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Pattern and factors leading to the diffusion of magnetic resonance imaging in Korean hospitals

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Objectives: The purpose of this study was to examine the diffusion patterns of new medical technologies in Korean hospitals. We also sought to identify critical factors leading to the decision to acquire capital-intensive medical technology. The rationale and timing of magnetic resonance imaging (MRI) acquisitions were retrospectively evaluated according to a "whether, when, and why" paradigm.
Methods: We analyzed data pertaining to 232 hospitals with active medical residency programs. Of these, 185 hospitals owned or leased an MRI unit, and 47 had not acquired units as of June 2004. Data were collected from the Ministry of Health and Welfare, Korean National Statistical Office, and Korean Hospital Association databases, and variables were identified and classified as predisposing, enabling, or reinforcing factors.
Results: The MRI diffusion rate curve was linear for two types of hospital but was S-shaped for tertiary hospitals, which were early adopters of MRI. Significant predictors for MRI adoption included the per capita number of regional physicians (+), total number of existing regional MRI units (−), percentage of the regional population over 65 years of age (+), private ownership of the hospital, presence of a radiology residency program, number of beds (+), and regional per capita taxable income (+).
Conclusions: Diffusion of MRI technology is occurring rapidly across Korean hospitals. The factors affecting MRI adoption in Korea are similar to the factors documented in other countries, namely regional population over age 65, regional income per capita, large hospitals, and teaching hospitals. This study provides baseline information for predicting diffusion patterns of other new and/or expensive medical technologies.

Keywords: MRI, Diffusion of innovation, Adoption, Hospitals

Technological innovation improves the quality of health care and affects healthcare costs (5;12). In many countries, the government has focused on limiting the use and introduction of new medical technologies to restrain increases in healthcare spending (5), making it difficult to determine an appropriate diffusion model for new technologies. This situation is especially true for computed tomography (CT) and a magnetic resonance imaging (MRI) equipment (14). It is difficult to weigh the cost increases attributable to the use of new medical technologies against improvements in the quality and effectiveness of care provided by advanced medical technologies. Advanced diagnostic equipment, including MRI machinery, can identify diseases earlier than prior technologies (18), which may prevent disease manifestation or

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delay disease progression. Consequently, this early detection may also reduce healthcare utilization and the cost of care (12). Diagnostic advances have reduced misdiagnoses and improved prevention, treatment, and rehabilitation (7).

Korea has experienced a rapid increase in CT and MRI procurement over the past 10 years (7;10). National Health Insurance (NHI) in Korea has covered the use of MRI for all patients since 2005. Many factors related to the adoption of this high-priced new technology that have to be considered include the appropriateness of MRI costs, the quality of diagnosis, and other indications for MRI use. The rapid rate of procurement has been met with many changes in regulatory policy. The regulatory changes as well as changes in fee schedules for MRI and CT diagnoses have affected all regions of Korea equally. Although regional economies and the local needs of physicians and patients play roles in the diffusion of new technologies, the effects of regulatory changes are broadly equalized across Korea.

The Korean national health budget and general quality of health care may be influenced by the MRI diffusion rate and usage. Therefore, it is necessary to confirm the factors that are important in the adoption and diffusion of new medical technologies in Korea.

The main purpose of this study was to identify factors influencing the diffusion of MRI equipment in Korea. We identified an S-shaped diffusion pattern consistent with the pattern suggested by Rogers (15). We also identified enabling and predisposing factors leading to technology diffusion. Lastly, we confirmed previously reported effects of regulatory changes on MRI procurement.

METHODS

Conceptual Model and Measures

We selected factors on MRI diffusion based on reviewing much of the preceding literature and grouped factors into three dimensions based on the model by Oh et al. (13) and using an approach similar to that described by Banta (3). This process included identifying factors such as predisposing, enabling, or reinforcing (Figure 1). We defined the time of adoption as the number of elapsed months between September 1988 and the MRI installation date. As the end point of the study was July 2004, this period covered 190-months.

