out-of-pocket cost (16,875.0 ¥ vs. 50,333.4 ¥, $p < 0.001$), and surgical cost (6,916.0 ¥ vs. 43,424.9 ¥, $p < 0.001$) compared to the RLR group. However, the LLR group had significantly higher medication cost (15,879.4 ¥ vs. 9,955.6 ¥, $p < 0.001$), examination cost (1,260.0 ¥ vs. 1,160.0 ¥, $p = 0.010$), nursing cost (1,164.0 ¥ vs. 989.6 ¥, $p = 0.001$), and consumable cost (21,113.4 ¥ vs. 12,094.4 ¥, $p < 0.001$).

After balancing baseline characteristics through PSM, a total of 162 patients (81 in the LLR group and 81 in the RLR group) were included in the study. The LLR group still had significantly lower total total hospitalization cost (58,643.8 ¥ vs. 82,885.3 ¥, $p < 0.001$), out-of-pocket expense (15,972.7 ¥ vs. 50,706.2 ¥, $p < 0.001$), surgical cost (6,616.0 ¥ vs. 43,424.9 ¥, $p < 0.001$), and other cost (341.0 ¥ vs. 535.0 ¥, $p = 0.004$) compared to the RLR group. However, the LLR group had significantly higher medication cost (16,517.6 ¥ vs. 9,975.0 ¥, $p < 0.001$), examination cost (1,365.0 ¥ vs. 1,115.0 ¥, $p = 0.010$), nursing cost (1,174.0 ¥ vs. 988.6 ¥, $p = 0.001$), and consumable cost (21,565.4 ¥ vs. 12,069.4 ¥, $p < 0.001$) compared to the RLR group (Table 2).

D. outcomes of subgroup analysis

Subgroup analysis using the IWATE surgical difficulty classification as a covariate showed that in the "Low," "Intermediate," and "Advanced" subgroups, the total hospitalization cost for the LLR group were significantly lower than those for the RLR group (Low: 46,125.7 ¥ vs. 76,647.9 ¥, $p < 0.001$; Intermediate: 52,692.8 ¥ vs. 76,428.8 ¥, $p = 0.003$; Advanced: 67,548.3 ¥ vs. 84,725.0 ¥, $p = 0.001$). However, in the "Expert" group, there was no significant difference in total hospitalization cost between the LLR and RLR groups (75,709.0 ¥ vs. 88,292.6 ¥, $p = 0.325$) (Figure 2).

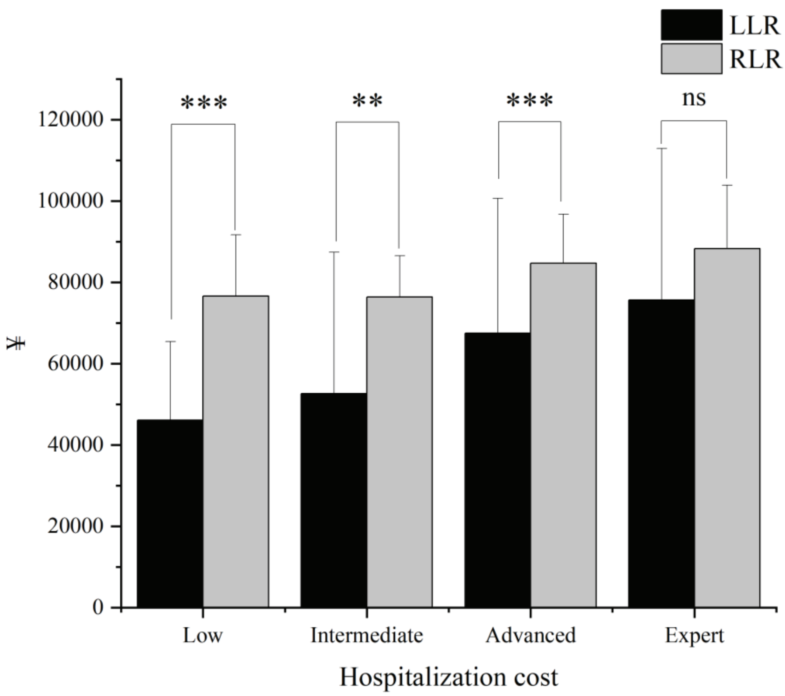

FIGURE2. SUBGROUP ANALYSIS OF TOTAL HOSPITALIZATION COST BASED ON SURGICAL DIFFICULTY

***: p＜0.001

**: p＜0.005

ns: p＞0.05

IV. Conclusion

For patients with hepatocellular carcinoma, robotic liver resection has better surgical safety and higher medical costs compared to laparoscopic liver resection. Simultaneously, robotic liver resection appears to be more cost-effective for patients with high surgical difficulty.

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Clinical Efficacy and Health Economic Evaluation of Robot-Assisted Hip and Knee Joint Replacement Based on Real-World Data: Progress Report

By Beini Lyu Yang Song AND Yixin Zhou*

Knee replacement is the most effective treatment for end-stage knee arthritis. Compared to traditional surgical procedures, robot-assisted knee replacement offers advantages such as high precision in positioning, high consistency, reduced postoperative pain, and early functional recovery, potentially improving patient prognosis. However, the costs associated with robot-assisted knee replacement are higher than traditional surgery, necessitating a systematic health technology assessment of its value. After preliminary data cleaning, this study included 281 patients who underwent robot-assisted total knee replacement (TKA). After matching on age, gender, date of surgery, and side of surgery, 281 patients who underwent non-robotic-assisted TKA were included. Patients in both groups were similar in age, body mass index and baseline comorbidity burden. Compared with patients with non-robot-assisted TKA, those with robot-assisted TKA had longer operation time (97.56 minutes vs. 79.05 minutes, $p<0.001$), but less intraoperative drainage volume (1.42% vs. 9.25% intraoperative drainage volume >0, $p<0.001$). The study will continue to follow up and collect data on patients' satisfaction, quality of life, and medical expenditures to further evaluate the clinical prognosis and economics of the two surgeries.

*Lyu: Institute for Global Health and Development, Peking University (email: blyu@pku.edu.cn); Song & Zhou: Beijing Jishuitan Hospital, Capital Medical University.

I.Introduction

With population aging in China, the burden of knee arthritis is steadily increasing. By the end of 2019, approximately 120 million people in China were estimated to have knee arthritis (Long et al. 2020). Joint replacement is the most effective treatment for end-stage knee arthritis (Kim et al. 2020). Traditional knee replacement surgery faces problems such as insufficient surgical accuracy, lack of digital intelligent tools, and high revision failure rate. Robot-assisted knee replacement has attracted widespread attention due to its advantages such as high positioning accuracy and consistency, reduced postoperative pain, and early functional recovery (Yang et al. 2024; Subramanian et al. 2019). Early research shows that compared with traditional surgery, robot-assisted knee replacement has the advantages of accurate osteotomy, personalized prosthesis placement, better protection of soft tissue around the knee joint, and reduced use of analgesic drugs. However, there are shortcomings such as prolonged surgical time (Shao et al. 2023; Subramanian et al. 2019; Yang et al. 2024). Although robot-assisted knee replacement is expected to improve patient outcomes, its medical costs are much higher than traditional surgery, which poses a challenge to balance limited medical resources and improve patient health. The policy for basic medical insurance for orthopaedic surgical robots is evolving. For robot-assisted knee replacement, there is currently a lack of systematic economic evaluation in Chinese population, which restricts the formulation and adjustment of key policies such as medical insurance payment.

Using data from real-world patients undergoing total knee replacement surgery (TKA), the study will compare the clinical outcomes, quality of life, and costs of robotic-assisted and non-robotic knee replacement, aiming to exam the cost-effectiveness of robotic-assisted knee replacements.

II. Methods

The study is a retrospective cohort study. The study includes patients aged 21-80 years old, with osteoarthritis or joint deformity, underwent robot-assisted or traditional total TKA at the Jishuitan Hospital Orthopedics Department from July 2020 to March 2024, and with ASA scores of I-II. Patients who are pregnant, undergoing knee joint revision, have severe flexion deformity (>20°), severe varus or valgus deformity (>20°), rheumatoid arthritis, or infectious arthritis are excluded.

The study extracted patient's demographic characteristics (age and sex), surgical indications, comorbidities (cerebrocardiovascular disease and diabetes), surgical duration, intraoperative bleeding and drainage volume, postoperative complications and other information from electronic medical records. Follow-up and data collection are ongoing regarding radiographic assessment (such as hip-knee-ankle angle, distal femoral lateral angle, and proximal medial tibial angle), clinical outcomes such as prosthetic revision and prosthetic loosening, quality of life, and healthcare expenditures.

Statistical analysis: Continuous variables are presented as mean (standard deviation) and categorical variables are presented as frequency (percentage). The study used t-test or chi-square test to compare the differences in patient characteristics between the two groups of robot-assisted and traditional knee replacements, with two-sided $p<0.05$ defined as a statistically significant difference.

III.Preliminary results

After preliminary data cleaning, the study included 281 patients who received robotic assisted TKA. After matching 1:1 on age (±3 years), sex, date of surgery (±60 days), and side of surgery, we included 281 patients who underwent non-robotic assisted TKA. After matching, the age and sex distributions of patients in the robot-assisted and non-robotic-assisted groups were almost identical (age: 67.33 [6.86] years in the robot-assisted group was and 67.38 [6.51] years in the non-robotic surgery group, Table). The preoperative knee disease diagnosis of all patients was osteoarthritis, and 52.67% of the patients had left joint replacement. There were no significant differences in body mass index (BMI), cerebrocardiovascular diseases, diabetes, or American Society of Anesthesiology (ASA) scores between the two groups ($p>0.05$ for all).

We observed significant differences in surgery-related indicators between the two groups. The operation time of the robotic assisted group was 97.56 (21.25) minutes, while that of the non-robotic group was 79.05 (19.54) minutes. The operation time of the robotic surgery group was significantly longer than that of the non-robotic group ($p<0.001$). In terms of the amount of intraoperative drainage, most patients had no intraoperative drainage, and the study used whether there was drainage as the outcome indicator. We found the proportion of patients with intraoperative drainage was significantly lower for robotic surgery group than that in the non-robotic group (1.42% VS. 9.25, $p<0.001$). There was no significant difference in intraoperative blood loss between the two groups of patients.

IV. Brief discussion

After matching key characteristics, there were no significant differences in baseline characteristics between patients who underwent robot-assisted TKA and those who underwent non-robotic TKA. Regarding surgery-related indicators, robot-assisted surgeries took longer but had less intraoperative drainage. The lower drainage associated with robot-assisted TKA is consistent with the literature. Research suggests that robot-assisted TKA better protects the medial and lateral collateral ligaments and preserves the tibial attachment of the posterior cruciate ligament than traditional surgery (Hampp, Sodhi, et al., 2019). A prospective cohort study indicated that robot-assisted TKA could reduce iatrogenic soft tissue capsule damage (Kayani et al., 2018). Siebert et al. (2002) retrospectively analyzed 120 patients, with 70 of whom underwent robot-assisted TKA, and found that soft tissue swelling was less after robot-assisted TKA.

Furthermore, as a technique that enhances the accuracy of bone cutting, robot-assisted knee arthroplasty can effectively reduce alignment abnormalities (Hampp, Chughtai, et al., 2019). The protection of soft tissues in robot-assisted surgery facilitates better restoration of postoperative lower limb alignment, maintenance of the joint line, balancing of flexion and extension gaps, and preservation of a normal Q angle (Shao et al., 2023). Accurate bone cutting may lower the rate of osteotomy failures, minimize unnecessary soft tissue damage, and result in lower pain levels, reduced analgesic needs, and fewer physical therapy sessions compared to traditional surgery (Hampp, Chughtai, et al., 2019).

The study will continue data collection to clarify the impact of robot-assisted TKA on clinical outcomes, quality of life, and medical costs and to better evaluate the economic value of robot-assisted TKA.

TABLE. CHARACTERISTICS OF PATIENTS IN ROBOT ASSISTED TKA AND NON-ROBOT-ASSISTED TKA GROUPS.

	Robot-assisted (n=281)	Non-robot-assisted（n=281)	P value
Age, year	67.33 (6.86)	67.38 (6.51)	0.38
Sex, female	230 (81.85)	230 (81.85)	1.0
Osteoarthritis	281 (100)	281 (100)	1.0
Year of surgery, after 2022	147 (52.31)	142 (50.53)	0.74
Side of surgery, left	148 (52.67)	148 (52.67)	1.0
BMI, kg/m2	28.94 (10.93)	26.68 (3.86)	0.068
Cerebrocardiovascular disease	156 （55.52）	136 48.40)	0.11
Diabetes	50 (17.79)	48 (17.08)	0.91

ASA, class 1	93 (33.10)	106 (37.72)	0.33
Surgery duration，min	97.56 (21.25)	79.05 (19.54)	<0.001
Blood loss during operation，mL	50.14 (37.79)	46.26 (27.55)	0.17
intraoperative drainage >0 mL	4 (1.42)	26 (9.25)	<0.001

BMI， body mass index; ASA, American Society of Anesthesiologists.

Continuous variables were presented as mean (standard deviation) and categorical variables were presented as number (percentage).

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Subjective attitudes in the adoption choices of surgical robot technology

By Ting Chen Lu Ao Yuhang Pan

Chufan ZhouAND Jie Pan*

Attitude is an individual's psychological tendency toward a certain type of social phenomenon, comprising cognitive, emotional, and behavioral components. Although the formation of subjective attitudes is always based on existing objective evidence and actual experience, in society and the market, subjective attitudes are often influenced by a variety of social factors and social network interactions, especially in the healthcare market. In this short essay, we will use a literature review and interview analysis to briefly describe, from multiple perspectives, the subjective attitudes, and their causes towards the adoption of health technology, exemplified by surgical robots, in both the international and Chinese healthcare markets.

Surgical robotics is an acknowledged popular and promising technology with high cost and unknown cost-efficiency (Abrishami, Boer, and Horstman 2020; Lanfranco et al. 2004). Over 7,700 robotic surgical systems had been clinically used worldwide at the end of 2022(Intuitive Surgical 2023; Peng et al. 2023), and more than 14 million procedures have been performed in the past nearly three decades(Intuitive Surgical 2023), mainly in the departments of general surgery, urology, gynecology, and cardiothoracic surgery(Anderson et al. 2012). Generally, the clinical benefits of robotic surgery is feasible, including a comfortable operating environment for surgery, high-resolution three-dimensional vision in all-round view, elimination of hand tremors, and the achievement of

*Chen: West China School of Public Health, Sichuan University/The Fourth Hospital of West China, Sichuan University(email:HEOA Group chenting_723@163.com);Ao:West China School of Public Health, Sichuan University/The Fourth Hospital of West China, Sichuan University(email: HEOA Group 2352480696@qq.com);Pan: Institute for Global Health and Development, Peking University (email: yhpan@pku.edu.cn);Zhou:West China School of Public Health, Sichuan University/The Fourth Hospital of West China, Sichuan University(email:HEOA Group 2023224040041@stu.scu.edu.cn); Pan:West China School of Public Health, Sichuan University/The Fourth Hospital of West China, Sichuan University(email:HEOA Group panjie.jay@scu.edu.cn)

precise operation performed as envisioned by the surgeon(Lanfranco et al. 2004), resulting in some clinical benefits, which were reported widely those years, such as lower surgical complications, a shorter length of stay in hospital, and better and faster postoperative functional recovery(Song et al. 2022). However, there still was controversial of the evidence on the costs and benefits of robotics versus traditional technologies, also those benefits were varied by different surgical site, surgical volume, and the proficiency of the surgeon, which all might be considered by who deciding whether to purchase the technology. (Abrishami, Boer, and Horstman 2020) pointed that over two decades of rapid dissemination of da Vinci surgery was accompanied by a growing body of research, but the results of these studies are inconclusive and cannot guide the decisions on the acquisition, procurement, and large-scale provision of robotic surgery.

Rational, evidence-based thinking is a necessary process, but a growing body of evidence seemingly all have pointed to a conclusion that health technology adoption may be more of a matter of judgment. (Randell et al. 2019) emphasized that not only the technical limitation, social and psychological factors were important clinically obstructive factor influencing the adoption of this new technology by medical professionals. Public acceptance towards the development of new (robotic) technologies is believed to be one of the most crucial factor, as drive innovation and investment in these advancements (Fabian Dekker, Anna Salomons, and Jeroen van der Waal 2017). However, research reported that journalists believed much of the public's interests in a health innovation was came from its technical mechanism of action or how the new thing works rather than the clinical effects it works (Abrishami, Boer, and Horstman 2020).

A study of Europe explored people perception of robots in 2007, medicine and surgery is one of the most frequent words associated with the term “robot” in the popular mind, but only less than 5% saw positive aspects in the development of robots for medicine and surgery(Ray, Mondada, and Siegwart 2008). However, the perceptions and attitudes towards contemporary robots in different cultures exhibited substantial variances, cultural differences are found by a following Japanese study who can see robots in medicine(80%) more than Europeans (Haring et al. 2014). Furthermore, for the famous Da Vinci surgical robot, the name will give the public a high-end impression: a robot; the novelty of the technology; The da Vinci robot has been enthusiastically received as a ‘symbol’ of providing advanced care(Abrishami, Boer, and Horstman 2020).

