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Are hospitals “keeping up with the Joneses”?: Assessing the spatial and temporal diffusion of the surgical robot☆

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ABSTRACT

Background: The surgical robot has been widely adopted in the United States in spite of its high cost and controversy surrounding its benefit. Some have suggested that a “medical arms race” influences technology adoption. We wanted to determine whether a hospital would acquire a surgical robot if its nearest neighboring hospital already owned one.
Methods: We identified 554 hospitals performing radical prostatectomy from the Healthcare Cost and Utilization Project Statewide Inpatient Databases for seven states. We used publicly available data from the website of the surgical robot's sole manufacturer (Intuitive Surgical, Sunnyvale, CA) combined with data collected from the hospitals to ascertain the timing of robot acquisition during year 2001 to 2008. One hundred thirty four hospitals (24%) had acquired a surgical robot by the end of 2008. We geocoded the address of each hospital and determined a hospital's likelihood to acquire a surgical robot based on whether its nearest neighbor owned a surgical robot. We developed a Markov chain method to model the acquisition process spatially and temporally and quantified the “neighborhood effect” on the acquisition of the surgical robot while adjusting simultaneously for known confounders.
Results: After adjusting for hospital teaching status, surgical volume, urban status and number of hospital beds, the Markov chain analysis demonstrated that a hospital whose nearest neighbor had acquired a surgical robot had a higher likelihood itself acquiring a surgical robot (OR = 1.71, 95% CI: 1.07–2.72, $p = 0.02$).
Conclusion: There is a significant spatial and temporal association for hospitals acquiring surgical robots during the study period. Hospitals were more likely to acquire a surgical robot during the robot's early adoption phase if their nearest neighbor had already done so.

1. Introduction

The surgical robot has been widely adopted in the United States in spite of its high cost and controversy surrounding its benefit[1,2] since its approval by the Food and Drug Administration in 2001. Facilitating the performance of laparoscopic procedures, robotic surgical devises allow a surgeon to operate remote-controlled robotic arms which can manipulate a patient's tissues, while the surgeon is seated at a console in the operating room. The surgical robot is very expensive: purchase prices range between $1 million and $2.25 million, an annual service contract costs $140,000 and per case disposables cost over $2000.[1,3,4] Published studies of the efficacy of robotic surgery have provided mixed results. Some studies have shown that robotic surgery results in benefits such as

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reduced length of stay and reduced intraoperative blood loss,[5–8] as compared to open surgery or standard laparoscopy. However, other studies have shown robotic surgery outcomes to be similar to or even worse than outcomes associated with traditional open or laparoscopic procedures.[9–12]

Given the high cost and uncertain benefit of surgical robots, the reasons for rapid adoption of this technology are unclear. Some have suggested that factors other than improving health outcomes, such as the robot's utility in hospital marketing, played a role[13]; a new literature has emerged focusing on hospital-intrinsic factors associated with the adoption of the surgical robot. Adopter institutions tend to have higher surgical volume and are larger; located in urban areas, and tend to be academic medical centers.[13] In addition to intrinsic hospital factors, environmental factors, such as hospital competition for physician-recruits and patients may also play a role in the diffusion of the surgical robot.[14–16] In this medical competition model, technology is more likely to be adopted when a hospital's competitors acquire it. It is unknown whether such a neighborhood effect was important in the diffusion of the surgical robot.

We sought to determine whether a hospital was more likely to acquire a surgical robot if its neighbors acquired the technology. Because the surgical robot was diffusing throughout the US, a given hospital's neighborhood could change through time depending upon whether and when its neighbors might have acquired robots. To account for this challenge, we developed a two-state Markov chain method to determine the likelihood of a hospital adopting the surgical robot given whether the nearest neighbor hospital owned a robot or not. This novel method is able to quantify the “neighborhood effect” which we define as the likelihood of robot adoption as a function of local robot adoption. We hypothesized that having neighbor hospitals with surgical robots would increase the likelihood of a non-robot owning hospital's adoption of the same technology. If this hypothesis was true, it would suggest that a hospital's purchasing decisions, at least in part, are based on regional competition rather than on clinical evidence alone. If we found no neighborhood effect, it might suggest that regional competition was less significant than the hospital's intrinsic characteristics when deciding to adopt new technology. Understanding the diffusion of the surgical robot is extremely valuable to policy makers, physicians and patients who should be aware of factors influencing hospital behavior and their adoption of new technology, especially when this technology may be costly and unproven.