In this study, we defined predisposing factors as the supplier demand, customer (patient) demand, market competitiveness, and individual characteristics of hospitals. The supplier demand was estimated from the number of physicians and healthcare facilities per capita and the number of previously existing MRI units in the region (2;13;19). The customer demand was the percentage of people over 65 years of age in a population in the region (2;13;16). The number of regional MRI units was the MRI count in the region before the adoption of a new MRI by a given hospital (13). To gauge regional competition, we used the number of beds

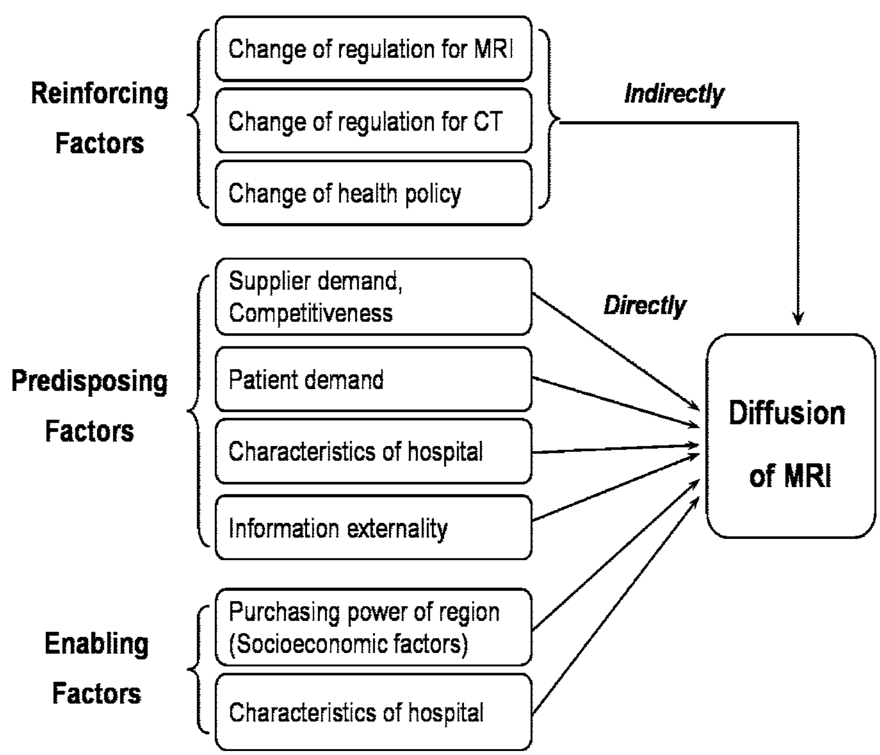

Figure 1. The research framework. MRI, magnetic resonance imaging; CT, computed tomography.

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to calculate the Hirschman–Herfindahl Index for each region, which indicated the monopoly power in a particular region (20). This measure reports low levels of competition as higher index values and high levels of competition as low index values. The presence or absence of a training program in radiology and the number of radiologists were considered reasonable proxies for measures of information externality (4;5).

We defined each hospital according to ownership type, size, the presence of a residency program, year of establishment, and the number of CTs and MRIs. Hospitals were categorized according to size as hospitals, general hospitals, and tertiary hospitals based on NHI fee standards. Hospital ownership was categorized as privately owned, government owned, or medical school (17;19). Training programs were classified according to whether a hospital possessed both a medical residency program and a medical internship program, or only an internship program (2;19).

As enabling factors are functions of the regional and individual hospital purchasing power, they were separated into regional (environmental) and hospital (individual) components. The regional component was measured as the local per capita gross domestic product (GDP) and taxable income (2;16); the individual hospital component was measured as the number of beds at the time of MRI installation (17;19).

To identify the effects of political change on MRI diffusion rates, we assigned four event points along a timeline and analyzed the factors reinforcing the adoption of MRI technology at each point. Event 1 corresponded to 27 November 1991, which was when the Korean government permitted MRI installations at general hospitals that had both a radiologist training program and more than 400 beds. Before that time, MRI installations were permitted only at tertiary hospitals. Event 2 was defined by the 1994 regulatory change that permitted hospitals with radiologists and 400 staffed beds to install MRI equipment even if those beds were affiliated with another hospital. At that time, it also became permissible for clinics to install CT units (8). Event 3 was defined by the 1996 decision to allow NHI to provide payments for CT procedures. The International Monetary Fund economic crisis in Korea in 1997 was assigned as Event 4. During that time, the Korean government abrogated the regulation of CT adoption, allowing clinics specializing in radiology to adopt MRI technology.

