INTRODUCTION

Robotic surgery has been widely applied in the field of prostate cancer surgery since it was first performed at Severance Hospital in July 2005.\(^1,2\) Radical prostatectomy has been reported to account for more than 78% of robotic surgeries in Korea.\(^2\)

The robotic surgical system was approved by the Ministry of Food and Drug Safety in 2005, and the National Health Insurance (NHI) registered robotic surgery as a non-covered item in July 2006. Health technology should meet the standards of safety, effectiveness, and cost-effectiveness to be compensated by the NHI; however, robotic surgery lacked economic evidence at that time.

Since 2006, several attempts have been made to cover the cost of robotic surgery through the NHI. In July 2013, robotic surgery was reviewed to strengthen NHI coverage for major diseases such as cancers and cardio-cerebrovascular diseases. It was then reconsidered to reduce patient co-payments when the government announced a policy that would include all non-covered items by the NHI in July 2017. However, robotic surgery has not been covered by the NHI until 2021. There were three reasons for robotic surgery not being covered by the NHI. First, there was insufficient evidence on clinical safety and ef-
fectediveness compared to open or laparoscopic surgery, except for some indications. Second, robotic surgery could be a burden on the NHI budget, since it is more expensive than open or laparoscopic surgery. Open and laparoscopic surgery costed 1.43 and 3.63 million KRW, respectively, whereas robotic surgery costed 12.7 million KRW at that time. Low cost-effectiveness is a barrier to NHI coverage. Third, healthcare providers opposed the coverage of robotic surgery as the price of surgery could be lowered.

Nevertheless, robotic surgery has established itself as a major surgery for radical prostatectomy. In the United States, robotic surgery accounted for more than 60% of radical prostatectomies, and was conducted more frequently than open surgery in 2009. In Korea, robotic surgery was performed similarly to open and laparoscopic surgery in the early 2010s.

The treatment patterns of prostate cancer in the early 2010s were analyzed using the Korean health insurance claims data. Sixty-one medical facilities had 92 robotic surgical systems in 2019. Compared to 2014, the number of robotic surgical systems has doubled; but since then, no studies have been conducted on the number of robotic surgeries or surgical patterns in prostate cancer. Therefore, this study aimed to analyze the number of radical prostatectomy surgeries and surgical patterns between 2007 and 2019. In addition, this study analyzed how the number of surgeries and surgical patterns changed when a medical facility adopted the robotic surgical system. The results of this study will clarify how existing medical technologies are replaced by the adoption and diffusion of new medical technologies.

MATERIALS AND METHODS

Source
The medical equipment status report data and NHI claim data from 2007 to 2019 were used in the Health Insurance Review and Assessment Service. The status of the robotic surgery system and radical prostatectomy were identified using medical equipment status report data and NHI claims data, respectively. Radical prostatectomy was defined by the fee schedule code for surgery, anesthesia, and malignant tumor examination for a claim in which the primary disease was a malignant neoplasm of the prostate (C61).

Between 2007 and 2019, 62 medical facilities had a robotic surgical system, of which two medical facilities did not perform radical prostatectomy. A total of 139 medical facilities underwent radical prostatectomy, and 62804 surgeries were performed over 13 years. During the analysis period, six surgeries were performed at four hospital-level medical facilities. Due to the low number of surgeries per facility, statistical estimation of hospital-level medical facilities was difficult; hence, it was excluded from the final analysis. A total of 62798 surgeries from 135 medical facilities above the general hospital level were included in the final analysis. As of 2019, 8475 surgeries from 102 facilities were analyzed.

Constructing data
The number of surgeries and surgical patterns were analyzed by merging the radical prostatectomy claims data with the robotic surgical system data and constructed by the medical facility in a year. Medical facilities had a maximum of 13 data points from 2007 to 2019.