In general, in the hospital administrators’ perspective, the subjective attitude towards technology adoption decision-making can be divided into two aspects: hospital support and gain of social benefits. The hospital support might be divided into two aspects. One is the material and management cost: providing adequate funding, time for study, space for the placement and operation of new technologies and staffing(Randell et al. 2019). Some scholars believe that the diffusion of robotic surgery has been slow, mainly because of the high capital and maintenance costs(Soomro et al. 2020). The other one is the cultural: there needs to be an open-minded culture that encourages innovation and tolerates disruption of the previous practice(Randell et al. 2019), furthermore, whether the adoption of innovation were coherence with organizational values and mission was also a key factor(Compagni, Mele, and Ravasi 2015). Gain of social benefits means searching for organizational visibility, building reputation for technological leadership, and using technology as a marketing tool(Compagni, Mele, and Ravasi 2015). A lot of the time, surgical robots have been seemed as a frequent focus of hospital advertising, and used as a signal of quality by patients (Schwartz and Woloshin 2019; Sheetz, Claflin, and Dimick 2020). Competition is a key word of the social benefit. In traditional markets, many organizations are interested in making themselves be seen as“cutting-edge” with the most advanced and newest technological equipment. like most innovative technologies, “Acquiring a surgical robot is in essence the entry fee into marketing an institution’s surgical specialties as the most advanced”(Lanfranco et al. 2004). Regional competition has been identified as a key determinant of hospital adoption of robotics(Barbash et al. 2014; Wright et al. 2016). However, a new study in USA find when the competitors have adopted robotic surgery system, some organizations that serve more difficult customer might choose to defer the investment in order to differentiate and focus elsewhere (Sundaresan, Boysen, and Nerkar 2023). However, the degree of competition to which an organization is subjected is difficult to assess objectively, and it is mainly judged by the subjective feelings of management decision makers.

For the surgeons’ perspective, the subjective attitude might be affected by: Technical benefits; Pressure from the organization and patients; Career development and preference. Although, results on the benefits of treatment effects and economic returns were inconsistent, robotic surgery systems do offer direct advantages to surgeons in the surgical process. A study comparing musculoskeletal ergonomic parameters of open, laparoscopic and robotic prostatectomy, reported that 50% and 56% of surgeons after open and laparoscopic approach would reported a neck and/or back pain, but the number just 23% in surgeons operating with robotic assisted(Bagrodia and Raman 2009). Learning might be a real consideration of the surgeons. A study reported that the average urologist could adopt the robotic prostatectomy with greater ease than the laparoscopic approach, the number of cases to achieve competency is estimated to be between 200–750 cases for the traditional laparoscopic surgery while the learning curve for robotic surgrey to bring operative times below 4 hours was about just 40 cases(Shah et al. 2021). However, there were still some obstacle characteristics of this technology for surgeons. For example, robot-assisted surgery has been considered having longer operating times for many procedure types, which may influence the efficiency of the surgeons with a busy schedule(Turchetti et al. 2012). Some surgeons described the feeling of "pressure" from higher management to "offer" robotic surgery for surgical procedures that "had not been thought about before."(Abrishami, Boer, and Horstman 2020). In addition, for institutions already had this equipment, increasing the volume of procedures helps to reduce the average cost of the procedure, this encouragement will intensify(Shah et al. 2021). Moreover, some "pressure" also came from the patients, some scholars point out that differences in patients' preferences can be an important source of variation in the adoption of robotic surgery(Miraldo et al. 2019). Some surgeons reflected that when the results of patients with da Vinci procedures were good, they often attributed the results to the method of surgery, but if the results turned out less satisfactory, the results were often attributed to the experience of the surgeon who has not mastered the robot well(Abrishami, Boer, and Horstman 2020).

There are research finding that the implementation of robot-assisted surgery has largely been surgeon led. Also, these innovations are usually introduced into surgical practice through informal processes with an absence of quality control efforts, and risk assessment(Randell et al. 2019). Search for social gains or career development might be a major driver of adoption for surgeons: opportunity to gain prominence and professional growth(Compagni, Mele, and Ravasi 2015). Moreover, research-related affordances were considered commonly, surgeons have a stake in conducting and publishing research on the robot(Abrishami, Boer, and Horstman 2014). However, in addition to these subjective factors, some constraints also occur in practice. For instance, the opportunities for learning this new technology are different within one department, studies point that more senior residents were involved in robotic cases compared with junior residents(-Farivar, Flannagan, and Leitman 2015), this may be due to the limited access to learning and training in the early days of technology introduction.

Summary and Further Plan

In this short essay, we briefly described the important role of the subjective attitudes of various stakeholders in the decision-making process of adopting surgical robots, as well as the possible reasons for the formation of these attitudes. However, the attitudes and perceptions of various stakeholders actually influence and constrain each other, and they vary in different healthcare markets. This study will conduct further research, interviews, and analysis to clarify the current situation and characteristics, major conflicts, and extended issues within the Chinese healthcare system.

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AI And Career Barriers in Surgery Departments: Analysis Plan

By Yuhang Pan Junjian Yi Qingyuan Zhou *

The study examines the impact of surgical robot adoption on the gender composition in surgical departments. In this article, we summarize data sources, the baseline model, robustness checks, heterogeneity analysis and methods for testing potential mechanisms.

I.Data

In order to examine the effects of the introduction of da Vinci surgical robots on gender ratios in different departments, we use three data sources. The first data source specifies months in which da Vinci robots are installed and first used in a procedure at 284 Chinese hospitals from 2006 to 2023. The second data source documents every surgery that is performed using da Vinci surgical robots. It contains detailed information such as the surgeon, the location and time of the procedure. From 2007 to 2022, we observe 314,138 da Vinci procedures conducted by 282 female surgeons and 2,349 male surgeons. The third data source consists of front pages of medical records from 498 tier-3, grade-A hospitals across China, among which 79 hospitals have introduced surgical robots while 419 hospitals have not.

In the front pages, we can observe names of four physicians — the department head, the chief, the attending, and the resident — that are in charge of the patient. This enables us to ascertain the physicians' professional titles and predict their genders based on the names. We then utilize the "ngender" package from github to predict gender, achieving an accuracy rate of approximately 82%. Additionally, we employ other machine learning methods to predict gender as a part of robustness checks.

* Authors contribute equally and are ranked in alphabetical order. Pan: Institute for Global Health and Development, Peking University (email: yhpan@pku.edu.cn); Yi: National School of Development and Institute for Global Health and Development, Peking University (email: junjian@nsd.pku.edu.cn); Zhou: School of Economics, Peking University (email: qingyuanzhou.econ@gmail.com). All errors are our own.

II.Estimation Specifications

To identify the effect of the staggered adoption of surgical robots on gender ratio in surgical departments as well as promotion opportunities of females, we employ the event study model. After the introduction of robots, it may take some time for changes to gradually occur in recruitment decisions of hospitals and the choices made by medical students regarding their specialties. This potentially results in the dynamic treatment effect. Thus, we first assume homogeneous treatment effects between hospital-departments treated at different times, and use the standard event study model as the baseline model to decompose the dynamic effect of robot adoption and test the parallel pre-trend assumption. Our estimation specification is as follows:

$$Y_{it} = \sum_{k=-12,\, k\neq -3}^{k=24} \beta_k MR_{it,k} + \delta_i + \eta_t + \epsilon_{it} \#(1)$$

where the outcome variables Y_{it} denotes indicators of the presence, the workload as well as the promotion opportunities of females in hospital-department i in month-year t . As for the extensive margin, Y_{it} takes 1 if there are females in hospital-department i in month-year t, and 0 otherwise. Besides, it equals 1 if there are female heads and 0 otherwise. As for intensive margins, the dependent variables are ratios of female physicians, ratios of procedures conducted by female physicians, as well as ratios of female heads, chiefs, attendings and residents in hospital-department i in month-year t. $MR_{it,k}$ represents dummy variables that equal 1 if in month-year t, there are months before(after) the first robotic-assisted procedure in hospital-department i ,and 0 otherwise. The estimation window goes from one year before the first procedure to two years after the first procedure in hospital-department , enabling us to show both the short-term and long-term impacts through dynamics of β_k. We use k=-3 as the reference group because the effects of robot adoption could happen before its first operational use, and the dummy for k=-3 is omitted. We also control for hospital-department fixed effect and month-year fixed effect η_t.. The hospital-department fixed effect δ_i control for time-invariant and hospital-department specific confounders that might influence female ratios. The month-year fixed effect η_t. account for shocks that are common to all hospitals in a specific month, such as changes in nationwide healthcare policies and seasonal fluctuations in number of visits by patients. ϵ_{it} is the idiosyncratic error term. The standard errors are clustered at the hospital-department level.

However, as discussed in Sun and Abraham 2021, the estimator in the dynamic TWFE regression in equation (1) can be inconsistent if treatment effects are heterogeneous across groups. In our setting, for instance, effects of robot adoption on female ratios might be more significant for hospitals in more developed parts of China. If this is the case, with parallel trend, the pre-treatment coefficients may not be zero and with deviating trends, the pre-treatment coefficients may still be zero. In order to provide consistent estimator with such heterogeneity in treatment effects across groups, we refer to heterogeneity-robust estimators proposed by Borusyak, Jaravel, and Spiess 2024, Callaway and Sant'Anna 2021, de Chaisemartin and d'Haultfoeuille 2020 and Sun and Abraham 2021. Note that we use the never-treated groups as controls for the estimator proposed by Sun and Abraham 2021. Therefore, it is identical to the estimator proposed by Callaway and Sant'Anna 2021.

III.Robustness Checks

This section presents a series of robustness checks.

First, a threat to our estimation is the violation of no anticipation effect. In some hospitals, different departments share a single da Vinci surgical system. Actually, we observe a delay between the installation of systems and their first operational use in certain departments. Consequently, the recruitment staff in these departments may anticipate the use of the surgical robots and make personnel adjustments before the first procedure in their departments. Therefore, we exclude hospital-department where the time between the installation of the robot and its first surgical use exceeds three months.

Second, we examine spillover effects. The adoption of surgical robots in one hospital may influence gender ratios in neighboring hospitals. For instance, hospitals with robots may attract skilled surgeons, including female surgeons, from nearby hospitals. Additionally, hospitals in the vicinity of those with surgical robots might anticipate adopting the same technology in the near future and proactively recruit surgeons, particularly females. Therefore, we redefine the treatment group as hospital-departments that first introduce da Vinci robots in a city. We categorize control groups into the nearby control group and the distant control group. The former are departments of never treated hospitals in cities that introduce surgical robots. The latter are hospitals in cities that never introduce surgical robots. Then, we exploit the estimation specification of equation (1) to compare these three groups pairwise to explore whether there are spillover effects.

Third, we estimate equation (1) with alternative estimation windows, drop branches of hospitals and keep hospital-departments that continuously appear during the estimation window.

IV.Heterogeneity

In this section, we examine the heterogeneous impacts of robot adoption for different subsamples based on hospital and department characteristics.

First, we examine whether hospitals departments with females doing robot-assisted procedures in the first quarter after the adoption are more likely to see a rise in the number of female surgeons afterwards. It is plausible that with female role models in place, recruiters are more inclined to perceive females as capable of performing da Vinci surgeries. As a result, female role models may encourage more female to enter the department and recruiters may hire more females.

Second, we explore which types of hospitals are more likely to respond to the robot adoption. We hypothesize that changes in female ratios might differ along rankings and geographical factors of hospitals. For example, it is possible that employers in hospitals with higher rankings and in more developed regions are more likely to recognize the change in comparative advantages brought by the technological advancement. Hence, we measure the rankings of hospitals by whether it appears on “2022 China Hospital Rankings”, which contains top 100 hospitals in China compiled by experts from Chinese Medical Association and Chinese Medical Doctor Association. As for geographical factors, following the regional economic division by the National Bureau of Statistics, we divide China into four regions: eastern, central, western and northeastern. Additionally, we categorize hospitals based on whether they are located in provincial capitals or direct-administered municipalities.

V.Mechanisms

In this section, we explore three underlying channels through which robot adoption can influence gender dynamics in surgery departments: reduction in physical demands, changes in financial incentives and changes in patient preferences.

First, the rise in female ratios may be driven by the change in gender comparative advantage. The use of robots can decrease the need for physical stamina and strength which previously favor male surgeons. To examine whether females are no longer at a disadvantage due to physical strength, we will distribute questionnaires to the recruitment staff and physicians.

Second, the change in gender composition may stem from gender difference in response to changes in compensation structures and financial incentives. The adoption of robotic technology leads to changes in surgical fees and, consequently, the compensation structure for surgeons. Males and females may respond differently to the financial incentive, potentially due to social norms and career aspirations. For instance, if robotic-assisted procedures lead to higher compensations, they might attract more female surgeons if they place a higher value on financial rewards. To rule out this competing hypothesis, we control for average price differentials between robotic-assisted and traditional surgeries in each hospital department.

Third, the adoption of surgical robots might change patients' preferences regarding the gender of surgeons in charge. This shift could be driven by patients' perceptions regarding which gender of surgeons is more adept with such technology. Therefore, we assess patients' preferences towards the gender of surgeons in traditional open surgeries and da Vinci robotic-assisted surgeries through a survey.

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Does Robotic Surgery Help Reduce the Economic Burden of Malignant Tumors in the Pancreas? A Cost-of-Illness Study

By Yin Shi Ziting Wu*

Objective: To summarize the effectiveness and costs of comparing robotic surgery with laparoscopic or open surgery for pancreatic cancer. Methods: Through literature review, we summarized the main results and conclusions from existing studies, as well as the unresolved issues in this field. Results and conclusions: Despite higher initial expenses, robotic pancreatic cancer surgery shows potential for enhancing patient results and reducing long-term costs. To validate these claims, more extensive research with standardized methods is imperative, alongside a focus on large-scale studies in both developing countries and long-term effects. Ensuring sufficient sample sizes and accounting for surgeons' learning curves in future research are critical to comprehensively assess robotic surgery's cost-effectiveness across diverse settings.

I. Background and Objective

Although the history of pancreatic surgery spans over a century, it is still considered the most challenging abdominal surgery due to the high incidence of complications and mortality rates. Treatment modalities for pancreatic cancer include open surgery, laparoscopic surgery, and robot-assisted surgery. Open surgery is the traditional treatment for pancreatic cancer, while laparoscopic and robotic surgery are minimally invasive

*Shi: Department of pharmacy, Xiangya Hospital Central South University, Changsha, Hunan, P.R. China, 410008 ；National Clinical Research Center for Geriatric Disorders，Xiangya Hospital, Central South University, Changsha, Hunan, P.R. China, 410008；Institute for Global Health and Development, Peking University, Beijing, China, 100871, (email: shiyin910515@csu.edu.cn); Wu (Corresponding author): Institute for Global Health and Development, Peking University, Beijing, China, 100871 (email: wuziting@pku.edu.cn).

approaches that have developed in recent years. Currently, the controversy over the application of laparoscopic or robot-assisted surgery for curative treatment of pancreatic cancer mainly focuses on the oncological evaluation of treatment effects and surgical safety. However, there lacks the cost comparison between those surgery methods.

II. Methods

We searched PubMed without language restrictions, using the terms "pancreatic" and "pancreas" in combination with "cancer," "adenocarcinoma," and "carcinoma." We also combined these terms with "cost effectiveness," "cost utility," or simply "cost," and further combined the results with "robot," "robotic," and "surgery." The most relevant clinical trials, systematic reviews and meta-analyses, other original research articles, and guidelines from January 1, 2011, to May 30, 2024, were included. One researcher screened the literature and summarized the key points.

III. Results

Cost or Cost-Effectiveness/Utility Studies Comparing Robotic Surgery with Laparoscopic or Open Surgery for Pancreatic Cancer

There are currently few studies on the cost or cost-effectiveness/utility of robotic surgery compared to laparoscopic or open surgery for pancreatic cancer, with a total of 5 studies found(Kowalsky et al. 2019; Vicente et al. 2020; Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022). Among them, 3 are cost analyses and 2 are cost-utility studies (Table 1).

Most existing studies are based on real-world data and are retrospective in nature, focusing on short-term perioperative or postoperative outcomes within one year. (Kowalsky et al. 2019; Vicente et al. 2020; Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022) — Data is typically collected retrospectively from institutional databases. There is a lack of long-term cost-effectiveness studies, making it difficult to assess whether robotic surgery has advantages over laparoscopic or open surgery in terms of long-term outcomes and cost-benefit. In addition, all five studies are single-center studies, which may affect the external validity and generalizability of the research results. (Kowalsky et al. 2019; Vicente et al. 2020; Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022)

Current research generally shares similar outcome measures, with the measurement indicators in cost-effectiveness studies being ICER and health outcome indicators being QALY. — Clinical efficacy-related indicators include perioperative-related measures such as hospital stay duration, operative time, blood loss, complication rates (e.g., pancreatic fistula, wound infection), and recovery time. Cost collection only considers direct medical costs during the perioperative period. Comprehensive cost analyses are required to include not only direct surgical costs but also long-term outcomes and indirect costs such as rehabilitation and return to work. (Caruso et al. 2022)

Existing research predominantly focuses on developed countries, lacking results from developing countries. — Due to differences in economic and social development levels, the cost-effectiveness results from developed countries are difficult to generalize to developing countries. It is highly necessary to pay attention to the cost-effectiveness of robotic surgery in the treatment of pancreatic cancer in developing countries.