Data Collection

We used MRI registry data for July 2004 from the Ministry of Health and Welfare (MOHW) in Korea. All hospitals report their MRI acquisitions, including installation and manufacture dates and the location of all MRI units, to the MOHW. We collected information about hospital age, ownership type, bed count, and teaching status using a national hospital directory of the Korean Hospital Association (KHA). Regional data related to the number of physicians and hospitals, GDP per capita, population, and local taxable income per person were taken from the Korean National Statistical Office.

The initial sample size was 248 hospitals with training programs as of 31 July 2004. Of these 248, we excluded 16 mental hospitals. The final analyses were performed on 232 hospitals, 185 of which had adopted MRI technology as of 31 July 2004.

Analysis

We confirmed the factors that influenced the adoption time of MRI technology using Cox's proportional hazard model, which was calculated in SAS version 8.0. The Cox regression models the probability that adoption will occur at a specific time at an eligible hospital, without assuming a specific distribution underlying the timing of the event (19). Cox's proportional hazard model does not analyze reinforcing factors, because it is difficult to directly model regulatory change. Therefore, we used a logistic regression model to analyze the factors that influenced the timing of adoption with respect to the timing of regulatory changes. We excluded the numbers of specialists and radiologists, because the correlation was significantly high between hospital size and these variables (cor = .838, .764).

RESULTS

Diffusion Pattern of MRI Technology in Korea

The first MRI in Korea was installed at the Seoul National University Hospital in September 1988. The number of MRI installations in Korea reached a total of 561 units by July 2004. Figure 2 gives a detailed pattern of MRI adoption by hospital size. For tertiary hospitals with advanced technologies and highly qualified staffs, the diffusion curve determined in this study fit the logistic patterns described in previous diffusion studies (4;5;9;15).

Factors Affecting the Rate of Diffusion

Table 1 shows the odds ratios for the adoption of MRI (hazard) using Cox's proportional hazard model to analyze factors influencing MRI diffusion. With regard to predisposing factors, five variables positively affected the diffusion rate, especially the number of physicians per 100,000 persons, presence of a radiology residency program, and the number of MRI units previously available at the hospital, whereas the cumulative number of MRI units and year of establishment negatively affected the diffusion rate. For enabling factors, we found that the local taxable income had a positive effect on the diffusion rate in both models.

We used a logistic regression model to analyze the impact that changes in related regulations and laws had on

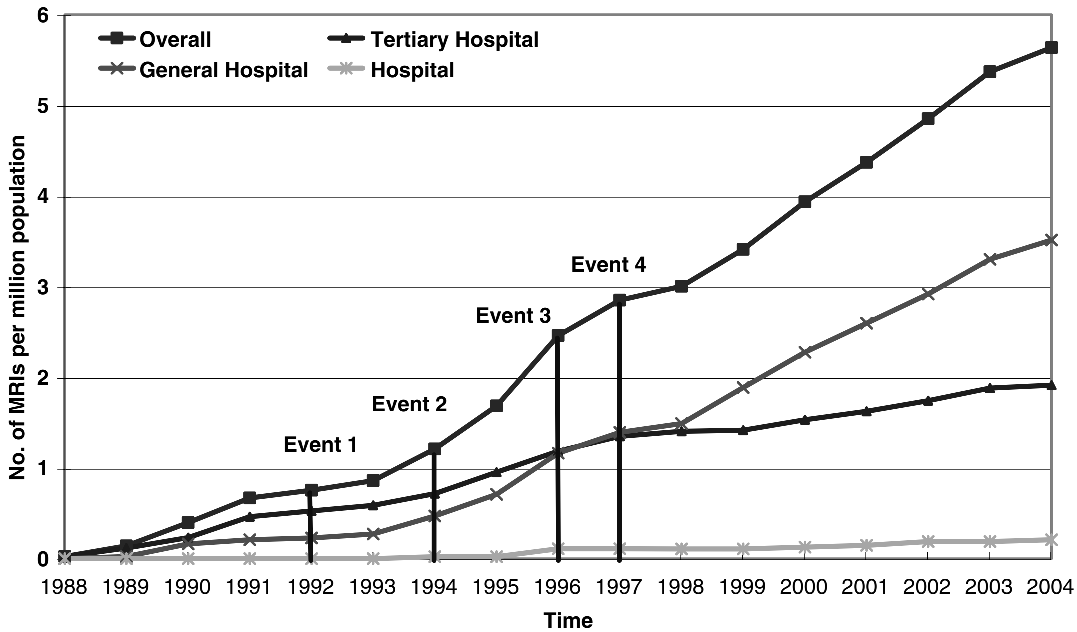

Figure 2. Diffusion pattern of magnetic resonance imaging units (MRIs) by hospital size.