Radical prostatectomy was classified into open radical prostatectomy (ORP), laparoscopic radical prostatectomy (LRP), and robot-assisted laparoscopic radical prostatectomy (RARP) according to the surgical method. Four groups of fee schedule codes were used to classify surgical methods: surgery (R3950, R3960), laparoscopic medical material (N0031001), anesthesia (L1211), and malignant tumor test (C5500, C5503, C5504, C5505, C5506, C5507, C5508, C5918, C5919, C5605, C5606, and C5607). Cases claiming four groups of fee schedule codes were defined as LRPs, and those without laparoscopic medical material codes were classified as ORPs. Medical facilities cannot charge the NHI with the RARP fee code, as they are not covered by the NHI. However, hospitalization fees, anesthesia fees, and examination expenses incurred during RARP are billed to the NHI. Therefore, a claim in which no prostate operation codes (R3940, R3950, R3960, R3975, R3976, and R3977) were included was defined as RARP, but anesthesia and malignant tumor examination fee codes were confirmed.

Analysis
The number of radical prostatectomies and surgical patterns by year were presented using descriptive statistics. The chi-square test was used to determine whether the adoption of the robotic surgical system differed according to medical facility characteristics in 2019. The t-test or analysis of variance was used to test the differences in the number of radical prostatectomies and surgical patterns according to the medical facility characteristics. Finally, a linear mixed model was used to analyze the effect of adopting a robotic surgical system on the number of surgeries and surgical patterns between 2007 and 2019. The number of surgeries and the share of each surgery in the medical facilities were used as dependent variables. We analyzed whether the adoption of robotic surgical systems had an effect on each dependent variable after adjusting for the year and characteristics of the medical facility. A random coefficient regression model in which the year and intercept were treated as random effects was used, since the error terms of the same medical facilities correlated with each other. Data construction and statistical analysis were performed using SAS Enterprise Guide 7.1.

This study was reviewed by the Institutional Review Board of Health Insurance Review and Assessment Service and was given an exempt determination (no. 2018-032-001).
RESULTS

Number of radical prostatectomy and surgical patterns between 2007 and 2019

Table 1 summarizes the number of radical prostatectomies performed between 2007 and 2019. In 2007, 72 medical facilities performed radical prostatectomy. The number of medical facilities that performed radical prostatectomy increased until 2019, with a temporary decrease in the years 2012, 2015, and 2018. In 2019, 102 medical facilities performed radical prostatectomies. The number of radical prostatectomies increased from 1756 in 2007 to 8475 in 2019, with an annual average increase of 14.0%. Regarding the surgical method, RARP increased by 28.6% annually, while RLP and ORP increased by 8.4% and 1.9%, respectively.

The share of ORP was high at the beginning of the introduction of the robotic surgical system; but as the number of RARP surgeries surged in 2008, RARP had the largest share in 2009. The share of RARP in 2007 increased from 17.5% to 74.3% in 2019. There was also a period when the market share of RARP decreased slightly from 2011 to 2013. However, as the number of robotic surgical systems increased in 2014, the share of RARP also increased. On the other hand, ORP, which accounted for 67.9% in 2007, decreased to 17.7% in 2019. The share of LRP also decreased from 14.5% in 2007 to 7.9% in 2019 (Fig. 1).

Table 1. Number of Medical Facilities Operating Radical Prostatectomy and Number of Surgical Cases in 2007–2019

| Year | Medical facilities operating radical prostatectomy | Total | ORP | LRP | RARP |
|------|-------------------------------------------------|-------|-----|-----|------|
| 2007 | 72                                              | 1756  | 1193 (67.9) | 255 (14.5) | 308 (17.5) |
| 2008 | 79                                              | 2557  | 1152 (45.1) | 292 (11.4) | 1113 (43.5) |
| 2009 | 88                                              | 3448  | 1416 (41.1) | 425 (12.3) | 1607 (46.6) |
| 2010 | 94                                              | 3673  | 1404 (38.2) | 419 (11.4) | 1850 (50.4) |
| 2011 | 97                                              | 4421  | 1768 (40.0) | 605 (13.7) | 2048 (46.3) |
| 2012 | 90                                              | 4618  | 1764 (38.2) | 712 (15.4) | 2142 (46.4) |
| 2013 | 98                                              | 4730  | 1787 (37.8) | 705 (14.9) | 2238 (47.3) |
| 2014 | 103                                             | 4713  | 1581 (33.5) | 660 (14.0) | 2472 (52.5) |
| 2015 | 99                                              | 4798  | 1460 (30.4) | 531 (11.1) | 2807 (58.5) |
| 2016 | 100                                             | 5825  | 1351 (23.2) | 610 (10.5) | 3864 (66.3) |
| 2017 | 101                                             | 6460  | 1441 (22.3) | 605 (9.4)  | 4414 (68.3) |
| 2018 | 99                                              | 7324  | 1354 (18.5) | 666 (9.1)  | 5304 (72.4) |
| 2019 | 102                                             | 8475  | 1504 (17.7) | 672 (7.9)  | 6299 (74.3) |

ORP, open radical prostatectomy; LRP, laparoscopic radical prostatectomy; RARP, robot-assisted laparoscopic radical prostatectomy.