Most studies considered robotic surgeries generally have higher intraoperative costs due to expensive equipment and longer operative times. However, these costs are often offset by reduced hospital stays and lower complication rates. (Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022)— Studies indicate that robotic pancreatic surgery may be cost-effective within certain willingness-to-pay thresholds. For instance, ICERs often fall within acceptable ranges for cost-effectiveness. (Caruso et al. 2022; Benzing et al. 2022) Some studies highlight the high upfront costs of robotic systems as a barrier to widespread adoption, emphasizing the need for long-term cost savings through reduced postoperative care and faster recovery. (Caruso et al. 2022; Benzing et al. 2022) Other studies argue that the learning curve associated with robotic surgery can initially increase costs and operative times, but these metrics improve significantly as surgeons gain experience.

Overall, while robotic surgery for pancreatic cancer presents higher initial costs, it shows promise in improving patient outcomes and potentially reducing long-term healthcare costs. Further research with standardized methodologies and larger sample sizes is necessary to solidify these findings. Additionally, studies focusing on developing countries and long-term outcomes are crucial to provide a more comprehensive understanding of the cost-effectiveness and benefits of robotic surgery in various contexts.

TABLE 1— SUMMARY OF KEY INFORMATION ON COST OR COST-EFFECTIVENESS/UTILITY STUDIES COMPARING ROBOTIC SURGERY WITH LAPAROSCOPIC OR OPEN SURGERY FOR PANCREATIC CANCER

Author and year	Country	Economic analysis	Perspective	Design	Intervention	Comparison	Time horizon	Primary outcomes	conclusion
Kowalsky SJ (2019) (Kowalsky et al. 2019)	US	Cost analysis	/	Retrospective study	RPD	OPD	2-year	postoperative LOS for the index (operative) admission and total 30-day costs (including costs of any readmissions within this period)	A combination of enhanced recovery after surgery and robotic approach synergistically decreases hospital stay and overall cost compared with other strategies.
Vicente E (2019) (Vicente et al. 2020)	Spain	CUA	payer perspective	Prospective study	RDP	LDP	1 year	ICER	The overall mean total cost was similar in both groups. Mean QALYs for RDP (0.652) was higher than that associated with LDP (0.59) ($P > .5$). The result showing some benefits for RDP.
Caruso R (2022) (Caruso et al. 2022)	Spain	CUA	payer perspective	prospective study (Case-matched analysis)	RPE	OPE	1 year	ICER	RPE may be acceptable in terms of cost-effectiveness.
Franco GD (Di Franco et al. 2022)	Italy	cost analysis	/	Case-matched analysis	RPD	OPD	short-term post-operative course	Perioperative data and direct healthcare costs	Robot-assisted surgery is more expensive because of higher acquisition and maintenance costs. However, although RPD is associated to higher material costs, the advantages of the robotic system associated to lower hospital stay costs and the absence of difference in terms of personnel costs thanks to the similar operative time with respect to OPD, make the OVCs of the two techniques no longer different.

									Hence, the higher costs of advanced technology can be partially compensated by clinical advantages, particularly within a high-volume multidisciplinary center for both robot-assisted and pancreatic surgery.
Benzing C (2022) (Benzing et al. 2022)	Germany	Cost analysis	/	Retrospective analysis	RPS	OPS	Perioperative	Perioperative data and intra- and postoperative costs	Surgical outcomes of RPS were similar to those of OPS. Higher intraoperative costs of RPS are outweighed by advantages in other categories of cost-effectiveness such as decreased lengths of hospital stay

RPD, robotic pancreatoduodenectomy; OPD, open pancreatoduodenectomy; RDP, robotic distal pancreatectomy; LDP, laparoscopic distal pancreatectomy; RPE, robotic pancreatic enucleation; OPE, open enucleation; RPS, robotic pancreatic surgery; OPS, open pancreatic surgery. QALYs, quality-adjusted life years; ICERs, cost-effectiveness ratios.

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Medical Technologies with Comparative Advantages on Different Dimensions: Evidence from Hysterectomy

By Nathaniel Breg *

Understanding the extent of technological diffusion is important to economics broadly and in the context of health care specifically. I show that new technologies may pose tradeoffs between different dimensions or quality or productivity. In a Roy model, I show that these tradeoffs can explain why two technologies coexist. The model also serves as a theoretical basis for using an instrumental variable to uncover evidence of tradeoffs. These local average treatment effects can be used in a benefit-cost analysis to assess whether the technology has diffused to an efficient extent. I use a patient's distance to hospitals performing laparoscopic (minimally invasive) surgery, relative to her distance to hospitals performing any surgery at all, as an instrument for whether she undergoes laparoscopic, as opposed to abdominal (open), hysterectomy. In Medicare inpatient claims, I find that laparoscopic surgery causes a shorter length of stay but a greater readmission rate, relative to abdominal hysterectomy, among patients on the margin between the alternatives with respect to this quasi-experiment. This demonstrates laparoscopic surgery's tradeoff, at least among some patient subpopulations. In a back-of-the-envelope benefit-cost analysis, I estimate that laparoscopic surgery may pose a net loss among these marginal cases, suggesting there may be too much laparoscopic surgery in this setting.

* Nathaniel Breg, Stanford University.

I.Contribution

My main conceptual contribution is to show that old and new technologies may coexist if a technology poses tradeoffs between different dimensions of quality or productivity. The prior literature finds that products evolve along multiple dimensions of features and that consumers value these innovations, for example, in the markets for computed tomography (CT) scanners and for cars (Trajtenberg, 1989; Grieco, Murry and Yurukoglu, 2023). Different features could affect different dimensions of a technology's productivity. I demonstrate with a Roy model that two technologies may coexist because one technology offers relative improvements on one dimension but also pose setbacks on another dimension, at least in some applications. In my setting, laparoscopic surgery causes a shorter length of stay than the alternative, open procedure in all cases, but not all patients choose it. Therefore, it must cause greater readmission risk for patients near-indifferent between the two technologies. Prior work has found other factors in the speed or incompleteness of diffusion of new technologies, such as financial incentives (Finkelstein, 2007; Acemoglu and Finkelstein, 2008; Clemens and Gottlieb, 2014), information frictions (Skinner and Staiger, 2015), and administrative hurdles to billing for the use of new procedures (Dranove, Garthwaite, Heard and Wu, 2021). In other industries, coexistence of technologies has been attributed to the costs and benefits of different coinventions (Bresnahan and Greenstein, 1996), limitations imposed by product features (Gross, 2018), firm size (Karshenas and Stoneman, 1993), and lack of presence of complementary capital (Goldfarb, 2005). I show that technologies may coexist because old technologies may still have an advantage among some patients in terms that affect patient's physical health.

My first methodological contribution is to show how to uncover evidence of a technology's tradeoff by estimating the relative effectiveness of the technology among marginal patients using instrumental variable methods. I build on the intuitive and common approach of estimating treatment effects among patients on the margin between two alternatives by using a patient's relative distance to one alternative over the other as an instrumental variable (McClellan, McNeil and Newhouse, 1994). Similarly, I estimate the effects of laparoscopic, as opposed to abdominal, hysterectomy on two key adverse outcomes by comparing patients who live closer to hospitals that perform laparoscopic hysterectomy, relative to their distance to hospitals that perform any hysterectomies. I ground this approach with a microeconomic model of cases sorting between treatments on the basis of comparative advantage. Patients who are near indifferent between alternatives face a tradeoff between improvement on one dimension and detriment on another. They could also be induced into one or other by an instrumental variable. Marginal treatment effect methods from the labor econometrics literature identify the treatment effects of these marginal cases, and the local average treatment effect identified by two-stage least squares regression is a positively weighted combination of these marginal treatment effects (Heckman and Vytlacil, 1999, 2001; Heckman, Urzua and Vytlacil, 2006).

Second, this quantification of the tradeoff can be used to show how to assess the efficiency of a technology's diffusion using these estimates of marginal effects.

II.Theory

To illustrate the paper's central point,I build a Roy (1951) model in which patients and physicians choose a technology on the basis of how the alternatives affect two dimensions of productivity, rather than just one as is typical. This allows me to consider the role that heterogeneity of a technology's improvements across quality dimensions may play in determining the extent of that technology's diffusion. In this setup, laparoscopic surery is better on the length of stay dimension of quality in all cases because it is minimally invasive, but not everyone chooses it. Therefore, laparoscopic surgery must cause greater readmission risk than abdominal surgery, at least among marginal patients and inframarginal abdominal patients.

III.Methods

To estimate laparoscopic surgery's relative effectiveness among marginal cases, I use a patient's distance to her nearest hospital that performs laparoscopic surgery, relative to her nearest hospital performing any hysterectomy method, as an instrumental variable for undergoing laparoscopic, as opposed to abdominal, hysterectomy. I estimate the local average treatment effect in Medicare Part A insurance claims. This identification strategy, following McClellan, McNeil and Newhouse (1994), uses patients' preference for health care providers who are closer to their residence. To assuage concerns raised by Hadley and Cunningham (2004) that the effect of distance on care choices may be confounded by socioeconomic conditions related to health, I control for a host of characteristics of the patient's neighborhood, some hospital characteristics, and Hospital Referral Region fixed effects.

IV.Data

I observe all Medicare Part A-covered total hysterectomies from 2007 to 2008. This includes 61,241 hysterectomies performed in 3,340 hospitals. These claims detail the patient conditions as well as procedures performed. It also details patient and hospital Zip codes. I merge in patient neighborhood characteristics from the American Community Survey.

V.Results

I find evidence that laparoscopic surgery poses a tradeoff between reducing a patient's length of stay in the hospital and increasing her readmission risk, at least for patients on the margin between the alternative hysterectomy methods. I estimate that patients who comply with the relative distance instrument experience about a 55 percentage point lesser chance of a length of stay of 2 or more days under laparoscopic surgery than under abdominal surgery, but they also experience a 23 to 36 percentage point increase in the chance of a 10-day all-cause readmission. I am unaware of any other literature that uses instrumental variables to seek evidence of a tradeoff between different quality dimensions among marginal patients.

I use these point estimates to conduct a preliminary benefit-cost analysis of laparoscopic hysterectomy relative to abdominal hysterectomy among these compliers of the relative distance quasi- experiment, to demonstrate how to assess the efficiency of the extent of diffusion of a technology like laparoscopic hysterectomy. If an extra day in the hospital costs $2,490 (Foundation, 2021) and a readmission costs $15,200 (Weiss and Jiang, 2006), then my point estimates suggest that laparoscopic surgery poses a net loss of $2,054 in expectation among patients on the margin. This is likely an underestimate, since this excludes non-pecuniary costs, which are likely higher for a readmission than for an extra day in the hospital. Therefore, there may be too much laparoscopic surgery among these Medicare-covered hysterectomy patients, from the perspective of an individual patient's utility.

Finally, I also find suggestive evidence that different cases perceive a different technology to have the comparative advantage because patients with the greatest unobserved resistance to (i.e., least propensity for) laparoscopic surgery would experience the greatest increases in readmission risk, even though they would experience the greatest potential reductions in length of stay due to that procedure, although these marginal treatment effect estimates are imprecise. These point estimates tell a story similar to that of Suri (2011), who finds that farmers who would experience the greatest benefit from adopting new hybrid maize technology also face the highest costs of adoption and thus do not use it.

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机器人对比传统腹腔镜辅助的直肠低位前切除术在中低位直肠癌的卫生技术评估队列研究课题进展汇报

胡雪峰 蔡泽荣 王清波 武子婷 吕蓓妮*

摘　要 机器人辅助手术在直肠癌治疗中具有较好的应用，尽管机器人手术具有诸多优势，但由于研究证据的不一致性和高成本，其应用仍存争议。目的：1）本研究拟通过建立建立全国范围内多中心的观察性队列，以评估机器人手术与传统手术的疗效、健康产出和成本。2）对比采用机器人辅助手术、腹腔镜手术和开腹手术三类术式的直肠低位前切除术的直肠癌患者的总医疗费用、直接医疗费用与间接医疗费用。分析三类患者在灾难性卫生支出与因病致贫发生概率方面的差异及其影响因素。方法：1）综合考虑地理位置、经济发展水平、医院综合实力、结直肠外科实力、合作意愿等因素，选择最终参与本研究的临床医院。2）数据来源于《机器人对比传统腹腔镜辅助的直肠低位前切除术在中低位直肠癌的卫生技术评估》项目的随访问卷。对三类患者的总医疗费用、直接医疗费用与间接医疗费用进行单因素方差检验；以是否发生灾难性卫生支出/因病致贫为二分类因变量构建Probit模型；以发生灾难性卫生支出/因病致贫程度为连续性因变量构建多水平Cox回归模型。结果：现阶段，本研究根据区域和技术特性选取了16个具有全国代表性的临床医院参与研究，将真实反映机器人手术在直肠癌治疗中的应用情况。机器人辅助手术、腹腔镜手术和开腹手术患者灾难性卫生支出与因病致贫发生概率方面的差异尚在分析中。

一、背景

结直肠癌是我国最常见的消化道恶性肿瘤之一，其发病率在近年来呈现上升趋

* 胡雪峰,北京大学全球健康发展研究院，E-mail：huxuefengDSG@outlook.com ；蔡泽荣，中山大学附属第六医院结直肠外科，广东省胃肠病研究所，广东省结直肠及盆底疾病重点实验室；王清波，北京大学全球健康发展研究院，E-mail：wangqingbo89@163.com；武子婷，北京大学全球健康发展研究院，E-mail：wuziting@pku.edu.cn；北京大学全球健康发展研究院，E-mail：blyu@pku.edu.cn。通信作者：吕蓓妮，北京大学全球健康发展研究院，E-mail：blyu@pku.edu.cn。

势。其中，直肠癌在结直肠癌中占50%-60%，并以腹膜返折平面以下的中低位直肠癌为主。该部分直肠癌患者的手术操作难度大，对术者技术的要求高，需要良好的术野暴露与精细操作才能达到对肛门功能与泌尿生殖神经的保护。直肠低位前切除术是目前开展最广、应用较多的保肛术式。目前，已有多个国内外研究开展了机器人手术与传统腹腔镜手术在直肠癌手术中的有效性与安全性。由于机器人手术耗费比传统手术高，因此有必要对机器人直肠癌手术进行卫生经济学评价。目前，该领域的研究主要关注临床效果，仅有少数国外研究关注了结直肠癌患者的短期内的质量调整生命年，具有成本效用（Collinson et al. 2012;Jayne et al. 2019）。但该部分研究存在以下不足：（1）针对机器人手术的卫生经济学评价多为模型相关研究，尚无统一、明确结论；（2）研究多以单中心回顾性研究为主，样本量较小，检验效能不足；（3）此类卫生经济学评价研究大多是以小规模临床研究结局指标作为健康产出的成本效果研究，对患者术前及术后心理因素、长期生命质量关注较少，较少涉及国际通用的成本效用指标；（4）目前尚缺少基于中国人群机器人手术应用于直肠癌患者的成本效用分析，无法评价机器人手术在直肠癌患者中的性价比。

基于以上现状，本研究拟在全国范围内建立一个前瞻性、多中心的观察性队列，对比接受不同术式直肠癌患者的临床疗效、健康产出和成本，为机器人直肠低位前切除术在直肠癌患者中的应用提供卫生经济学参考。

二、目标

本研究旨在从全国范围内选取具有代表性的临床医院，通过考虑地理位置、经济发展水平、医院综合实力、结直肠外科实力、合作意愿等因素，以确保研究结果的代表性和可靠性。此外，通过对比采用机器人辅助手术、腹腔镜手术和开腹手术三类术式的直肠低位前切除术的直肠癌患者的总医疗费用、直接医疗费用与间接医疗费用。分析三类患者在灾难性卫生支出与因病致贫发生概率方面的差异及其影响因素。

三、方法

在队列研究中，选择具有区域代表性的医院至关重要（Healy and Devane 2011）。既需要选择经济发达的地区，从而得出在具有较强的技术实力和丰富的医疗资源情况下，直肠癌治疗的结果；又需要选择那些经济发展水平相对不发达的地区，从而得出在医疗资源相对紧张的情况下的结果。以此获得全面的样本（Willett and Colditz 1998）。

所选择的医院应该技术和经验达标（Wang and Kattan 2020）。本研究需要对比接受不同术式直肠癌患者的临床疗效、健康产出和成本，所以所选择的医院需要在不同术式方面都需要达标，以保障研究的准确性（Keung et al. 2020）。

基于以上两点要求，本研究采取以下方法选取具有区域代表性和技术水平达标的临床医院。首先，根据地理位置、经济发展水平等因素对全国范围内的潜在医院进行筛选，从而保障研究的区域代表性。其次，分析医院的技术情况，根据医院的医疗基础设施、医生组成、手术量等要素，评估所选择医院的技术和经验达标性。然后，与选定的这些医院进行沟通，达成合作意向，确定合作意愿所能提供的相关数据。最后，综合考虑各种因素，选择最终的临床医院。