the MRI diffusion rate (Table 1). The number of physicians (positively) and the cumulative number of MRI units in the region (negatively) affected the diffusion of MRI in all the events.

DISCUSSION

In Korea, the overall diffusion rate for MRI technology before 1998 showed a sigmoid shape when viewed as a logistic curve, reflecting a classic diffusion pattern of new technology. However, MRI diffusion rates have accelerated since 1999, and the overall diffusion rate curve was linear from 1988 to 2004. Baker (2) also showed a linear diffusion rate curve for MRI technology in the United States between 1983 and 1993. The Korean MRI diffusion rate between 1988 and 1994 was somewhat conservative, and the MRI diffusion curve increased sharply after 1994. MRI diffusion in the United States began accelerating 3 years after its first adoption. Thus, the Korean MRI diffusion rate was slower than that in the United States.

The analysis based on hospital size, revealed that tertiary hospitals followed a sigmoidal curve during the early years of MRI adoption. The fact that most tertiary hospitals are associated with a medical school and have several beds and highly qualified physicians probably influenced this early growth with respect to MRI technology. The rapid MRI diffusion rate at tertiary hospitals might also have been influenced by a strong desire to acquire new technologies to increase the number of patients and yield greater revenues (1;6;17). In addition, technically advanced facilities can more easily recruit proficient physicians, benefiting the reputation of the hospital (6;19). In the Korean market, tertiary hospitals tend to compete for technological preeminence.

The findings from this study were consistent with the results of other studies (6;13;14;16;19). The number of physicians per capita in a given region is a good proxy variable for physician demand, because competition is proportional to the number of physicians (13). This study suggests that the number of local physicians was proportional to the local rate of MRI diffusion. This result agrees with the results of previous studies, which suggested that hospitals with more competition in a region adopted MRI technology more rapidly (1;2;6;13).

A low level of extant MRI units in a region predicted a higher probability that new MRI equipment would be adopted in that region, which is consistent with a technological preeminence competition model. Furthermore, it appears to refute the "bandwagon" model, in which MRI units might be acquired to compete with hospitals already possessing similar equipment (6). The percentage of the population over the age of 65 years was used as a proxy for the degree of patient demand. We found that patient demand affects the MRI diffusion rate. This result is consistent with a study by Oh et al. (13), which suggested that patient demand affected the adoption of MRI.

Older hospitals showed greater rates of acquisition. Older hospitals place considerable importance on their reputation within local markets (17) and often have greater purchasing power (11). Both of these factors could enable the adoption of new technologies. The existence of a

Table 1. Results of Cox Regression and Logistic Regression for Factors Influencing MRI Adoption, According to Event