Fig. 1. Patterns of radical prostatectomy in 2007–2019. ORP, open radical prostatectomy; LRP, laparoscopic radical prostatectomy; RARP, robot-assisted laparoscopic radical prostatectomy.
Robotic surgical system adoption rate, number of surgeries, and surgical pattern of radical prostatectomy by medical facility characteristics in 2019

Among medical facilities that performed radical prostatectomy in 2019, 60 (58.8%) medical facilities had a robotic surgical system. Tertiary hospitals and medical facilities with more than 900 beds had the highest rate of adoption of robotic surgical system, which was statistically significant as a result of the chi-square test. The adoption rate of the robotic surgical system in teaching hospitals was higher than that in non-teaching hospitals, and it was statistically significant. However, the adoption rates of medical facilities in metropolitan areas and private medical facilities were not statistically significantly higher (Table 2).

Medical facilities performed 83.1 surgeries per facility in 2019. The share by surgical method was 35.6% for ORP, 23.1% for LRP, and 41.3% for RARP. The mean number of surgeries at medical facilities with robotic surgical system was 128.3, with RARP accounting for 70.2%. On the other hand, the number of surgeries at medical facilities not adopting the robotic surgical system was 18.5 cases, which was significantly lower than that of medical facilities adopting it. The ORP and LRP shares were similar at the 50% level.

Based on the results of the t-test or ANOVA, there were statistically significant differences in the number of surgeries and surgical patterns by medical facility characteristics, except for the variables of whether medical facilities are located in metropolitan areas or not and whether they are public or not (Table 3).

| Table 2. Distribution of Medical Facilities Operating Prostatectomy according to the Possession of Robotic Surgical System and Characteristics of Medical Facilities in 2019 |
|-------------------------------------------------|
| Classification of hospital | Adopting robotic surgical system | p value |
|----------------------------|----------------------------------|---------|
|                            | Yes (n=60) | No (n=42) |       |
| Tertiary                   | 35 (65.4) | 6 (14.6)  | <0.001|
| General                    | 25 (41.0) | 36 (59.0) |       |
| ≥900                       | 24 (92.3) | 2 (7.7)   | <0.001|
| 600–899                    | 26 (60.5) | 17 (39.5) |       |
| 300–599                    | 8 (29.6)  | 19 (70.4) |       |
| <300                       | 2 (33.3)  | 4 (66.7)  |       |
| Metropolitan area          | 0.216     |           |       |
| Yes                        | 36 (64.3) | 20 (35.7) |       |
| No                         | 24 (52.2) | 22 (47.8) |       |
| Teaching                   | <0.001    |           |       |
| Yes                        | 52 (74.3) | 18 (25.7) |       |
| No                         | 8 (25.0)  | 24 (75.0) |       |
| Public                     | 0.892     |           |       |
| Yes                        | 15 (57.7) | 11 (42.3) |       |
| No                         | 45 (59.2) | 31 (40.8) |       |