针对灾难性卫生支出与因病致贫发生概率方面的差异及其影响因素研究，数据来源于《机器人对比传统腹腔镜辅助的直肠低位前切除术在中低位直肠癌的卫生技术评估》项目的随访问卷。分析方法主要包括：（1）对三类患者的总医疗费用、直接医疗费用与间接医疗费用的单因素方差检验；（2）以是否发生灾难性卫生支出/因病致贫为二分类因变量的 Probit 模型；（3）以发生灾难性卫生支出/因病致贫程度为连续性因变量的多水平 Cox 回归模型。

四、结果

现阶段，仅报告临床医院选取结果。本研究选取了 16 家医院作为本次队列研究的参与单位，包括中山大学附属第六医院、深圳市人民医院、复旦大学附属肿瘤医院、南昌大学第一附属医院、福建医科大学附属协和医院、北京大学人民医院、中国医科大学附属盛京医院、新疆维吾尔自治区人民医院、陆军军医大学西南医院、兰州大学第一医院、成都市第三人民医院、郑州大学第一附属医院、青岛大学附属医院、中国人民解放军总医院哈尔滨医科大学附属第二医院、哈尔滨医科大学附属第二医院。

图 1 显示了这些医院的分布。从区域代表性来看，医院既包括了东部地区，也包括了中西部地区，具有良好的代表性。其中，中山大学附属第六医院、深圳市人民医院是华南地区的代表性医院，医疗设备先进，临床经验丰富；复旦大学附属肿瘤医院在华东地区具有较强的技术影响力；南昌大学第一附属医院位于中部地区，同样有较为先进的技术和较强的影响力；福建医科大学附属协和医院反映了东南沿海的较高的医疗水平。同时，北京大学人民医院、中国医科大学附属盛京医院、新疆维吾尔自治区人民医院、陆军军医大学西南医院、兰州大学第一医院、成都市第

三人民医院、郑州大学第一附属医院、青岛大学附属医院等医院分别可以显示华北、东北、西北、西南等地区的医疗水平，从而使得队列研究的地理分布能够显示典型性特征。

图 1. 队列研究医院分布

从技术和经验达标性性来看，这些医院在直肠癌手术治疗领域均具备高度的专业性，有很强的技术实力。中山大学附属第六医院、深圳市人民医院、复旦大学附属肿瘤医院、南昌大学第一附属医院等医院在机器人手术、腹腔镜手术及开腹手术方面均有较强的技术实力，也在这些手术上积累了丰富的经验。福建医科大学附属协和医院、北京大学人民医院等医院在直肠癌的综合治疗、早期诊断和个体化治疗等方面也具有较高的技术水平和丰富的临床经验。这些医院的技术和经验完全符合机器人手术、腹腔镜手术及开腹手术对比的要求，也能够为研究提供高质量的数据。

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引入手术机器人对手术风险和不确定性的影响

陈尔默*

摘　要　本文通过一项回溯性的研究对医院引入手术机器人后，手术在成本、结局和死亡等要素上的风险和不确定性进行评价，并对其影响和方向和显著性进行研究。该研究是手术机器人卫生技术评估课题的一部分，是一项针对一般性的手术机器人引入的效果的评价测算。分析使用了两个数据源，一个是市场上占主导地位的医疗机器人供应商的服务记录，另一个是一家信息技术供应商提供的覆盖中国数千家医院的统计结果数据。

本文的评估结果显示，结局方面，医疗机器人的引入会显著降低医院的手术死亡率，但并未对住院时长的效率指标带来明显的变化。在费用方面，虽然例均费用上显示出了显著的上升，但是费用的波动程度的并未出现明显的变化。这或许意味着手术机器人的引入在标准化和稳定性上均为医院手术带来了提升，本项目将对此进行后续的研究。

关 键 词　手术机器人；死亡率；费用波动性；住院时长；风险与不确定性。

一、背景介绍

先前的研究并未显示引入医疗机器人对手术有明显的好处，见 Borden et al.(2007) 和 Alemzadeh et al.(2016)。而在现实世界中，医疗机器人确有越来越受欢迎的趋势。因此，还需要挖掘该趋势更多的驱动因素。在既往的队列研究中，由于样本太少，无法得出关于期望之外的度量可靠的结果，如风险和不确定性。这使我们必须开展以回顾的方式使用更大的数据集的研究。

在前序研究中，我们发现了引入医疗机器人对死亡率变化的影响。结果表明，医疗机器人可显著降低手术死亡率。在本文中，我们围绕手术机器人对住院时长、费用的平均水平和波动性等成本和效率指标展开研究。本研究是手术机器人对医疗事故和医疗错误影响研究的一个部分。

* 北京大学数学科学学院/全球健康发展研究。
通信地址：北京市海淀区颐和园路五号，100871；E-mail：chenermo@stu.pku.edu.cn。

二、数据

与前序研究相同，本文的研究基于一家在市场上占据主导地位的医疗机器人供应商在中国大陆的服务记录，记录了每个病例的医院名称、手术日期和手术类别。同时，我们也使用一家信息技术提供商的统计报告。该报告是一份基于内部数据的统计报告，样本涵盖 2007-2022 日历年的中国大陆 6252 家医院。每个医院每个月的样本数、死亡率、平均费用、费用差异和住院天数，以及每个手术或科室的类别都有报告。此外， 报告 还提供了医院的地点、级别和等级。

两个数据源可以通过医院和日期进行匹配。分析覆盖 6252 家医院，其中 97 家有医学机器人的手术记录，覆盖了手术记录的 28328/314152 = 9%。经过数据清洗，4231 家医院，30936 个医院 × 季度进入统计分析。

三、分析模型

本章的回归模型使用

$$DeathRate_{i,t} \sim Robot_{i,t} + X_i + I_t, \quad \omega = SampleSize_{i,t}, \text{（1）}$$

其中 $Robot_{i,t}$ 是机器人使用的程度，采用例数 (Num_of_Robot) 和例数占比 (Robot_Rate) 两种口径。这是因为统计记录数据是根据样本得出的，而不是完整的记录，因此例数占比的评估不够准确。但例数占比是对效果进行显著性检验所必需的。因此，在分析过程中要同时考虑这两个因素。

考虑两种固定效应。一种是直接使用医院的唯 ID，这种方法比较简单，但受限于统计结果数据中的一些缺失结果。另一种是使用医院所在的省、医院等级和医院级别来代替，这可能会丢失一些信息，但结果会更加稳健。我们对两种方法均加以使用。

对于住院时长的建模， 本文的回归模型使用

$$InHospitalDays_{i,t} \sim Robot_{i,t} + X_i + I_t, \ \omega = SampleSize_{i,t} \text{（2）}$$

其中 $InHospitalDays_{i,t}$ 代表第 t 年第 i 个医院的住院病历的平均入院时长。其余

的是定与死亡率分析部分相同。

对于费用方面，关于平均费用的建模使用

$$\text{ExpectedCost}_{i,t} \sim \text{Robot}_{i,t} + \text{X}_i + \text{I}_t,\ \omega = \text{SampleSize}_{i,t} \quad (3)$$

其中 $\text{ExpectedCost}_{i,t}$ 代表第 t 年第 i 个医院的住院病历的例均费用。而对于费用的波动性方面，回归模型使用

$$\text{VarianceCost}_{i,t} \sim \text{Robot}_{i,t} + \text{Robot}_{i,t}(1 - \text{Robot}_{i,t}) + \text{X}_i + \text{I}_t, \quad \omega = \text{SampleSize}_{i,t}, \quad (4)$$

其中 $\text{VarianceCost}_{i,t}$ 代表第 t 年第 i 个医院的住院病历的例均费用的方差。值得注意的是，此处引入了交乘项 $\text{Robot}_{i,t}(1 - \text{Robot}_{i,t})$ 来对组内方差和总方差进行分离，分离的具体原理见附录。

四、模型结果

4.1 死亡率的分析结果

以机器人手术例数的为自变量，对医院死亡率建模的模型结果如下表所示。

结果表明，在控制时间和医院的固定效应（直接和间接） 的情况下，机器人手术次数与死亡率之间存在明显的负相关关系。如果不控制固定效应，尤其是医院效应，结果就会变得复杂。这是由于医院在引进机器人时存在选择偏差造成的，这种偏差很常见，因为机器人的手术是非常昂贵的。

	死亡率的分析结果			
机器人手术例数	1.65E-06	1.12E-06	-6.19E-06	-2.12E-06
机器人手术例数的p-value	0.0838	0.2436	0.0000	0.0094
固定效应：时间		Yes	Yes	Yes
固定效应：医院				Yes
固定效应：科室				
固定效应：省份			Yes	
固定效应：医院等级			Yes	
固定效应：医院级别			Yes	
样本点数	30,936	30,936	30,936	30,936
F统计量	2.9890	5.1351	100.2786	17.8164

拟合优度	0.0001	0.0104	0.2454	0.7417

4.2 平均住院时长的分析结果

以机器人手术例数的为自变量， 对医院死亡率建模的模型结果如下表所示。

	平均住院时长的分析结果			
机器人手术例数	-1.33E-01	-9.52E-02	-2.99E-02	7.37E-01
机器人手术例数的p-value	0.8756	0.9121	0.9729	0.5969
固定效应：时间		Yes	Yes	Yes
固定效应：医院				Yes
固定效应：科室				
固定效应：省份			Yes	
固定效应：医院等级			Yes	
固定效应：医院级别			Yes	
样本点数	30,904	30,904	30,904	30,904
F统计量	0.0245	0.2178	0.9134	0.3736
拟合优度	0.0000	0.0004	0.0030	0.0568

结果表明，引入机器人手术对平均住院时长的影响没有显著的效果，这与其他研究得到的结论形成了相互印证。

4.3 平均成本的分析结果

以机器人手术例数的为自变量， 对住院病历例均成本的模型结果如下表所示。

	例均成本的分析结果			
机器人手术例数	2.72E+01	2.63E+01	1.93E+01	3.34E+00
机器人手术例数的p-value	0.0000	0.0000	0.0000	0.0017
固定效应：时间		Yes	Yes	Yes
固定效应：医院				Yes
固定效应：科室				
固定效应：省份			Yes	
固定效应：医院等级			Yes	
固定效应：医院级别			Yes	
样本点数	30,936	30,936	30,936	30,936

F统计量	744.2504	17.9099	113.2246	9.5432
拟合优度	0.0235	0.0353	0.2686	0.6060

从结果可以看出引入手术机器人对例均成本带来显著的大幅提升，这与常识和预期完美吻合。该部分的结果也印证了本文数据和方法的有效性。

4.4 成本方差的分析结果

以机器人手术占比的为自变量，对住院病历成本方差的模型结果如下表所示。值得注意的是， 附录展示 的方差分离定理要求该回归使用机器人手术占比而不是例数进行回归。

	成本方差的分析结果			
机器人手术例数	3.71E+12	1.85E+12	-1.34E+12	-6.30E+12
机器人手术例数的p-value	0.9400	0.9702	0.9784	0.9318
固定效应：时间		Yes	Yes	Yes
固定效应：医院				Yes
固定效应：科室				
固定效应：省份			Yes	
固定效应：医院等级			Yes	
固定效应：医院级别			Yes	
样本点数	30,936	30,936	30,936	30,936
F统计量	0.0185	0.4753	0.6423	0.7605
拟合优度	0.0000	0.0010	0.0021	0.1092

分析结果显示，机器人手术费用的组内方差并未显示出比传统手术更大的不确定性，没有证据表明机器人手术的引入显著引入了新的风险因素。

五、结论

以上的分析结果支持了如下的结论。

1. 机器人手术的引入引起了医院例均费用的显著增加；
2. 机器人手术的引入引起了医院平均死亡率的显著下降；
3. 机器人手术的引入未对平均住院时长带来显著影响；
4. 没有证据表明机器人手术的引入显著引入了新的不确定性来源；

在后续的分析中，我们会引入差分结构对引入效果的因果关系进行识别。

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A 费用方差回归建模的理论解释

当观测为两种不同的分组混合得到的结果时，如果两种分组在均值和方差上均存在差异，我们很难通过传统的回归来判断新引入的一个分组的方差是否与原分组具有显著的差别。为此，为了研究手术机器人费用的方差与传统手术间的大小关系，我们引入如下的回归技巧。

由于有

$$X_i \sim \mathbb{E}[X_i] = \mu_1, \quad \mathrm{Var}[X_i] = \sigma_1^2, \forall i \tag{5}$$

和

$$Y_j \sim \mathbb{E}[Y_j] = \mu_2, \quad \mathrm{Var}[Y_j] = \sigma_2^2, \forall j, \tag{6}$$

其中X代表传统手术，Y代表机器人手术。在某个确定的医院观测得到的样本中，假设其由N1例X和N2例Y组成。尽管不能观测到每一例具体的数据，但是我们知道该观测的方差是通过如下的方式计算得到的。

$$\begin{aligned}\mathrm{Var}[Z] &= \frac{1}{N-1}\left[\sum_{i=1}^{N_1}\left(X_i - \frac{\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j}{N}\right) + \sum_{j=1}^{N_2}\left(Y_j - \frac{\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j}{N}\right)\right] \\ &= \frac{1}{N-1}\left(\sum_{i=1}^{N_1} X_i^2 + \sum_{j=1}^{N_2} Y_j^2 - \frac{1}{N}(\sum_{i=1}^{N_1} X_i + \sum_{j=1}^{N_2} Y_j)^2\right),\end{aligned} \tag{7}$$

其中 N = N1 + N2。

因此我们可以得到

$$\begin{aligned}
\mathbb{E}[\mathrm{Var}[Z]] &= \frac{1}{N-1}\left[N_1(\mu_1^2+\sigma_1^2)+N_2(\mu_2^2+\sigma_2^2)-\frac{1}{N}\mathbb{E}[(\sum_{i=1}^{N_1}X_i+\sum_{j=1}^{N_2}Y_j)^2]\right] \\
&= \frac{1}{N-1}\left[N_1(\mu_1^2+\sigma_1^2)+N_2(\mu_2^2+\sigma_2^2)-\frac{1}{N}\left(N_1(\mu_1^2+\sigma_1^2)+N_2(\mu_2^2+\sigma_2^2)\right)\right] \\
&+ \frac{1}{N-1}\left[\frac{1}{N}\left(N_1(N_1-1)\mu_1^2+N_2(N_2-1)\mu_2^2+2N_1N_2\mu_1\mu_2\right)\right] \\
&= \frac{N_1}{N}(\mu_1^2+\sigma_1^2)+\frac{N_2}{N}(\mu_2^2+\sigma_2^2)-\frac{N_1}{N}\frac{N_1-1}{N-1}\mu_1^2-\frac{N_2}{N}\frac{N_2-1}{N-2}\mu_2^2-2\frac{N_1}{N}\frac{N_2}{N}\mu_1\mu_2.
\end{aligned}$$

（8） 简记 $\frac{N_2}{N}=\lambda$ 由不是一般性的假设

$$N_1 \ll N_2 \ll 1,\quad (9)$$

我们可以得到

$$\frac{N_1}{N}=1-\lambda,\ \frac{N_2-1}{N-1}\approx\lambda,\ \frac{N_1-1}{N-1}\approx 1-\lambda. \tag{10}$$

进而可以得到

$$\begin{aligned}
\mathbb{E}[\mathrm{Var}[Z]] &= [\sigma_2^2-\sigma_1^2+(\mu_2-\mu_1)^2]\lambda-(\mu_2-\mu_1)^2\lambda^2+c \\
&= (\sigma_2^2-\sigma_1^2)\lambda+(\mu_2-\mu_1)^2[\lambda(1-\lambda)]+c
\end{aligned} \tag{11}$$

其中c与λ独立。

这意味着可以通过 $\mathbb{E}[\mathrm{Var}[Z]]$ 对λ和λ(1-λ)的同时回归得到$\sigma_2^2-\sigma_1^2$.的估计和检验结果。

机器人在中国医院的采用：分析计划

梁钧霆　潘聿航*

摘　要　我们实证研究了医疗机器人首次使用对中国医院科室绩效的影响。采用结合了双向固定效应（TWFE）和事件研究（Event-Study）方法的稳健分析框架，分析了从2013年1月到2022年12月的每日科室数据。我们的重点是量化首次使用这种先进的手术技术后，对科室总收入的影响。

由于中国前所未有的经济发展和日益增长的需求，中国已成为手术机器人增长最快的国家之一。这篇文章将研究中国医院，特别是科室里达芬奇手术系统（达芬奇外科手术系统）的技术采用情况。截至 2022 年，达芬奇手术机器人的母公司 -- 直观复星 Intuitive Fosun-- 被认为是最大的机器人辅助手术（Robotic Assisted Surgery）技术培训供应商，并获得 FDA 等认证。全球有超过 70 个国家近 7000 台达芬奇系统执行了超过 1000 万次微创机器人手术程序（薛瑞华、刘荣，2021）

达芬奇外科系统于 2006 年首次在中国引入，当时中国人民解放军总医院采用了该系统。从 2006 年至 2023 年，共有 284 家中国医院实施了达芬奇 RAS 系统。这一技术随后被 2000 多名外科医生用于多种手术，这些外科医生共进行了 180 多种手术，其中泌尿科的手术量最高，约为 15 万次。