		Cox regression		Logistic regression											
				Event 1 (1992)			Event 2 (1994)			Event 3 (1996)			Event 4 (1997)		
		Hazard risk	*p* value	OR	95%	CI	OR	95%	CI	OR	95%	CI	OR	95%	CI
Number of physicians (per 100,000 persons)		1.014	<.001	1.053	1.019	1.088	1.050	1.021	1.079	1.063	1.024	1.103	1.085	1.043	1.129
Cumulative number of MRIs in region		.929	<.001	.858	.774	.951	.921	.862	.984	.811	.715	.92	.768	.676	.872
Hirschman–Herfindahl Index		12.288	.428	90.398	<.001	>999.99	>999.99	<.001	>999.99	>999.99	.001	>999.99	8.438	<.001	>999.99
Percentage of population over 65		1.204	.020	.931	.524	1.654	1.577	.911	2.727	2.040	1.113	3.739	2.511	1.372	4.598
Hospital size	Hospital	1.000								1.000			1.000		
	General hospital	.483	.192							.907	.009	92.739	.030	.001	.874
	Tertiary hospital	1.470	.562							3.781	.022	649.17	.260	.004	17.72
Ownership[a]	Public[a]	1.000		1.000			1.000			1.000			1.000		
	Private[b]	1.707	.038	30.157	1.536	591.908	4.225	.701	25.453	3.922	.563	27.312	7.044	1.165	42.599
Number of CTs in hospital		1.332	.053	3.632	1.179	11.187	1.121	.428	2.936	1.279	.356	4.599	3.143	.858	11.516
Number of MRIs in hospital		1.618	.015	.599	.165	2.175	1.646	.517	5.239	2.037	.361	11.479	3.313	.504	21.786
Ownership[b] (Medical school)	Not owned	1.000		1.000			1.000			1.000			1.000		
	Owned	.646	.172	.343	.059	1.978	.549	.127	2.380	.799	.132	4.836	.176	.022	1.388
Year of establishment		.989	.034	.985	.949	1.022	1.001	.970	1.033	.951	.905	.998	.979	.938	1.023
Radiologist residency	No	1.000					1.000			1.000			1.000		
program	Yes	2.239	.023				14.221	1.524	132.702	2.342	.311	17.638	1.111	.149	8.307
Local taxable income per capita (US$)		1.013	<.001	1.014	.998	1.031	1.008	.994	1.022	1.037	1.015	1.060	1.047	1.024	1.071
GDP per capita in region (US$)		.672	.121	.200	.018	2.202	.179	.027	1.180	.128	.018	.926	.274	.046	1.647
Number of beds	≤ 300	1.000		1.000			1.000			1.000			1.000		
	301–500	1.411	.202	1.243	.162	9.542	2.881	.524	15.839	4.532	.624	32.909	9.198	1.608	52.619
	>500	.502	.094	2.963	.223	39.353	7.071	.887	56.359	1.972	.139	27.873	3.610	.342	38.131

Note.
[a] Nonprofit.
[b] For profit.
MRI, magnetic resonance imaging; OR, odds ratio; CI, confidence interval; GDP, gross domestic product.

radiology residency program was related not only to the prominence of the physicians in a hospital but also to information externality (4;5). Thus, information externality, a factor previously reported to influence the adoption of new technologies (5), affected the adoption of MRI technology in Korea. Additionally, privately owned hospitals were more likely than nonprofit hospitals to be early adopters of MRI technology, particularly at Event 1. Early adopters represent opinion leaders within their markets and enhance their reputations by defining the safety and efficacy of new technologies (5). Considering that more than 80 percent of hospitals in Korea are privately owned, the likelihood that a private hospital will adopt a new technology may be related to its desire to position itself as a technological leader in a competitive and volatile environment (19).

We confirmed that hospitals in regions with high per capita taxable income were much more likely to be early adopters of MRI (16). We suggest that regional purchasing power is an important factor leading to the adoption of MRI technology.

We indirectly identified reinforcing factors, such as the effects of regulatory changes, by comparing the results of Cox's proportional model with those of the logistic model. Most of the variables that influenced MRI adoption in the Cox's proportional model also affected adoption rates in the logistic regression model.

To the best of our knowledge, this is the first study to identify the factors affecting MRI diffusion on a nationwide scale in Korea. However, there were some limitations to the study. First, we could not include the hospital budget in hospital purchasing power; the KHA database, from which hospital financial data were taken, was missing a lot of data. Therefore, we used hospital size as a proxy of purchasing power. Second, we could not include the costs of MRI, because these data were often not included in the national MRI registry.

We advocate a more directed approach to understanding the diffusion rate and patterns, focusing specifically on predisposing, enabling, reinforcing factors. Furthermore, investigation is warranted regarding whether these findings extend to the situation since 2005, when NHI in Korea first covered the use of MRI for all patients.

POLICY IMPLICATIONS

Although Korea has the highest MRI adoption rate in Asian countries (10), results of this study suggest that MRI adoption is likely to increase continually in the future. Patient demand, physician demand, purchasing power in the hospital and the region, and information externalities are factors influencing MRI adoption. It is necessary to manage MRI diffusion at a national level, because acquisition of MRI requires a large capital investment, which can increase healthcare costs.

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