| Table 3. Number of Surgeries and Patterns of Radical Prostatectomy according to Characteristics of Medical Facilities in 2019 |
|-------------------------------------------------------------------------------------------------------------------------------------|
| Number of surgeries                                                                                                              | Share of surgeries (%)                                                                                       |
| Mean±SD | p value | Mean±SD | p value | Mean±SD | p value | Mean±SD | p value |
|---------|---------|---------|---------|---------|---------|---------|---------|
| Total   |         |         | ORP     |         | LRP     |         | RARP    |         |<0.001 |
|         |         |         | 83.1±164.7 | -       | 35.6±40.4 | -       | 23.1±38.0 | -       | 41.3±43.0 | - |
| Adopting robotic surgical system | <0.001 |         | 128.3±202.0 | 0.002 | 25.6±33.2 | 4.2±11.7 | 70.2±33.1 |         |         |
| Yes     |         |         | 18.5±28.2  |         | 49.9±45.7 | 50.1±45.7 |         |         |         |
| No      |         |         | 159.0±236.9 |         | 24.7±33.6 | 10.4±25.0 | 64.9±37.4 |         |         |
| Classification of medical facilities | <0.001 | 0.025 |<0.001 |         | 0.005 |<0.001 |         |         |         |
| Tertiary |         |         | 32.1±40.6  | 0.005 | 42.9±43.2 | 31.7±42.8 | 25.4±39.2 |         |         |
| General  |         |         |         |         |         |         |         |         |         |
| Number of beds | <0.001 |         |<0.001 |         | 0.019 |<0.001 |         |         |         |
| ≥900     |         |         | 209.2±283.5 | 0.015 | 16.1±18.0 | 7.6±20.7 | 76.3±32.2 |         |         |
| 600–899  |         |         | 52.5±49.8  |         | 39.7±39.1 | 22.1±36.6 | 38.2±40.4 |         |         |
| 300–599  |         |         | 26.7±44.8  |         | 39.1±44.3 | 39.9±46.7 | 21.0±39.0 |         |         |
| <300     |         |         | 10.0±15.3  |         | 74.8±42.0 | 22.4±40.4 | 2.6±7.0   |         |         |
| Metropolitan area | 0.085 |         | 0.301 |<0.001 |         | 0.051 |<0.001 |         | 0.462 |
| Yes      |         |         | 108.5±213.8 |         | 39.4±41.7 | 16.5±32.3 | 44.1±43.5 |         |         |
| No       |         |         | 52.1±56.9  |         | 31.1±38.8 | 31.2±42.9 | 37.8±42.5 |         |         |
| Teaching | 0.933   |         |<0.001 |         |         |<0.001 |         |<0.001 |         |
| Yes      |         |         | 84.0±144.2 |         | 33.8±39.9 | 12.8±28.6 | 53.4±42.2 |         |         |
| No       | 81.0±205.1 |         | 39.5±42.0 |         | 45.7±46.0 | 14.8±31.6 |         |         |         |
| Public   | 0.499   |         | 0.909 |<0.001 |         | 0.718 |<0.001 |         | 0.833 |
| Yes      |         |         | 102.1±122.4 |         | 34.8±39.9 | 25.5±39.5 | 39.7±42.0 |         |         |
| No       | 76.6±177.1 |         | 35.9±40.9 |         | 22.3±37.7 | 41.8±43.5 |         |         |         |

ORP, open radical prostatectomy; LRP, laparoscopic radical prostatectomy; RARP, robot-assisted laparoscopic radical prostatectomy; SD, standard deviation.
Effect of the adoption of robotic surgical system on the number of surgeries and surgical pattern of radical prostatectomy

The adoption of a robotic surgical system in medical facilities from 2007 to 2019 increased the number of radical prostatectomies as a result of linear mixed model analysis. Even after adjusting for both year and medical facility characteristics, the adoption of robotic surgical system significantly increased the number of surgeries by 12.1 cases (Table 4).

The adoption of a robotic surgical system also affected the surgical pattern of radical prostatectomy as a result of the linear mixed model analysis. It increased the share of RARP by 47.2%, while that of ORP and LRP decreased by 27.7% and 16.3%, respectively. It was found to reduce the share of ORP more than the LRP (Table 4).

DISCUSSION

This study confirmed that the number of radical prostatectomies increased by 14.0% annually, and the share of RARP increased from 17.5% in 2017 to 74.3% in 2019 due to the diffusion of the robotic surgical system based on the analysis of health insurance claims data from 2007 to 2019. The introduction of the robotic surgical system increased the number of surgeries at medical facilities by 76.5 on average, and RARP replaced ORP and LRP.