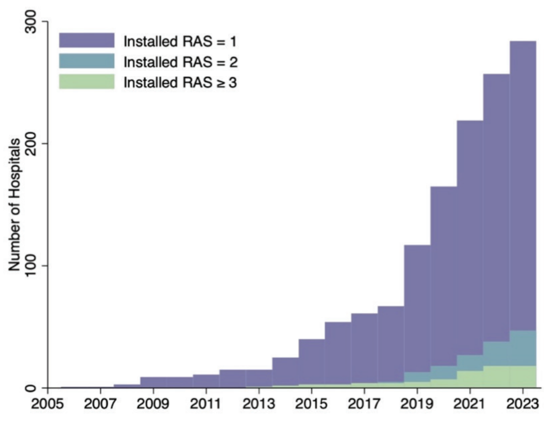

图 1. 中国拥有达芬奇手术系统的医院数量

* 梁钧霆：北京大学全球健康发展研究院 (E-mail: kwanting@stu.pku.edu.cn)；潘聿航（通信作者）：北京大学全球健康发展研究院（E-mail:yhpan@pku.edu.cn）。我们感谢达芬奇提供的市场数据。文中所有的错误均由作者承担。

中国医院现有的达芬奇手术系统包括：DaVinci SP、DaVinci S、DaVinci Si和DaVinci Xi。我们主要关注达芬奇手术系统在不同类别和不同科室中进行的第一台手术。图1展示了达芬奇手术系统在中国医院的普及情况。可以观察到两个显著的增长期。第一个发生在2014年，当时配备达芬奇系统的医院数量几乎翻倍。第二次增长发生在2019年，配备达芬奇手术系统的医院数量从69家增加到119家。

图2描绘了安装达芬奇手术系统和其在各个外科部门首次使用之间的时间间隔。数据表明，普通外科和泌尿外科部门从系统安装到运行的时间间隔较短，可能是由于这些领域手术对达芬奇手术系统高需求和直接适用性。达芬奇手术系统可用于广泛的手续程序。在泌尿外科，它可以执行前列腺、肾脏和膀胱癌的微创手术。在普通外科领域，该系统可以在复杂的消化系统里进行胃癌和直肠癌的微创手术切除。胸外科则利用达芬奇的先进能力处理肺癌和食管癌等疾病。在妇科，达芬奇系统可以用于子宫切除，宫颈癌，卵巢癌等妇科癌症。在图2的分类基础上，我们的分析扩展到医院部门级别，包括小儿外科、胃结直肠外科、肝胆胰外科和甲状腺外科。如图3所示，只有甲状腺外科在达芬奇系统安装与其首次操作之间有显著间隔，这表明某些专业对达芬奇辅助手术机器人的应用仍处于开发阶段。

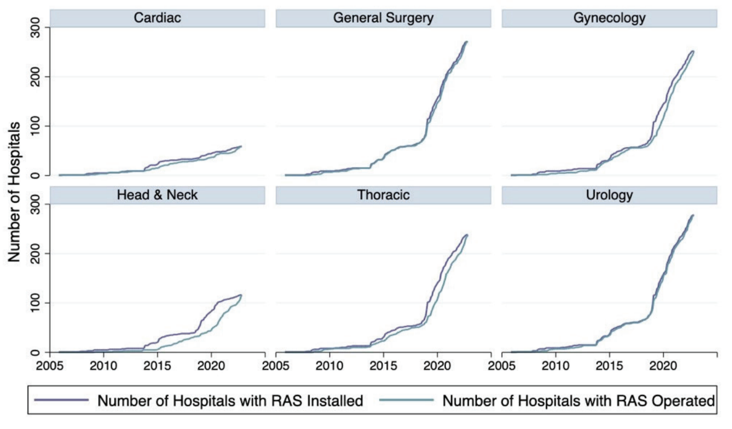

图 2. 医院各类别安装与首次使用时间间隔

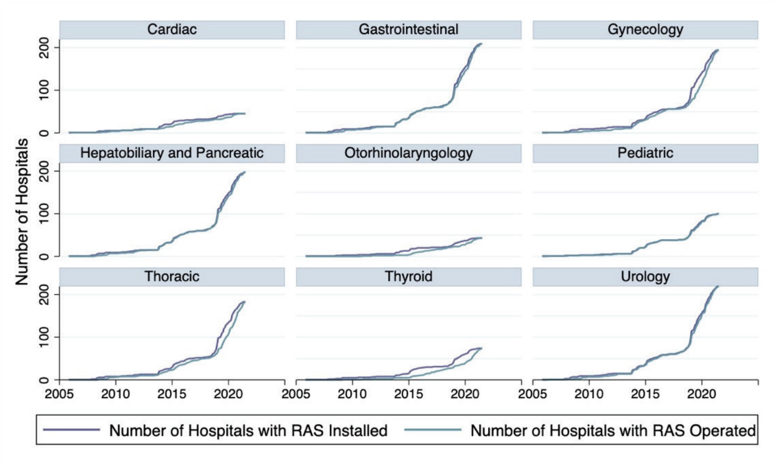

图 3. 医院各科室安装与首次使用时间间隔

数据

每个观测值代表单个病人整个住院期间的信息，病人级别的数据按科室级别每日汇总。数据包括病人特征、消费、住院时间和入院及出院日期。由于缺乏每日病人付款信息，我们对医院如何收取这些付款做了三种假设。首先，医院每天收取相同金额；第二，医院在入院日期收取一次性总额；第三，医院在出院日期收取一次性总额。

假设病人在住院期间每天花费相同，根据他们的总消费除以住院时间计算每日收入。假设医院在入院时收取一次费用，在入院日期将每位病人的总消费相加计算当日总收入。假设医院在出院时收取一次费用，在出院日期将每位病人的总消费相加计算当日总收入。

病人特征信息包含性别和年龄段。性别包括 1 代表男性，2 代表女性，3 代表未知。分配了六个年龄组：0-15 岁，16-30 岁，31-45 岁，46-60 岁，61-75 岁，以及 76 岁以上。计算了三种类型的病人特征：第一，为目前在医院的所有病人累计；第二，为刚入院的病人；第三，为出院的病人。

实证

为了测试平行趋势并研究使用达芬奇机器对医院科室的治疗效果动态，我们估

计了双向固定效应模型的事件研究版本。具体来说，我们估计了以下规范：

$$Y_{ijt} = \alpha_{ij} + \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

我们的结果变量 Y_{ijt} 是医院 i 科室 j 在时间 t 的不同收入的组合。Y_{ijt} 包括每日收入、入院总收入、出院总收入、自费服务收入、手术护理其他病理诊断、实验室诊断、影像学诊断、临床诊断、非手术治疗、手术治疗、康复收入。

虚拟变量 D_{ijt} 共同代表达芬奇首次使用事件，将医院 i 科室 j 首次安装达芬奇机器人系统的年份定义为 s_i 。我们定义 $D_{ijt}^{-15} = 1 \text{ if } t - s_i \leq -15$ 否则为 0。在基准模型中，我们控制了是医院 i 科室 j α_{ij} 和时间 δ_t. 的固定效应。标准误差在医院层面上聚类；在未来的稳健性检查中，我们将在更小的类别层次上聚类。

在接下来的三个模型中，我们运行了不同组合的固定效应。在第二个模型中，我们添加了医院－时间效应，以捕捉医院和时间之间的方差。注意，捕捉医院效应也意味着一个位置效应，因为医院不可能移动。在第三个模型中，我们添加了科室－时间固定效应，以捕捉科室和时间之间的方差。在最后一个模型中，我们添加了两个固定效应。

$$Y_{ijt} = \alpha_{ij} + \theta_i \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

$$Y_{ijt} = \alpha_{ij} + \eta_j \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

$$Y_{ijt} = \alpha_{ij} + \theta_i \times \delta_t + \eta_j \times \delta_t + \beta_k \times \sum_{k=15}^{k\leq -15,\, k\neq 1} D_{ijt}^{k} + \epsilon_{ijt}$$

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机器人与腹腔镜肝切除术治疗肝细胞癌的卫生经济学研究

梁霄 官海静 郑俊浩 杨辰越 *

摘　　要 相比腹腔镜肝切除术，机器人肝切除术可以降低术后并发症发生率、住院时间，提升患者术后生命质量。然而，机器人肝切除术的费用较高，使用机器人肝切除术治疗肝细胞癌是否具有经济性，目前仍然缺乏中国证据。目的：探索机器人肝切除术相比腹腔镜肝切除术用于肝细胞癌切除术的临床价值与医疗费用。方法：我们回顾性收集了2016年1月至2023年7月浙江大学附属邵逸夫医院单一医疗团队内接受微创肝切除术的肝细胞癌患者的数据，将患者分为研究组即机器人肝切除组与对照组即腹腔镜肝切除组，进行倾向性评分匹配后，比较匹配前后的围术期指标和医疗费用，并以手术难度为协变量进行亚组分析，分析不同手术难度下两种术式围术期预后和医疗费用的差异。结果：共有277例患者被纳入本研究（腹腔镜肝切除组175例，机器人肝切除组102例）。在应用倾向性评分匹配控制混杂因素后，共162例患者（两组各81例）被纳入进一步分析。结果显示，机器人肝切除组相比腹腔镜肝切除组术中出血、术后并发症较少、中转开腹率较低，手术安全性更好。机器人肝切除组具有更高的医疗费用（82885.3元 vs. 58643.8元，$p<0.001$），然而，腹腔镜肝切除组除手术外的其他各项费用显著更高。亚组分析显示，在高难度肝切除术中，两种术式的费用没有显著差异。结论：对于肝细胞癌患者，机器人肝切除比腹腔镜肝切除具有更好的手术安全性和更高的医疗费用，同时，高手术难度患者采用机器人肝切除术更具有经济性。

一、引言

机器人肝切除术（robotic liver resection, RLR）作为一项新技术，相比腹腔镜肝切除术（laparoscopic liver resection, LLR）可能具有更佳的手术安全性，但其手术

* 梁霄，浙江大学医学院附属邵逸夫医院；官海静，首都医科大学附属北京天坛医院；郑俊浩，浙江大学医学院附属邵逸夫医院；杨辰越，浙江大学医学院附属邵逸夫医院。通信作者：梁霄 E-mail：srrshlx@zju.edu.cn。

费用往往更高。因此，使用机器人切除术治疗肝细胞性肝癌（Hepatocellular carcinoma，HCC）是否具有经济学效应，目前仍然缺乏相关证据。

当今机器人肝切除相关的卫生经济学研究在国内外报道较少。2022 年 1 篇纳入了 4 篇相关文献的 meta 分析显示，RLR（20,205.92 美元）的成本远远高于 LLR（15,789.75 美元）。费用是制约 RLR 开展的重要因素（Ciria 等 2022）。然而，随着现代医学的发展，手术不仅是为了治愈，也是为了提高生活质量。2020 年 Mejia 等报道了 214 例肝切除患者，指出与 LLR 相比，RLR 尽管费用更高，但患者住院时间更短，对于小范围肝切除患者是更好的选择（Mejia 等 2020）。然而，2016 年我国学者根据机器人和腹腔镜肝左外叶切除手术的 39 例患者资料指出，对于肝左外叶切除，RLR 比 LLR 手术费用更昂贵，但在疗效和安全上差异无统计学意义（尹注增等 2016）。因此，RLR 是否能改善生活质量并具有成本效益仍然是一个争论。

2023 年的国际机器人肝切除专家指南指出，相较于 LLR，RLR 在肝脏相关疾病中具有独特的治疗价值，其成本效用值得未来继续研究（Liu 等 2023）。在泌尿外科、大肠外科等学科中，已有研究认为机器人手术具有成本效益，或者指出有利于提高机器人的应用率所需降低的费用（Simianu 等 2020；Song 等 2022）。

二、研究方法

开展真实世界研究，回顾性收集浙江大学附属邵逸夫医院 2016 年 1 月 -2023 年 7 月诊断为 HCC 的住院患者，根据患者的手术方式分为 RLR 组与 LLR 组，在描述性分析的基础上，通过倾向性评分匹配控制混杂因素，探索不同治疗方式对于治疗结局和医疗费用的净效益，并进行经济学评价。开展亚组分析，探索研究结果的稳健性。

正态分布的连续变量描述为平均值 ± 标准差，偏态分布的连续性变量描述为中位数（四分位距），分类变量描述为频率和百分比。将年龄、BMI、AFP、INR、ALB、AST、TBIL、Child 分级、血管浸润、手术难度、ASA 分级作为协变量纳入模型进行拟合，计算倾向性评分，进行最邻近法匹配。PSM 采用 SPSS 25.0 版本进行分析。将患者按照 IWATE 手术难度分级分为“低难度”“中等难度”“高难度”“专家难度”4 个亚组，进行亚组分析。

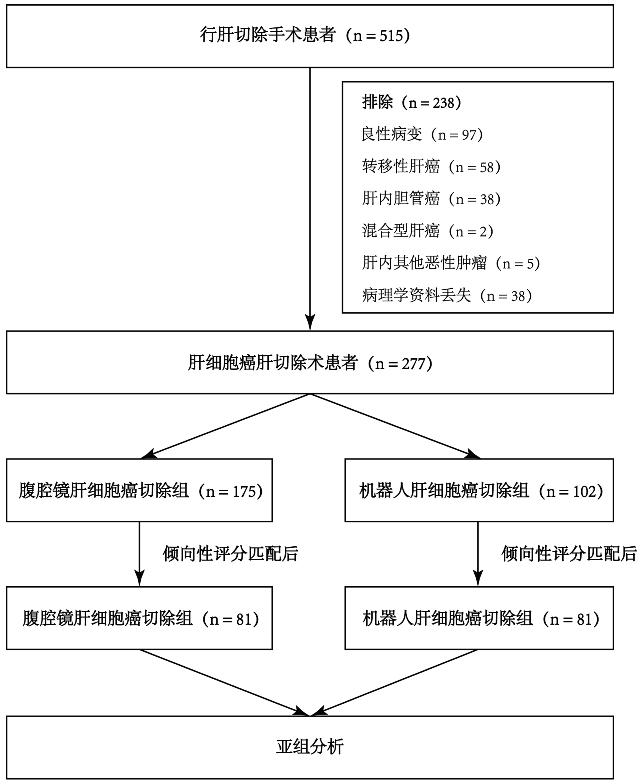

图 1. 纳入、排除标准及流程图

三、结果

经纳入、排除标准筛选后，共有 277 例患者被纳入本研究，根据手术方式分为 LLR 组（175 例）和 RLR 组（102 例）。PSM 后，两组各 81 例进一步进行比较分析。

3.1 患者基线指标

在倾向性评分之前，LLR 组的 BMI、AFP、PLT、INR、ALB、AST、肝硬化、Child-Pugh 分级、门脉高压、IWATE 手术难度分级与 RLR 组有显著性差异（均 $p < 0.05$）。余指标均无显著性差异。经过倾向性评分匹配平衡基线指标后，162 例患者（LLR 组与 RLR 组各 81 例）纳入进一步分析，LLR 组与 RLR 组的基线指标均无显著性差异。（附表 1）

3.2 患者临床结局指标

在倾向性评分之前，LLR组的术中出血量（100.0 vs. 50.0 ml，p＜0.001）、术中输血率（33［18.8%］vs. 10［9.8%］，p=0.045）、术后并发症发生率（35［20.0%］vs. 7［6.8%］，p=0.003）、术中转开放率（20［11.4%］vs. 0［0.0%］，p=0.001）、术后住院时间（6.0 vs. 5.0 day，p=0.001）、总住院时间（13.0 vs. 9.5 day，p=0.001）显著高于RLR组，其余指标均无显著性差异（均p≥0.05）。经过倾向性评分匹配平衡基线指标后，共162例患者（LLR组与RLR组各81例）被纳入研究，LLR组的术中出血量（100.0 vs. 50.0 ml，p=0.002）、术后并发症发生率（16［19.8%］vs. 7［8.6%］，p=0.043）、术后住院时间（6.0 vs. 5.0 day，p=0.005）、总住院时间（12.0 vs. 10.0 day，p＜0.001）显著高于RLR组，其余指标均无显著性差异（均p≥0.05）。（附表2）

3.3 患者费用结局指标

在倾向性评分之前,LLR组的住院总费用(57150.9 vs. 81432.5元,p＜0.001)、自付费用(16875.0 vs. 50333.4元,p＜0.001)、手术费用(6916.0 vs. 43424.9元，p＜0.001）显著低于RLR组，然而药物费用（15879.4 vs. 9955.6元，p＜0.001）、检查费用（1260.0 vs. 1160.0元，p=0.010）、护理费用（1164.0 vs. 989.6元，p=0.001）、耗材费用（21113.4 vs. 12094.4，p＜0.001）显著高于RLR组。经过倾向性评分匹配平衡基线指标后,共162例患者(LLR组与RLR组各81例)被纳入研究，LLR组的住院总费用（58643.8 vs. 82885.3元，p＜0.001）、自付费用（15972.7 vs. 50706.2元，p＜0.001）、手术费用（6616.0 vs. 43424.9元，p＜0.001）、其他费用（341.0 vs. 535.0元，p=0.004）显著低于RLR组，药物费用（16517.6 vs. 9975.0元，p＜0.001）、检查费用（1365.0 vs. 1115.0元，p=0.010）、护理费用（1174.0 vs. 988.6元，p=0.001）、耗材费用（21565.4 vs. 12069.4元，p＜0.001）显著高于RLR组。（附表2）