2. Methods

2.1. Study design and data source

We performed a retrospective study at the hospital level. We obtained data from the Healthcare Cost and Utilization Project (HCUP) Statewide Inpatient Databases (SID) for seven states (Arizona, Florida, Maryland, North Carolina, New York, New Jersey, and Washington) during the years 2001 and 2005 to determine which hospitals were at risk of acquiring a surgical robot. While there are a wide range of procedures which are now performed with the assistance of a surgical robot, its initial diffusion was driven primarily by the desire to perform robotic-assisted radical prostatectomy.[2] Therefore, we used these data to identify 554 hospitals in which at least one radical prostatectomy had been performed in any year between 2001 and 2005; two of these hospitals were excluded from the neighborhood analyses because of missing data. We combined publicly available data from the website of the surgical robot's sole manufacturer (Intuitive Surgical, Sunnyvale, CA) with data collected from the websites and personnel of the hospitals, who were contacted by telephone and email, to ascertain the date of robot acquisition by hospitals during 2001–2008. These data were subsequently linked with data from the 2005 American Hospital Association Annual Survey to determine hospital characteristics.

2.2. Neighborhood definition

We obtained the exact coordinates of each hospital using its address as reported in the AHA Annual Survey. We then geocoded each address and calculated the distance between any two hospitals. We were primarily interested in the effect of a hospital's nearest neighbor (i.e. a hospital's neighborhood as defined by its nearest hospital). Considering various definitions of a hospital's neighborhood, we conducted sensitivity analyses using two basic definitions: (1) the “Nearest K” Neighborhood and (2) the “Circle” Neighborhood. For the Nearest K Neighborhood method, we defined a hospital's neighborhood by its nearest K hospitals. As K increases more and more hospitals located in increasingly remote locations are included in the neighborhood and the neighborhood effect becomes progressively diluted; therefore, in order to maintain a sensible neighborhood definition, K should not be too large. The Circle Neighborhood method defined a hospital's neighborhood by those hospitals within a specified radius determined by the distance in miles from the reference hospital to its nearest neighbor plus K miles.[17] For both methods, we investigated $K=1$, 2, …, 5. Both definitions ensure that each hospital has at least one neighbor.[18] In addition, we restricted neighbors to being within the same state, except for NY and NJ, whose proximity led us to collapse them into a single region. In Fig. 1, an artificial example is used to illustrate these two neighborhood definitions.

2.3. Description of confounding variables

In studying the neighborhood effect, we sought to eliminate the possible confounding effects of hospital teaching status, urban status, hospital size and surgical volume, whose association with a hospital's time to adoption of the surgical robot has been previously described.[13] We adjusted our model for these factors as described in the next section. The distributions of surgical volume and hospital size were much skewed in the data, so we dichotomized a hospital's number of radical prostatectomies in 2001 (baseline) and number of beds using their respective medians.

2.4. Statistical analysis

In order to quantify the neighborhood effect on diffusion of the surgical robot, we analyzed the diffusion process by looking at how one hospital is influenced by its neighbor. We used a two-state Markov chain model to model the dynamic spatial and temporal process of surgical robot adoption. We assumed that the potential influence of prior adoption events does not vary with the length of time since their occurrence.[17] We modeled the probability of a hospital's having acquired a robot as a logistic function of calendar year, intrinsic hospital characteristics, and the robot ownership status of its neighbors during the prior year. The details of the modeling are given below.

Let $Y_i(t)=1$ if hospital i at year t has a robot and 0 otherwise. Suppose at the initial year $Y_i(1)$ is given. Let $Z_i(t)$ denote the robot acquisition status of hospital i's neighborhood at the end of year t. We considered two types of $Z_i(t)$: (1) the proportion of hospitals who had acquired robot(s) by the end of year t within the neighborhood of hospital i; or (2) a binary number which indicates whether any of its neighbor(s) had robot ($=1$) or not ($=0$) by the end of year t. X_i is a vector of the non-time dependent variables for hospital i. The conditional probability that the ith hospital would