The increase in the number of radical prostatectomies over the past 13 years was due to an increase in the incidence of prostate cancer in Korea. Prostate cancer was the 4th most common cancer in men in 2018, accounting for 11.5%. Although the prevalence rate of prostate cancer in Korea is lower than that in the United States, which accounts for 21% of male cancers, the incidence of prostate cancer in the United States is declining. In contrast, the prevalence of prostate cancer continues to increase in Korea. Prostate cancer occurred in 7.6 cases of the 100000 population in 2000; but in 2018, it increased by approximately 4.2 times to 32.0 cases per 100000 population. The increase in surgery as the main treatment method for prostate cancer may also be the cause for the increase in the number of radical prostatectomies, along with an increase in cases of prostate cancer. There are three main treatment methods for prostate cancer: surgery, radiation therapy, and hormone therapy, including androgen deprivation therapy (ADT). The share of surgery increased from 22.4% in 2003 to 45.5% in 2013, while the share of ADT decreased from 60.3% to 45.3%. The proportion of patients who underwent surgery only increased from 23.5% in 2005 to 39.4% in 2014, and the share of patients increased to 47.9% in 2014 after including patients who received surgery in combination with other treatments.

In Korea, after the first RARP was performed in 2005, the share of RARP increased to 17.5% within 2 years. The RARP shares in 2005 and 2006 were reported to be 2.6% and 5.6%, respectively, which increased to 17.5% in 2007. According to the innovation adoption curve, innovative technology spreads in an S-shape; and the adopters are categorized as innovators, early adopters, early majority, late majority, and laggards over the adoption period. The period when innovative technology spreads from the early adopters to the early majority and when innovative technology occupies 15%–20% is called the tipping

| Table 4. Changes in Number of Cases and Patterns of Radical Prostatectomy after Adopting Robotic Surgical System in 2007–2019 |
| Number of surgeries | Share of surgeries (%) |
|----------------------|------------------------|
|                      | C.E  | p value | C.E  | p value | C.E  | p value | C.E  | p value |
| Intercept            | 13.083 | 0.351 | 82.775 | <0.001 | 30.143 | 0.005 | -10.912 | 0.023 |
| Year                 | 3.106 <0.001 | -2.094 <0.001 | 0.886 | 0.052 | 1.112 | <0.001 |
| Adopting robotic surgical system | Yes vs. No | 12.124 | <0.001 | -27.682 | <0.001 | -16.286 | <0.001 | 47.240 | <0.001 |
| Classification of medical facilities | Tertiary vs. General | -0.979 | 0.876 | -2.425 | 0.768 | 0.527 | 0.946 | 1.025 | 0.735 |
| Number of beds       |                       |       |       |       |       |       |       |       |       |
| ≥900 vs. <300        | 6.598 | 0.658 | -10.060 | 0.467 | -0.849 | 0.948 | 7.669 | 0.160 |
| 600–899 vs. <300     | -1.396 | 0.922 | 0.003 | 1.000 | -0.375 | 0.974 | 1.335 | 0.787 |
| 300–599 vs. <300     | -5.693 | 0.688 | -11.204 | 0.320 | 6.056 | 0.568 | 5.055 | 0.280 |
| Metropolitan area    |                       |       |       |       |       |       |       |       |       |
| Yes vs. No           | 8.302 | 0.081 | 10.836 | 0.057 | -12.891 | 0.016 | 2.043 | 0.342 |
| Teaching             | -7.438 | 0.218 | -4.299 | 0.552 | -3.108 | 0.648 | 4.650 | 0.088 |
| Public               | 4.315 | 0.442 | 3.887 | 0.561 | -2.666 | 0.672 | -1.820 | 0.471 |

C.E, coefficient estimate; ORP, open radical prostatectomy; LRP, laparoscopic radical prostatectomy; RARP, robot-assisted laparoscopic radical prostatectomy.
point. When an innovation reaches a tipping point, it can no longer stop spreading and begins to expand rapidly. According to the innovation adoption curve, RARP reached a tipping point of 17.5% within 2 years after its introduction, and its share in 2008 increased significantly to 43.5%.

In the United States, after the first RARP was performed in 2000, it reached a tipping point between 2007 and 2008, and the share of RARP increased significantly to 59.6% in 2009. Although RARP in Korea reached the tipping point earlier compared to the United States, RARP’s share could reach 58.5% after 8 years. RARP quickly reached the tipping point because, in the early days of RARP introduction, the four largest hospitals that performed more than 300 radical prostatectomies per year started RARP. Afterwards, the spread of robotic surgery, including RARP, had stalled as it was reported that the safety and effectiveness of robotic surgery was uncertain in a study conducted to determine whether RARP was covered by health insurance. There was also a case in which a celebrity died after robotic surgery. However, the share of RARP increased again in 2013 and 2017, as robotic surgery was reviewed again as a part of strengthening the NHI coverage.