3.4 亚组分析结果

以IWATE手术难度分级为协变量进行亚组分析，结果显示，在“低难度”“中等难度”“高难度”3个亚组内，LLR组的住院总费用显著低于RLR组（低难度：46125.7 vs. 76647.9元，p＜0.001；中等难度：52692.8 vs. 76428.8元，p=0.003；高难度：67548.3 vs. 84725.0元，p=0.001），然而，在“专家难度”

组内，LLR 组与 RLR 组的住院总费用没有显著性差异（75709.0 vs. 88292.6 元，p=0.325）。（图 2）

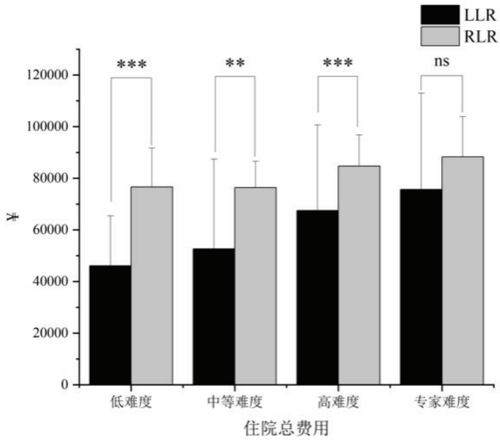

图 2. 住院总费用的手术难度亚组分析

注：

*** 代表 p ＜ 0.001

** 代表 p ＜ 0.005

ns 代表 p ＞ 0.05

四、小结

对于肝细胞癌患者，机器人肝切除比腹腔镜肝切除具有更好的手术安全性和更高的医疗费用，同时，高手术难度患者采用机器人肝切除术更具有经济性。

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附表 2.　PSM 前后 LLR 组与 RLR 组结局指标

基线指标						
	PSM前 (n=277)			PSM后 (n=162)		
	LLR (n = 175)	RLR (n = 102)	p值	LLR (n=81)	RLR (n=81)	p值
年龄 (SD), year	58.7±12.2	60.6±11.5	0.056	62.9±11.6	61.4±11.2	0.390
BMI (SD), kg/m^2	23.2±2.8	24.1±3.6	**0.021**	23.6±3.0	24.0±3.3	0.406
性别, n(%)			0.309			0.678
女	23 (13.1)	18(17.6)		13(16.0)	15(18.5)	
男	152 (86.9)	84(82.4)		68(84.0)	66(81.5)	
肿瘤最大径 (IQR), cm	2.6 (1.8-4.3)	3.0 (2.2-4.5)	0.163	2.5 (1.8-4.4)	3.2(2.2-4.7)	0.082
AFP (IQR), ng/mL	17.2 (3.4-277.5)	6.6 (2.5-110.2)	**0.048**	10.2 (3.2-139.8)	6.6(2.6-110.2)	0.403
PLT (IQR), $\times10^9/L$	126.0 (89.0-172.0)	143.5 (111.0-191.2)	**0.005**	124.0 (95.5-170.0)	138.0 (108.0-190.0)	0.050
PT (IQR), s	13.8 (13.1-14.6)	13.5 (13.0-14.2)	0.068	13.5 (12.9-14.1)	13.5 (13.1-14.2)	0.437
INR (IQR)	1.0 (1.0-1.2)	1.0 (1.0-1.1)	＜0. 001	1.0 (1.0-1.1)	1.0 (1.0-1.0)	0.307
TBIL (IQR), μmol/L	14.9(11.1-21.1)	14.8 (11.2-19.1)	0.728	14.2 (9.6-21.3)	15.3 (11.4-18.8)	0.589

ALB (SD), g/L	39.4±4.8	40.9±4..5	**0.013**	40.2±4.4	40.0±3.6	0.794
AST (IQR), U/L	27.0 (18.0-40.0)	30.0(23.8-38.0)	**0.026**	25.0(17.0-41.0)	29.0(23.5-38.0)	0.100
ALT (IQR), U/L	29.0(22.0-39.0)	27.0(19.0-42.3)	0.364	29.0(21.5-39.0)	27.0(19.0-41.5)	0.559
肿瘤数量, n(%)			0.819			0.658
单发	151(86.3)	87(85.3)		68(84.0)	70(86.4)	
多发	24(13.7)	15(14.7)		13(16.0)	11(13.6)	
肝硬化, n(%)	96(54.8)	41(40.2)	**0.016**	38(46.9)	32(39.5)	0.341
Child-Pugh分级, n(%)			**0.049**			1
A	159(90.9)	99(93.1)		78(96.3)	78(96.3)	
B or C	16(9.1)	3(2.9)		3(3.7)	3(3.7)	
门脉高压, n(%)	11(6.2)	0(0)	**0.028**	5(6.2)	0(0.0)	0.074
既往肝切除, n(%)	22(12.6)	14(13.7)	0.844	12(14.8)	12(14.8)	1
既往开腹手术, n(%)	56(32.0)	35(34.3)	0.693	27(33.3)	31(38.3)	0.512
既往新辅助治疗, n(%)	25(14.2)	10(9.8)	0.279	6(7.4)	9(11.1)	0.416
IWATE肿瘤位置 (IQR)	5.0(3.0-5.0)	5.0(3.0-5.0)	0.949	5.0(3.0-5.0)	5.0(3.0-5.0)	0.576
IWATE肿瘤大小 (IQR)	0.0(0.0-1.0)	1.0(0.0-1.0)	0.179	0.0(0.0-1.0)	1.0(0.0-1.0)	0.140
IWATE手术方式 (IQR)	0.0(0.0-4.0)	3.0(0.0-4.0)	0.195	0.0(0.0-4.0)	0.0(0.0-4.0)	0.946
IWATE靠近脉管 (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	0.541	0.0(0.0-0.0)	0.0(0.0-0.0)	0.135
IWATE Child-Pugh (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	**0.049**	0.0(0.0-0.0)	0.0(0.0-0.0)	0.988
IWATE手助腹腔镜 (IQR)	0.0(0.0-0.0)	0.0(0.0-0.0)	1	0.0(0.0-0.0)	0.0(0.0-0.0)	1
IWATE总分 (IQR)	6.0(5.0-9.0)	7.0(5.0-9.0)	0.176	6.0(4.0-9.0)	6.0(4.5-9.0)	0.57
IWATE难度分级，n(%)			**0.003**			0.916

低难度	27(15.4)	19(18.6)		16(19.8)	16（19.8）	
中等难度	82(46.9)	28(27.5)		29(35.8)	25(30.9)	
高难度	31(17.7)	35(34.3)		21(25.9)	23(28.4)	
专家难度	35(20.0)	20(19.6)		15(18.5)	17(21.0)	
ASA分级, n(%)			0.206			0.692
I级	8(4.6)	1(1.0)		2(2.5)	1(1.2)	
II级	155(88.6)	94(92.2)		72(88.9)	75(92.6)	
III级	12(6.9)	7(6.9)		7(8.6)	5(6.2)	
IV~VI级	0(0.0)	0(0.0)		0(0.0)	0(0.0)	
医疗保险，n(%)			0.074			0.070
城镇职工基本医疗保险	164(93.7)	101(99.0)		74(91.4)	80(98.8)	
其他保险	11(6.3)	1(1.0)		7(8.6)	1(1.2)	
居住地, n(%)			0.803			0.727
本地	47(26.9)	26(25.5)		24(29.6)	22(27.2)	
外地	128(73.1)	76(74.5)		57(70.4)	59(72.8)	

附表2.　PSM前后LLR组与RLR组结局指标

结局指标	PSM前 (n=277)			PSM后 (n=162)		
	LLR (n = 175)	RLR (n = 102)	p值	LLR (n=81)	RLR (n=81)	p值
手术时间 (IQR), min	168.0 (125.0-240.0)	165.0 (110.0-220.0)	0.263	180.0 (120.0-250.0)	160.0 (107.5-220.0)	0.134
切缘状态, n(%)			0.464			1
R0	172 (98.3)	98(96.1)		80(98.8)	79(97.5)	
R1 or R2	3 (1.7)	4(3.9)		1(1.2)	2(2.5)	
术中出血量 (IQR), mL	100.0 (50.0-400.0)	50.0 (50.0-112.5)	**<0.001**	100.0 (50.0-275.0)	50.0 (50.0-125.0)	**0.002**

术中输血情况，n(%)	33(18.8)	10(9.8)	**0.045**	12(14.8)	8(9.8)	0.339
术后并发症，n(%)	35(20.0)	7(6.8)	**0.003**	16(19.8)	7(8.6)	**0.043**
ClavienD-indo分级，n(%)			**0.006**			0.062
No	140(80.0)	95(93.1)		65(80.2)	74(91.4)	
I or II	25(14.3)	6(5.9)		10(12.3)	6(7.4)	
III or IV or V	10(5.7)	1(1.0)		6(7.4)	1(1.2)	
术中转开腹情况，n(%)	20(11.4)	0(0.0)	**0.001**	5(6.2)	0(0.0)	0.069
住院期间再次手术，n(%)	0(0.0)	0(0.0)	/	0(0.0)	0(0.0)	/
围术期死亡情况，n(%)	0(0.0)	0(0.0)	/	0(0.0)	0(0.0)	/
术后住院时间 (IQR), day	6.0(4.0-7.0)	5.0(3.8-6.2)	**0.001**	6.0(4.0-7.0)	5.0(3.5-6.0)	**0.005**
术后30天因并发症再入院，n(%)	3(1.7)	1(1.0)	1	2(2.5)	1(1.2)	1
总住院时间 (IQR), day	13.0(10.0-16.0)	9.5(7.0-13.0)	**<0.001**	12.0(10.0-16.0)	10.0 (8.0-12.0)	**<0.001**
住院总费用 (IQR), 元	57150.9 (44313.0-76302.3)	81432.5 (74644.9-90934.2)	**<0.001**	58643.8 (45171.2-75899.8)	82885.3 (75617.3-90501.2)	**<0.001**
自付费用 (IQR), 元	16875.0 (9911.2-23013.9)	50333.4 (46274.6-57632.8)	**<0.001**	15972.7 (8999.7-23056.8)	50706.2 (46796.8-57640.6)	**<0.001**
药物费用 (IQR), 元	15879.4 (11219.3-23459.2)	9955.6 (7687.4-14007.0)	**<0.001**	16517.6 (11994.0-24028.5)	9975.0 (7861.8-14117.4)	**<0.001**

手术费用(IQR), 元	6916.0 (6302.0-7834.3)	43424.9 (42808.6-43897.9)	**<0.001**	6616.0 (6165.0-7481.4)	43424.9 (42754.1-43994.5)	**<0.001**
检查费用(IQR), 元	1260.0 (930.0-2153.0)	1160.0(673.0-1752.8)	**0.010**	1365.0 (1075.0-2340.0)	1115.0 (659.0-1602.0)	**0.001**
护理费用(IQR), 元	1164.0 (879.0-1521.0)	989.6 (784.0-1291.3)	**0.004**	1174.0 (832.5-1555.0)	988.6 (779.9-1255.1)	**0.012**
耗材费用(IQR), 元	21113.4 (15486.0-31411.4)	12094.4 (10839.8-18034.8)	**<0.001**	21565.4 (15899.2-32842.0)	12069.4 (10898.8-19094.2)	**<0.001**
其他费用(IQR), 元	386.0(182.0-722.0)	486.5 (246.5-851.8)	0.054	341.0(182.0-683.4)	535.0 (276.5-863.0)	**0.004**

基于真实世界数据的机器人辅助膝关节置换术临床效能和卫生经济学评价：进展报告

吕蓓妮 宋洋 周一新*

摘　要　我国膝关节疾病负担重，其中人工关节置换是治疗终末期膝关节炎最有效的方法。相比于传统的手术方式，机器人辅助膝关节置换具有定位精准度高、一致性强、术后疼痛减少以及功能恢复早等优点，有望改善患者预后。但机器人辅助膝关节医疗费用较传统手术高，是否具体经济性需要进行系统的卫生经济学评价。经过前期数据清理，本研究纳入281例机器人辅助全膝关节置换的患者，匹配年龄、性别、手术日期和术侧后，纳入281例接受非机器人辅助全膝关节置换的患者。初步数据发现，两组患者在年龄、体重指数和基线健康水平相似。相比于非机器人辅助手术患者，机器人辅助手术患者手术时间较长（97.56分钟VS.79.05分钟，p<0.001），但术中引流量较少（1.42%　VS.9.25%术中引流量>0,p<0.001）。研究将继续随访收集患者关节满意度、生活质量和医疗支出等数据，以进一步评估两种术式的临床预后和经济性。

一、背景

随着我国人口老龄化程度不断加剧，膝关节炎疾病负担也在不断上升，截至2019年底，我国约1.2亿人口患有髋膝关节炎 (Long et al. 2020)according to age, sex, and geographical location, from 1990 to 2017.</p><h3>Methods</h3><p>Data were obtained from systematic reviews of symptomatic osteoarthritis of the knee and hip in the Global Burden of Diseases, Injuries, and Risk Factors Study 2017 (GBD 2017。人工关节置换是治疗终末期膝关节炎最有效的方法 (Kim et al. 2020)。传统的膝关节置换术面临着手术精准性不足、缺少数字化智能化工具、翻修失败率高等问题。而机器人辅助膝关节置换凭借其定位精准度和一致性高、术后疼痛减少以及功能恢复早等优点而受到广泛关注 (杨 et al. 2024; Subramanian et al. 2019)。早期的研究表明，与传统手术相比，机器人辅助关节置换术具有准确辅助截骨、个体化置入假体、更好地保

* 吕蓓妮，北京大学全球健康发展研究院；宋洋，首都医科大学附属积水潭医院；周一新，首都医科大学附属积水潭医院。通信作者：吕蓓妮，E-mail：blyu@pku.edu.cn。

护膝关节周围软组织、减少镇痛药物使用等优势，但也存在手术耗时延长等不足（邵等 2023；Subramanian 等 2019；杨等 2024）。尽管机器人辅助关节置换有望改善患者预后，但其医疗费用远高于传统手术，这对于平衡有限的医疗资源与提升患者健康水平构成了挑战。骨科手术机器人在基础医疗保险方面的政策正在逐渐完善，针对机器人辅助关节置换，目前国内缺乏系统的经济性评价，这制约了医保支付等关键政策的制定和调整。利用接受髋膝关节转换的真实世界患者数据，研究将对比机器人辅助手术和非机器人手术髋、膝关节转换的临床效果、生活质量和成本，致力于明确机器人辅助髋膝关节置换的成本效果。

二、方法

研究将采用回顾性队列研究，纳入 2020.7-2024.3 期间因骨关节炎或关节畸形于就诊于积水潭医院矫形骨科，接受机器人辅助或传统全膝关节置换术、ASA 评分 I-II 级、21-80 岁的患者。研究排除妊娠期女性患者、膝关节翻修患者、伴有严重的屈曲畸形（＞20°）及严重内外翻畸形（＞20°）、类风湿性关节炎、感染性关节炎的患者。

研究通过医疗电子病历确认患者的人口学特征（年龄、性别）、手术适应症、术前全身疾病、手术时长、术中出血和引流量、术后并发症等信息。关于患者放射学评估指标（如髋－膝－踝角、股骨远端外侧角和胫骨近侧内侧角）、假体翻修、假体松动等事件以及患者的生活质量和关节和患者满意度，正在随访收集中。

统计分析：研究连续性变量呈现形式为平均值（标准差），分类变量的呈现形式为频数（百分比）。研究将使用 t 检验或卡方检验比较机器人辅助和传统膝关节置换术两组患者特征上的差异，双侧 $p<0.05$ 定义为有统计学显著差异。

三、初步结果

通过前期数据清理，研究纳入机器人辅助全膝关节置换手术患者 281 例，以 1：1 匹配年龄（±3 岁）、性别、手术日期（±60 天）和患侧，纳入 281 例接受非机器人辅助全膝关节置换手术患者。在匹配后，机器人辅助手术与非机器人辅助手术年龄和性别分布几乎完全一致（机器人辅助手术组平均年龄为 67.33 [6.86] 岁；非机器人手术组为 67.38 [6.51] 岁，表 1）。所有患者术前膝关节疾病诊断均为骨关节炎，其中 52.67% 的患者为左侧关节置换。两组患者在体重指数（BMI）、心脑血管疾病、糖尿病、美国麻醉学会（ASA）评分均无显著性差异（所有变量统计检测 $p>0.05$）。

我们观察到两组操作在手术相关指标上有显著差异。在手术时长时，机器人组

平均手术时长为97.56（21.25）分钟，而非机器人组为79.05（19.54）分钟，机器人手术组手术时长远高于非机器人组（p<0.001）。而在术中引流量上，大部分患者术中引流量均较少，故研究初步以是否有引流作为结局指标。研究观察到，机器人术中引流的比例远低于非机器人组（1.42% VS. 9.25,p<0.001）。两组患者在术中出血量上无显著差异。

四、初步讨论

经过关键特征匹配，研究纳入的机器人辅助全膝关节置换手术患者与非机器人手术组患者在基线特征无显著差异。在手术相关指标上，机器人辅助手术时间较长，但术中引流量少，这与既往研究相一致。研究提示机器人辅助膝关节置换术能够更好地保护内外侧副韧带，保留后交叉韧带胫骨侧止点 (Hampp, Sodhi, et al. 2019)。一项前瞻性队列研究表明，机器人辅助膝关节置换术可以减少医源性软组织包膜损伤 (Kayani et al. 2018)。Siebert 等人回顾性分析了 120 例患者（其中 70 例为机器人辅助全膝关节置换术），研究显示机器人辅助关节置换术后软组织肿胀较小 (Siebert et al. 2002)。此外，作为一种提高骨切割准确性的技术，机器人辅助膝关节置换手术可以有效减少肢体对齐的异常情况 (Hampp, Chughtai, et al. 2019)。机器人辅助手术对软组织的保护有助于更好地恢复术后下肢力线对齐、保持关节线、平衡屈曲和伸展间隙，并维持正常的 Q 角 (邵 et al. 2023)。准确的骨切割可能降低截骨失败率，减少软组织不必要的损伤，与传统手术相比，机器人辅助关节置换术后患者的疼痛程度、镇痛需求和物理治疗次数可能较低 (Hampp, Chughtai, et al. 2019)。

研究将继续数据收集，明确机器人辅助手术对关节置换假体存活等临床预后、生命质量以及医疗支出的影响，以更好地评估机器人辅助手术的经济性。

附表．机器人辅助全膝关节置换和非机器人辅助手术组的特征比较

	机器人组 (n=281)	非机器人组 （n=281）	P 值
年龄，岁	67.33（6.86）	67.38（6.51）	0.38
性别，女	230（81.85）	230（81.85）	1.0
膝关节骨关节炎	281（100）	281（100）	1.0

手术年份，2022 年以后	147 (52.31)	142 (50.53)	0.74
术侧，左侧	148 (52.67)	148 (52.67)	1.0
BMI，kg/m2	28.94 (10.93)	26.68 (3.86)	0.068
心脑血管疾病	156 （55.52）	136 48.40)	0.11
糖尿病	50 (17.79)	48 (17.08)	0.91
ASA 评分 1 级	93 (33.10)	106 (37.72)	0.33
手术时长，min	97.56 (21.25)	79.05 (19.54)	<0.001
术中出血量， mL	50.14 (37.79)	46.26 (27.55)	0.17
术中引流量 >0 mL	4 (1.42)	26 (9.25)	<0.001

BMI， body mass index; ASA, American Society of Anesthesiologists.
连续性变量为平均值（标准差），分类变量为频数（百分比）。

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手术机器人技术采用选择中的主观态度

陈婷 敖露 潘聿航 周楚帆 潘杰*

摘　要　态度是个体对某一类社会事物的一种心理倾向，其成分包括认知、情感和行为倾向。虽然主观态度的形成总是基于存在的客观事实证据和实际经验，但在社会和市场中，主观态度往往受到更多社会因素和社会网络的交叉影响，特别是医疗市场。在本次小短文中，我们将通过文献回顾和访谈分析，以多元视角简述了国际上及我国医疗市场中以手术机器人为例的卫生技术采用选择的主观态度及其成因。

关 键 词　手术机器人；技术采用；主观态度

尽管手术机器人具有高成本和成本效益尚不完全明确等特征，其在世界范围内已广泛扩散并仍具有较高的市场潜力 (Abrishami, Boer, and Horstman 2020; Lanfranco et al. 2004)。截至 2022 年底，全球已有超过 7,700 台机器人手术系统在临床中使用 (Intuitive Surgical 2023; Peng et al. 2023)，并在过去近三十年中，进行了超过 1,400 万例手术 (Intuitive Surgical 2023)，主要在普通外科、泌尿科、妇科和心胸外科等科室开展 (Anderson et al. 2012)。总体而言，机器人手术的临床优势是显然的，包括为手术提供舒适的操作环境、全方位的高分辨率三维视野、消除手部颤抖以及实现外科医生设想的精确操作等 (Lanfranco et al. 2004)，并在近年来被许多临床研究证实可一定程度上带来更好的临床效果，如较低的手术并发症、出血量、更短的住院时间以及更好更快的术后功能恢复等 (Song et al. 2022)。然而，关于手术机器人技术与传统技术相比的成本和收益的证据仍存在不少争议，这些益处还因不同的手术部位、手术量和外科医生的熟练程度而有所不同，理论上所有这些都可能需要在决定是否购买该技术时被考虑。研究表明，虽然二十多年来伴随达芬奇手术的快速传播发表了大量的临床效果研究，但这些研究的结果尚无定论，无法指导关于机器人手术的采购和采用的相关决策 (Abrishami, Boer, and Horstman 2020)。

基于科学临床证据的理性思考是一个必要的过程，但越来越多的专家和实证证

* 陈婷，四川大学华西公共卫生学院/四川大学华西第四医院 HEOA Group chenting_723@163.com；敖露，四川大学华西公共卫生学院/四川大学华西第四医院 HEOA Group 2352480696@qq.com；潘聿航，北京大学全球健康发展研究院 yhpan@pku.edu.cn；周楚帆，四川大学华西公共卫生学院/四川大学华西第四医院 HEOA Group 2023224040041@stu.scu.edu.cn；潘杰（通信作者），四川大学华西公共卫生学院/四川大学华西第四医院 HEOA Group panjie.jay@scu.edu.cn。

据指出，卫生技术，特别是先进技术的采用可能更多地被归于一个主观判断的决策过程 (Randell et al. 2019)。换言之，在技术扩散过程中，不仅是技术本身的性质，社会和心理因素也是影响是否采用这一新技术的重要考量。

公众对新技术（手术机器人）发展的接受度被认为是推动技术创新和进步的最关键因素之一 (Fabian Dekker, Anna Salomons, and Jeroen van der Waal 2017)。同时，有研究表明，大多时候公众对卫生创新技术的兴趣大多来自其技术机制或新事物如何运作，而不是其真正的临床效果 (Abrishami, Boer, and Horstman 2020)。一项在欧洲人群中展开的研究表明，在公众眼中，“医学和外科手术”是与“机器人”一词最频繁相关的词汇之一，但只有不到 5% 的人认为机器人在医学和外科手术领域的发展是积极的 (Ray, Mondada, and Siegwart 2008)。然而，不同文化背景下对现代机器人的认知和态度存在显著差异，一项延续研究表明，相比欧洲，日本人（80%）更能看到机器人在医学领域的积极作用 (Haring et al. 2014)。此外，对于著名的“达芬奇手术机器人”，这个名字即会在公众脑海中映射出一种“前沿高端”的印象，从而使其作为提供“先进医疗服务”的“象征”而受到看好和追捧 (Abrishami, Boer, and Horstman 2020)。

总体而言，技术采用决策的医疗机构方管理者对于手术机器人的主观态度，主要考量分为两个方面：“医院的支持成本”和“社会收益”。“医院的支持成本”可分为两个方面。一个是物质和管理成本：提供充足的资金、学习时间、新技术的放置和操作空间以及人员配备 (Randell et al. 2019)，部分学者认为，机器人手术的普及速度不足，主要是由于采购决策者考虑到高昂的成本和维护成本 (Soomro et al. 2020) 另一个方面是文化支持：需要有一种鼓励创新和容忍对以往技术实施干扰的开放的企业文化 (Randell et al. 2019)，此外，创新的采用是否与组织的定位和价值观相一致也是一个关键因素 (Compagni, Mele, and Ravasi 2015)。“社会收益”意味着寻求组织的知名度、建立技术领导力的声誉，以及将技术作为营销工具 (Compagni, Mele, and Ravasi 2015)。很多时候，手术机器人被视为医院广告的焦点，并被患者视为医疗质量高的标志 (Schwartz and Woloshin 2019; Sheetz, Claflin, and Dimick 2020)。因此，竞争是社会效益的关键词。就像大多数创新技术一样，“获得手术机器人实际上是将一个机构的手术专科营销为最先进领域的入场券” (Lanfranco et al. 2004)。区域竞争被认为是医院采用机器人技术的关键决定因素 (Barbash et al. 2014; Wright et al. 2016)=。调研结果表明，在现阶段的中国医疗市场下，手术机器人的“竞争收益”倾向与以往研究一致，虽然有最新研究表明在美国，部分医院会因竞争对手采用了手术机器人而“规避”该技术转而投资其它技术，以达到与竞争对手的“区别

化 ”(Sundaresan, Boysen, and Nerkar 2023)，这可能与医疗市场，机构定位和发展阶段有关，待研究进一步讨论。通常，一个组织所感知的竞争程度是很难完全客观评估的，主要是通过管理决策者的主观感受来判断。

在外科医生的视角下，对手术机器人的看法，主要取决于其对“技术收益”“机构和患者压力”“职业发展与定位”的感知与规划。虽然在治疗效果和经济回报方面的研究结果并不一致，但机器人手术系统确实在手术过程中为外科医生提供了直接便利。研究指出，50% 和 56% 的外科医生在开放和腹腔镜手术后会报告颈部或背部疼痛，但在机器人辅助手术中，这一数字仅为 23%(Bagrodia and Raman 2009)。另外，学习时间可能是外科医生重点考量的问题之一。一项报告称，平均每个泌尿外科医生可以比腹腔镜手术更容易地采用机器人前列腺切除术，传统腹腔镜手术估计需要 200-750 例患者，而机器人手术将手术时间控制在 4 小时以内的学习曲线约为 40 例 (Shah et al. 2021)。然而，该技术对外科医师也存在一些障碍。例如，机器人辅助手术被认为在许多手术类型中操作时间较长，这可能会影响外科医生的效率 (Turchetti et al. 2012)，同时访谈提及，手术机器人的开机预热时间较长，也是影响技术使用成本之一。“机构和患者压力”也被较多外科医生所感知，一些外科医生描述了来自高层管理的“压力”，要求他们“提供”机器人手术来完成“以前从未想过的”手术。(Abrishami, Boer, and Horstman 2020)。此外，对于已经配备机器人的机构，压力还来源于增加手术数量以降低平均成本 (Shah et al. 2021)。同时有研究表明，患者的偏好可能是促使医生采用机器人的一个重要因素 (Miraldo et al. 2019)。一些外科医生反映，当机器人手术患者的结果良好时，他们往往将结果归功于于技术，但如果结果不甚满意，则往往归因于外科医生没有很好地掌握机器人 (Abrishami, Boer, and Horstman 2020)。

有研究提出，机器人手术的实施在很大程度上是由外科医生主导的，但这些创新的实践通常通过缺乏严格的质量控制和风险评估 (Randell et al. 2019)。外科医生对风险和创新采用的态度是其对创新技术感知和偏好的核心因素之一 (Miraldo et al. 2019)。寻求社会收益或职业发展可能是外科医生实践的驱动因素：获得行业内突出地位和职业成长的机会 (Compagni, Mele, and Ravasi 2015)。此外，研究普遍认为，外科医生对科研和发表的追求也是影响其态度的因素之一 (Abrishami, Boer, and Horstman 2014)。虽然主观态度影响采用决策，但客观条件约束也应考虑。例如，在一个科室内，学习新技术的机会往往是不同的，与低年资医生相比，高年资的外科医生参与手术机器人技术学习与使用的机会更高 (Farivar, Flannagan, and Leitman 2015)，部分年轻医生即使有使用意愿暂时也无法实现，特别是在技术使用的早期。

总结与进一步计划

在本次小短文中，我们简述了在手术机器人采用决策中各利益相关方的主观态度起到的重要作用，以及态度形成可能的原因，但各利益相关方的观念态度实际是互相影响和制约的，且在不用医疗市场下也有所不同。本研究将展开进一步调研访谈和分析，厘清和在中国卫生体系下的现况与特征、主要矛盾和延伸问题。

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人工智能与外科职业壁垒:分析计划

潘聿航 易君健 周清源

摘　要　本文探究手术机器人引入对于外科性别比例的影响。在本次报告中， 我们总结了数据来源，基准回归模型，稳健性检验，异质性分析以及机制检验方法。

一、数据

为了研究引入达芬奇手术机器人对不同科室医生性别比例的影响，我们使用了三个数据来源。第一个数据来源记录了 2006 年到 2023 年，284 家中国医院安装并首次使用达芬奇机器人进行手术的月份。第二个数据记录了每一例使用达芬奇手术机器人进行的手术，包含了医生姓名、手术地点和时间等信息。从 2007 年到 2022 年，我们观测到了由 282 名女外科医生和 2349 名男外科医生进行的 314,138 例达芬奇手术。第三个数据是全　国 498 家三级甲等医院的病案首页数据，其中 79 家医院引入了手术机器人，而 419 家医院没有引入。

在病案首页数据中,我们可以观测到负责患者的四位医师——科主任、主任医师、主治医师和住院医师的姓名。因此，我们能够确定医师的职称并根据姓名预测性别。我们利用 GitHub 上的 ”ngender” 包来预测医生性别，其预测准确率约为 82%。此外，我们还采用了其他机器学习方法进行性别预测，作为稳健性检验的一部分。

二、实证策略

为了识别手术机器人分阶段引入对外科部门性别比例以及女性晋升机会的影响，我们采用事件研究法。在引入机器人后，医院的招聘决策和医学生的专业选择可能在一段时间后才逐渐发生变化，从而存在动态处理效应。因此，我们首先假设在不同时间引入机器人的医院 - 科室之间有同质处理效应，并使用标准事件研究模型作为基准模型来分解机器人引入的动态效应，并检验事前平行趋势假设。我们的基准模型如下：

* 潘聿航：北京大学全球健康发展研究院（E-mail：yhpan@pku.edu.cn）；易君健：北京大学国家发展研究院和全球健康发展研究院（E-mail：junjian@nsd.pku.edu.cn）；周清源：北京大学经济学院（E-mail：qingyuanzhou.econ@gmail.com）。

$$Y_{it}=\sum_{k=-12,\,k\neq-3}^{k=24}\beta_k MR_{it,k}+\delta_i+\eta_t+\epsilon_{it}\#(1)$$

其中，结果变量Y_{it}是反映在年份－月份 **t**，医院－科室 **i** 中，女医生的存在性、工作量以及晋升机会的指标。在广延边际上，如果在年份－月份 **t**，医院－科室 **i** 中有女性，则Y_{it} 取 1，否则取 0。此外，如果有女性科主任，则其取 1，否则取 0。在集约边际上，因变量是医院－科室 **i** 在年份－月份 **t** 中女性医生的比例、女性医生做的手术的比例，以及女性科主任、主任医师、主治医师和住院医师的比例。$MR_{it,k}$ 是虚拟变量，如果在年份－月 **t**，医院－科室 **i** 中，距离首次进行机器人辅助手术有 **k** 个月，则取 1，否则取 0。估计窗口为首次手术前一年到首次手术后两年，因此我们可以通 β_k. 的动态变化展示手术机器人引入的短期和长期影响。我们使用 k=-3 作为参考组，因为机器人引入的影响可能在首次使用其进行手术前就已发生。k=-3 的虚拟变量在回归中被省略。我们还控制了医院－科室固定效应 δ_i 和年份－月份固定效应 η_t.。医院－科室固定效应 δ_i 控制了可能影响女性比例，随时间不变，但随医院－科室变化的混杂因素。年份－月份固定效应 η_t. 则控制了特定月份所有医院受到的共同冲击，比如全国医疗政策变化和季节性患者数量的波动。ϵ_{it} 是误差项，我们将标准误差在医院－科室层面聚类。

然而，Sun 和 Abraham 2021 指出，如果处理效应存在组间异质性，动态双向固定效应模型的估计量可能是不一致的。在我们的语境中，例如，相比于不发达地区，机器人引入对女性比例的影响在中国更发达地区的医院可能更显著。如果存在组间异质性，在满足平行趋势假设的情况下，处理前系数可能不为零；而在违反平行趋势假设时，处理前系数反而可能是零。因此，为了提供一致估计量，我们参考了 Borusyak, Jaravel, 和 Spiess 2024, Callaway 和 Sant'Anna 2021, de Chaisemartin 和 d'Haultfoeuille 2020 ，以及 Sun 和 Abraham 2021 提出的异质性稳健估计量。注意，对于 Sun 和 Abraham 2021 提出的估计量，我们使用从未接受处理的医院 - 科室作为控制组，因此该估计量与 Callaway 和 Sant'Anna 2021 提出的估计量相同。

三、稳健性检验

本章展示了一系列稳健型检验。

首先，我们的估计量可能面临的一个威胁是违反了无预期效应假设。在一些医院，

不同科室可能共用同一台达芬奇手术机器人。实际上，我们也观测到一些科室在机器人安装时间和首次使用时间之间存在延迟。因此，这些科室的招聘人员可能会预测到手术机器人的使用，并在该科室首次进行机器人手术之前就进行人员调整。因此，我们去掉了机器人安装到首次手术使用之间超过三个月的医院－科室。

其次，我们检验了溢出效应。一个医院引入手术机器人可能会影响附近医院的性别比例。例如，拥有机器人的医院可能会吸引附近医院优秀的外科医生跳槽。此外，附近那些没有手术机器人的医院可能预计在不久的将来采用同样的技术，并招聘外科医生，尤其是女性。因此，我们将处理组重新定义为城市中首次引入达芬奇机器人的医院－科室。我们将对照组分为邻近对照组和远距离对照组。前者是那些所在城市引入了手术机器人的医院中从未引入机器人的科室；后者是那些所在城市从未引入手术机器人的医院。然后，我们利用公式（1）的模型设定对这三组医院－科室进行两两比较，以探讨是否存在溢出效应。