While the number of radical prostatectomies is increasing every year, it was confirmed that the introduction of the robotic surgical system increased the number of surgeries in medical facilities even after the year was adjusted. It is possible that patients in medical facilities that did not introduce the robotic surgical system moved to the medical facilities that introduced the system. In addition, the patient probably chose minimally invasive RARP instead of radiation or hormone therapy. However, we cannot rule out the possibility that the number of surgeries through RARP had increased in medical facilities adopting robotic surgical systems. The introduction of new medical technology can increase medical utilization as medical suppliers can induce their usage. Although the number of prostate cancer cases in the United States has declined, the increase in the number of RARP surgeries has been explained by supplier-induced medical utilization. In contrast to the United States, the number of prostate cancer patients in Korea is increasing and requires more surgery than before. It is highly likely that medical facilities increased the number of surgeries with RARP, which can perform more surgeries in a limited time and leave a large profit per surgery.

In the present study, RARP replaced ORP and LRP in medical facilities that adopted a robotic surgical system. Similarly, in the United States and Australia, RARP replaced ORP or LRP and became the most frequently performed procedure. RARP may have replaced ORP and LRP to increase the profits of medical facilities in the same way that the number of surgeries has increased. However, clinical evidence of RARP and improved convenience for surgeons cannot be ignored. There is much evidence that robotic surgery for prostate cancer is clinically safer and more effective than open or laparoscopic surgery. The oncological outcomes of RARP and ORP are similar, and the incidence of complications and urinary incontinence is low. Compared with LRP, there was no difference in the conversion rate to ORP, and the risk of damage, such as peripheral organ damage and blood transfusion, was low. Moreover, although RARP lacks high-quality evidence as a random clinical trial, clinical evidence is accumulating that it has advantages similar to LRP in terms of non-invasiveness. However, the surgery time is shorter than that of LRP, and it does not take a long time to overcome the learning curve; therefore, surgeons may prefer RARP.

In Korea, robotic surgery is used not only for prostate cancer, but also for thyroid, colorectal, and various gynecological cancers. Although there is insufficient evidence that the safety and effectiveness of robotic surgery are superior to those of laparoscopic surgery, the number of surgeries is gradually increasing. This situation is the same in the United States, and there are concerns about side effects due to its use in situations where clinical evidence is uncertain. Since the benefits of health insurance in Korea apply to many citizens, if clinical evidence and economic feasibility are judged to be insufficient, a higher co-payment rate is applied. Medical use was monitored, and data on side effects were collected from medical facilities. However, since robotic surgery is not covered by the NHI, side effects are not monitored despite the disclosure of prices for each medical institution. In the absence of monitoring for side effects, robotic surgery has reached a point where it has already been applied to many people. It is necessary to reimburse payments to reduce the burden on patients, as many people undergo robotic surgeries. It is also necessary to continuously discuss which compensation method to choose and to be covered by NHI under the circumstance that a new technology is less cost-effective than the existing one.

This study presented the situations of robotic surgery over 13 years by analyzing Korea’s national data while focusing on radical prostatectomy. However, this study had two limitations. First, since RARP is not covered by the NHI, it is possible that it was underestimated compared to other procedures that covered by the NHI. Second, administrative data analysis is useful for understanding the overall trend of medical use, but it is not possible to determine whether ORP, LRP, and RARP are applied to patients with different clinical characteristics and surgical outcomes. Large-scale studies with well-designed clinical outcomes are needed to discuss health insurance reimbursement.

This study analyzed the number and pattern of radical prostatectomy in which robotic surgery was most frequently applied using the NHI claims data from 2007 to 2019. Robotic surgery reached a tipping point where medical technology spread in earnest in 2007 and has replaced existing medical technologies such as open and laparoscopic surgery. In addition, the adoption of robotic surgical systems in medical facilities increased the number of surgeries and the share of robotic surgery. Although its safety and effectiveness are uncertain and
cost-effectiveness is low, robotic surgery has already been widely used in clinical settings. The management of such new health technologies in the healthcare system should be discussed.

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