最后，我们分别更换了估计窗口期，去掉了分院，并保留窗口期持续出现的医院－科室重新估计公式（1）。

四、异质性分析

本章基于医院和科室的特征，考察机器人引入对不同子样本影响的异质性。

首先，我们探究在引入机器人后的第一个季度内有由女性进行机器人辅助手术的医院－科室，之后女性外科医生数量是否更有可能增加。可能的情况是，当有女性榜样存在时，招聘人员更倾向于认为女性能够胜任达芬奇手术。因此，女性榜样可能会鼓励更多女医学生进入该科室，招聘人员也可能会雇佣更多女性。

其次，我们探讨哪些类型的医院更可能对机器人引入做出反应。我们认为女性比例的变化可能因医院的排名和地理因素而异。例如，排名较高和位于发达地区的医院，雇主更有可能认识到技术进步带来的比较优势变化。因此，我们通过是否出现在“2022 年中国医院排行榜”上来测度医院的排名。该排行榜由中华医学会和中国医师协会的专家编制，包含了中国排名前 100 的医院。关于地理因素，我们按照国家统计局的区域经济划分标准，将中国分为四个区域：东部、中部、西部和东北。此外，我们还根据医院是否位于省会城市或直辖市对医院进行分类。

五、机制检验

在本节中，我们探讨机器人引入对外科性别结构产生影响的可能机制：体力需

求的减少、经济激励的变化以及患者偏好的变化。

首先，女性比例的上升可能是由性别比较优势的变化导致的。机器人的使用可以减少对体力和力量的需求，这些需求在机器人引入之前更有利于男性外科医生。为了检验女性是否不再因体力而处于劣势，我们将向医院招聘人员和外科医生发放问卷。

其次，性别构成的变化可能源于不同性别的人对薪酬结构和经济激励变化的反应不同。机器人技术的引入会导致手术费用发生变化，从而可能影响外科医生的薪酬结构。男性和女性可能会由于社会规范和职业抱负的不同，对经济激励作出不同的反应。例如，如果机器人辅助手术会带来更高的报酬，而可能会吸引更多重视财务回报的女性外科医生进入。为了排除这一竞争性假说，我们将控制每个医院－科室中机器人辅助手术和传统手术的平均价格差异。

第三，手术机器人的引入可能会改变患者对外科医生性别的偏好。这种变化可能源于患者对哪种性别的外科医生更擅长使用此类技术的认知。因此，我们将通过问卷调查评估患者对传统开放手术和达芬奇机器人辅助手术外科医生性别偏好的差异。

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机器人手术是否有助于降低胰腺恶性肿瘤的疾病经济负担？一项微观成本研究

石茵 武子婷*

摘　要　通过文献综述，总结机器人手术与腹腔镜或开放手术治疗癌症的成本的现有研究的主要结果和结论，以及该领域尚未解决的问题。主要结果和结论为：尽管初始费用较高，机器人胰腺癌手术显示出提高患者结果和降低长期成本的潜力。为了验证这些主张，需要进行更广泛的研究，并采用标准化方法，同时关注发展中国家的大规模研究和长期效果。外科医生的学习曲线对全面评估机器人手术在不同环境下的成本效益至关重要。

一、背景

虽然胰腺外科手术历史已逾百年，但由于较高的并发症发生率与病死率，仍被认为是腹部外科最具挑战的手术。胰腺癌的治疗方式包括开腹手术、腹腔镜手术和机器人辅助手术。开腹手术是传统的胰腺癌治疗方法，而腹腔镜和机器人手术是近年来发展起来的微创手术方式。当前，腹腔镜或机器人辅助手术应用于胰腺癌根治性治疗方面的争议焦点主要集中于治疗效果的肿瘤学评价与手术安全性等方面，但关于成本的比较则较少。

二、方法

研究人员通过检索 PubMed 中收录的文献获取研究所需信息。本研究使用了三组检索词，其一为“胰腺”和“胰腺”与“癌症”、“腺癌”和“癌症”，其二为“成本效益”、“成本效用”或简单的“成本”，其三为“机器人”和“外科手术”，将上述检索词以“AND”逻辑链接获得经济学评价主题结果。检索过程未限制语言。本研究纳入了 2011 年 1 月 1 日至 2024 年 5 月 30 日期间最相关的临床试验、系统综述和荟萃分析、其他原创研究文章和指南，由一名研究人员筛选和总结文献关键信息。

* 石茵，中南大学湘雅医院药学部；中南大学湘雅医院国家老年疾病临床研究中心；北京大学全球健康发展研究院，shiyin910515@csu.edu.cn；武子婷（通讯作者），北京大学全球健康发展研究院，wuziting@pku.edu.cn。

三、结果

机器人手术对比腔镜或开腹手术在胰腺癌治疗中的成本或成本效果/效用研究

关于机器人手术与腹腔镜或开放手术在胰腺癌治疗上的成本或成本效果/效用研究目前较少，共5项研究 (Kowalsky et al. 2019; Vicente et al. 2020; Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022)。其中，3项为成本分析，2项为成本-效用分析（详见表1）。

1. 大部分现有研究基于真实世界数据，属于回顾性研究，重点关注一年内的短期围手术期或术后结果 (Kowalsky et al. 2019; Vicente et al. 2020; Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022)。数据通常从机构数据库中回顾性收集。缺乏长期的成本效果或效用研究，难以评估机器人手术在长期结局和成本效果/效用方面是否优于腹腔镜或开放手术。此外，所有五项研究均为单中心研究，可能影响研究结果的外部效度和普遍适用性。

2. 当前研究普遍采用相似的结果衡量指标。成本效用研究中的测量指标为增量成本效果比（ICER），健康结果指标为质量调整生命年（QALY）。与临床效果相关的指标包括住院时间、手术时间、失血量、并发症率（如胰瘘、伤口感染）及恢复时间等围手术期相关指标。成本收集仅限于围手术期间的直接医疗成本。全面的成本分析应不仅包括直接手术成本，还应涵盖长期结果和间接成本，如康复及重返工作成本 (Caruso et al. 2022)。

3. 现有研究均集中在发达国家，缺少发展中国家的数据。由于经济发展水平和社会发展阶段的差异，发达国家的成本效益结果难以直接应用于发展中国家。因此，迫切需要关注机器人手术在发展中国家治疗胰腺癌的成本效益。

4. 多数研究表明，机器人手术因昂贵设备和较长手术时间而导致术中成本普遍较高。然而，这些成本往往因住院时间缩短和并发症率降低而得到补偿 (Caruso et al. 2022; Di Franco et al. 2022; Benzing et al. 2022)。一些研究强调了机器人系统的高额初始投入作为普及应用的障碍，突显了通过减少术后护理需求和加快康复速度实现长期成本节约的必要性 (Caruso et al. 2022; Benzing et al. 2022)。其他研究则指出，机器人手术的学习曲线初期可能会增加成本和手术时间，但随着外科医生经验的积累，这些指标会有显著改善。

总的来说，尽管机器人胰腺癌手术初期成本较高，但显示出改善患者预后并潜在降低长期医疗成本的前景。为了巩固这些发现，需要进一步采用标准化方法和更

大样本量的研究。此外，针对发展中国家和长期结果的研究对于全面理解不同情境下机器人手术的成本效果/效用和其他获益至关重要。

表 1 机器人手术对比腔镜或开腹手术在胰腺癌治疗中的成本或成本效果/效用研究关键信息汇总

作者和年份	国家	分析类型	研究角度	研究设计	干预组	对照组	时间范围	主要指标	结论
Kowalsky SJ (2019) (Kowalsky et al. 2019)	美国	成本分析	/	回顾性研究	RPD	OPD	2年	术后平均住院日（LOS），以及30天内的总费用（包括在这期间内任何再次住院的费用）。	加强术后恢复与机器人手术方法的结合，与其他策略相比，能够协同减少住院时间和总体成本。
Vicente E (2019) (Vicente et al. 2020)	西班牙	成本效用分析	支付者角度	前瞻性研究	RDP	LDP	1年	ICER	两组的总体平均总成本相似。RDP的平均QALY为0.652，高于LDP的0.59（P＞.5）。结果显示RDP更具优势。
Caruso R (2022) (Caruso et al. 2022)	西班牙	成本效用分析	支付者角度	前瞻性研究	RPE	OPE	1年	ICER	相比OPE，RPE的成本效用可接受。
Franco GD(Di Franco et al. 2022)	意大利	成本分析	/	病例匹配研究	RPD	OPD	术后短期	围术期数据及直接医疗成本	尽管RPD与更高的材料成本相关，但由于机器人系统与较低的住院成本相关，以及由于与OPD相比手术时间相似，人员成本没有差异，这使得两种技术的总体可变成本（OVCs）没有差别。因此，先进技术的更高成本可以部分地通过临床优势得到补偿，特别是在一个高样本、多学科中心。
Benzing C (2022) (Benzing et al. 2022)	德国	成本分析	/	回顾性研究	RPS	OPS	围术期	围术期数据及术中、术后成本	RPS的手术结果与OPS相似。RPS较高的手术中成本被其他成本效果上的优势所抵消，例如减少的住院时间长度。

RPD：机器人辅助胰十二指肠切除术；OPD：开放胰十二指肠切除术；RDP：机器人辅助远端胰腺切除术；LDP：腹腔镜远端胰腺切除术；RPE：机器人胰腺切除术；OPE：

开放胰腺切除术；RPS：机器人胰腺手术；OPS：开放胰腺手术；QALYs：质量调整生命年；ICERs：增加成本效果比。

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医疗技术在不同维度上的比较优势：来自子宫切除术的证据

Nathaniel Breg*

摘　　要　理解技术扩散的程度在经济学领域以及特定的医疗保健领域中都非常重要。这篇研究展示了新技术可能在不同维度上存在质量或生产率上的权衡。本研究利用Roy模型分析该权衡问题，并由此解释两种技术可以共存的原因。该模型也是使用工具变量揭示权衡相关证据的理论基础。局部平均处理效应可以用于成本效益分析，以评估技术是否已扩散到有效的程度。本研究使用患者到开展腹腔镜（微创）手术的医院的距离，相对于其到开展任意手术的医院的距离，作为她是否接受腹腔镜而非腹部（开放）子宫切除术的工具变量。在Medicare住院保险索赔中，通过准实验设计，本研究发现，对于在这两种手术方式之间选择的边际患者，相对于腹部子宫切除术，腹腔镜手术术后的住院时间更短，但再入院率更高。这表明，至少在某些患者子群体中，腹腔镜手术存在权衡。通过初步成本效益分析，本研究估计，对于这些边际患者，腹腔镜手术可能带来净损失，这说明对于该群体，可能存在过多的腹腔镜手术。

JEL 分类　I1，J0

关　键　词　比较优势　医疗生产率　医疗技术　医生决策　手术　女性健康

一、贡献

本研究在概念上的主要贡献是展示了如果技术在不同质量或生产率维度上存在权衡，那么新旧技术可以共存。以往文献表明，产品会在多个特征维度上不断演进，消费者也重视这些创新，这种现象在计算机断层扫描 (CT) 和汽车市场中得到了体现 (Trajtenberg, 1989; Grieco，Murry and Yurukoglu, 2023)。不同的特征可能会影响技术生产率的不同维度。本研究借助 Roy 模型证明，至少在某些应用场景中，两种技术可以共存，因为一种技术在一个维度上提供相对改进，但在另一个维度上可能存在缺陷。在本研究中，腹腔镜手术在所有情况下都比开放手术住院时间更短，

* Nathaniel Breg, Stanford University.

但并非所有患者都选择了它。因此，它必然对在两种技术之间几乎无差异的患者造成更高的再入院风险。先前的研究发现，影响新技术扩散速度或不完全性的其他因素，包括财务激励 (Finkelstein, 2007; Acemoglu and Finkelstein, 2008; Clemens and Gottlieb, 2014)、信息摩擦 (Skinner and Staiger, 2015) 和新技术计费过程中的行政障碍 (Dranove, Garthwaite, Heard and Wu, 2021)。在其他行业，技术共存的现象被归因于不同技术共同创新的成本和收益（Bresnahan and Greenstein, 1996)、产品特征的限制 (Gross, 2018)、公司规模 (Karshenas and Stoneman, 1993) 以及缺乏互补资本 (Goldfarb, 2005)。本研究表明了技术可以共存，因为旧技术在某些患者的身体健康方面仍然具有优势。

本研究在方法上的贡献首先为通过工具变量方法估计边际患者中的技术相对有效性，以揭露在技术上的权衡。研究基于直观且常见的方法 (McClellan, McNeil and Newhouse, 1994)，使用患者到一种替代方案相对于另一种替代方案的相对距离作为工具变量，来估计在两种选择之间处于边际状态的患者的处理效应。同样，研究通过比较住得离进行腹腔镜子宫切除术的医院较近的患者和离进行任何子宫切除术的医院较近的患者的相对距离，来估计腹腔镜子宫切除术相对于腹部子宫切除术在两个关键不良结果上的影响。研究方法基于一个比较优势微观经济模型。几乎无差别选择的患者在某个维度上的改进和另一个维度上的损害之间面临权衡，他们可能被工具变量引导选择其中一个。劳动计量经济学文献中的边际处理效应方法识别这些边际案例的处理效应，两阶段最小二乘回归识别的局部平均处理效应是这些边际处理效应的正加权组合 (Heckman and Vytlacil, 1999, 2001；Heckman, Urzua and Vytlacil, 2006)。

其次，通过量化这种权衡，可以使用边际效应估计来评估技术扩散的效率。

二、理论

为了说明本文的核心观点，本研究构建了一个 Roy (1951) 模型，在该模型中，患者和医生根据替代方案对生产率两个维度的影响（而不仅仅是一个维度）来选择技术。这使得本研究能够识别技术质量维度改进上的异质性在技术扩散程度中的作用。在模型中，腹腔镜手术在所有情况下都在住院时间维度上表现更好，因为它是微创的，但并非所有人都选择它。因此，腹腔镜手术至少在边际患者和部分腹部手术患者中造成更高的再入院风险。

三、方法

为估计腹腔镜手术在边际病例中的相对效应，本研究使用患者到最近的开展腹腔镜手术医院的距离，相对于其到最近的开展任何子宫切除术医院的距离，作为接受腹腔镜手术而非腹部子宫切除术的工具变量。本研究利用 Medicare Part A 保险索赔估计局部平均处理效应。这种识别策略利用了患者对离其住所较近的医疗服务提供者的偏好，遵循了 McClellan、McNeil 和 Newhouse (1994) 的研究结果。Hadley 和 Cunningham (2004) 提出，距离对护理选择的影响可能被与健康相关的社会经济条件混淆，为控制该影响，本研究控制了一系列患者所在社区的特征、医院特征和医院转诊区域固定效应。

四、数据

本研究纳入了 2007 年至 2008 年所有 Medicare Part A 覆盖的全子宫切除术。这包括在 3340 家医院中进行的 61,241 例子宫切除术。这些索赔详细描述了患者状况以及所进行的手术，也记录了患者和医院的邮政编码。本研究将这些数据与美国社区调查中的患者社区特征数据进行了合并。

五、结果

证据表明，对于在两种子宫切除术方法之间选择的边际患者，腹腔镜手术在减少住院时间和增加再入院风险之间存在权衡。研究估计，符合相对距离工具变量理论的患者在接受腹腔镜手术后，住院时间达到 2 天或更长的概率比接受腹部手术的患者低约 55%，但他们 10 天内全因再入院的概率增加了 23%-36%。未发现有其他文献使用工具变量来探索边际患者在不同质量维度之间的权衡。

本研究使用点估计，对准实验中符合条件的患者进行腹腔镜子宫切除术相对于腹部子宫切除术的初步成本效益分析，以评估类似于腹腔镜子宫切除术这样的技术扩散程度的效率。假设住院一天的费用是 2,490 美元 (Foundation, 2021)，再入院的费用是 15,200 美元 (Weiss and Jiang, 2006)，那么本研究的点估计表明，对于边际患者，腹腔镜手术可能带来预期净损失为 2,054 美元。这个结果很可能低估了净损失，因为研究中未纳入非金钱成本，而非金钱成本在再入院情况下可能比住院多一天更高。因此，从个体患者效用的角度来看，在这些 Medicare 覆盖的子宫切除术患者中，腹腔镜手术可能开展过多。

最后，本研究还发现患者对不同技术的反应存在差异，影响了技术的比较优势。

那些对腹腔镜手术有最大抵触情绪（即最不倾向于选择腹腔镜手术）的患者，即使他们在腹腔镜手术下住院时间的潜在减少最大，他们也会有最高的再入院风险，但是该边际效应估计并不精确。该结果类似 Suri (2011) 文章中的发现，他发现那些从采用新杂交玉米技术中获益最大的农民也面临最高的采用成本，因此不使用该技术。

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北京大学全球健康发展研究院
地址:北京市海淀区颐和园路5号100871
邮箱:ghd@pku.edu.cn
电话:+86 10 6275 7318
网址:www.ghd.pku.edu.cn

PKU Institute for Global Health and Development
5 Yiheyuan Road, Haidian District Beijing, China,100871
E-mail: ghd@pku.edu.cn
Office : +86 10 6275 7318
Website: www.ghd.pku.edu.cn