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Original Article

Trends of robotic-assisted surgery for thyroid, colorectal, stomach and hepatopancreaticobiliary cancer: 10 year Korea trend investigation

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ABSTRACT

Background: The current position of robotic surgery in the field of minimally invasive surgery remains ambiguous. We evaluated long-term trends of robotic general surgery and the future direction of its development.

Methods: Data on robotic cancer surgeries between 2005 and 2014 were retrospectively collected by volunteer institutions in the Republic of Korea. Spearman's correlation and logistic regression analyses were used to compare robotic and laparoscopic surgery trends in general surgery.

Results: The odds that robotic surgery was performed instead of laparoscopic surgery significantly decreased in the fields of colorectal, stomach, and hepato-biliary-pancreatic surgery (odds ratio [OR]: 0.95, 95% confidence interval [CI]: 0.93−0.97; OR: 0.90, 95% CI: 0.88−0.92; and OR: 0.71, 95% CI: 0.65−0.78, respectively), except for thyroid surgery (OR: 1.28, 95% CI: 1.25−1.30). Of the total numbers of each procedure, proportions of robotic intersphincteric resections, abdominoperineal resections, and pylorus-preserving surgery performed significantly increased ($r = 0.98$, $P < .001$; $r = 0.78$, $P = .01$; and $r = 0.86$, $P = .007$, respectively).

Conclusions: The use of robotic surgery failed to preponderate that of laparoscopic surgery, except for thyroid surgery. Robotic surgery is increasingly preferred for limited fields or complex surgeries, but the use of robotics in simple surgeries has decreased.

1. Introduction

Recently, robotic surgery has been gradually applied in many surgical fields. Although it has been more than 10 years since robotic surgery entered the clinical field, there is a lack of consensus among surgeons on the effectiveness of robotic surgery.[1–3]

Despite the rapid expansion of robotic surgery in Korea, the status of robotic surgery utilization in the clinical field remains unclear, and the choice of robotic surgery is based on hypothetical advantages rather than clinical evidence or patient benefit. Thus, a rational and scientific study on the current trends and status of robotic surgery in the clinical field is needed. There is currently no nationwide, pan-disciplinary study regarding robotic surgeries that has been conducted. We aimed to determine whether the suggested merits of robotic surgery influences surgeons' choices by analyzing nationwide long-term trends in the clinical application of robotic surgery.

This study reviewed data from the Korean Association of Robotic Surgeons (KAROS) registry and presents nationwide and long-term trends in robotic cancer surgeries since the introduction of the robotic surgical system in Korea. Twenty-one hospitals nationwide participated, and 22,439, 35,670, and 139,783 cases of robotic, laparoscopic, and open surgeries, respectively, were analyzed. Additionally, we compared trends in utilization between robotic surgery and conventional laparoscopic surgery. In this study, we

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aimed to clarify the current position of robotic cancer surgery use in clinical practice and its future direction of development.

2. Materials and methods

Data on robotic cancer surgeries performed in Korea between 2005 and 2014 were collected. Twenty-one hospitals that actively performed robotic surgery were recruited to participate in this study. The 21 hospitals involved (including public and private hospitals, medical centers, and university-related hospitals) did so in a completely voluntary role without financial support. Since the Korean general surgery only includes the following types, the colorectal, stomach, hepato-biliary-pancreatic (HBP), and thyroid. Thus, we only collected the above data belonging to the general surgery department in South Korea, not involving respiratory, gynecological and urological diseases. To make the cancer treatment indications of the relevant hospitals as similar as possible, we reached a consensus after several meetings during the initial stage of this study, and that was to explain the advantages and disadvantages of the operation in detail and objectively to the patient. All patients provided written informed consent for advantage and disadvantage of procedure of each surgical methods and chose the surgical approach during the study period. The data collected by the enrolled institutions were integrated by the information committee of KAROS for statistical analysis. This study protocol was approved by the institutional review board of Korea University College of Medicine, Seoul, Korea (approval number: K2019-0295-001).

The operative procedures performed for cancer surgery were investigated. However, cholecystectomy, one of the most widely performed robotic HBP surgeries, was excluded from this study. For each operative procedure included in the study, the numbers of cases of robotic, laparoscopic, and open approaches were examined.

2.1. Statistical analysis

Spearman's correlation analysis was used to evaluate temporal trends in the overall and organ-specific numbers of robotic surgeries.[4] It was also used to analyze the proportion of robotic procedures performed for each type of organ. Logistic regression analysis was used to assess whether there was an increase in the number of robotic surgeries compared to that of laparoscopic surgeries. In the analysis, the influence of year on the odds of robotic surgery versus laparoscopic surgery was evaluated. The association of year with an increased odds of robotic surgery would suggest that the number of robotic surgeries increased more than that of laparoscopic surgeries, which would imply increased usage of robotic surgery in the field of minimally invasive surgery. All analyses were performed using SPSS® version 20.0 (IBM Corp., Armonk, NY, USA). All P-values were derived from two-tailed tests, and statistical significance was set at $P < .05$.

3. Results

3.1. Overall trend

The total number of robotic surgeries performed in South Korea increased significantly since 2005 ($r = 0.82$, $P = 0.004$), and >3000 surgeries were performed in 2014 (Fig. 1). A two-step correlation analysis before and after 2009 revealed that the total number of investigated robotic surgeries significantly increased until 2009 ($r = 1.00$, $P < 0.001$). However, after 2009, the number of robotic surgeries plateaued and showed no significant trend until 2014 ($r = 0.14$, $P = 0.79$). Table 1 describes the number of participating institutions and the types of operative procedures included for each surgical department. The total number of participating institutions was twenty-one and three group which were divided to surgical approach such as robotic, laparoscopic, and open surgery were distributed by major surgical name of each surgical department. Thyroid surgeries were the most frequently performed robotic surgeries, constituting 78% (17,854/22,439) of the total investigated cases of robotic surgeries, followed by colorectal (13%, 2835/22,439) and stomach surgeries (9%, 1926/22,439). Data on only 94 cases of robotic hepato-biliary-pancreatic (HBP) surgeries were collected during the study period, which is close to 0% of the total number of investigated robotic surgeries because cholecystectomy cases were excluded.

3.2. Organ- and operation-specific trends

Although the number of robotic thyroid surgeries did not show a significant increase ($r = 0.60$, $P = 0.12$), they have been more

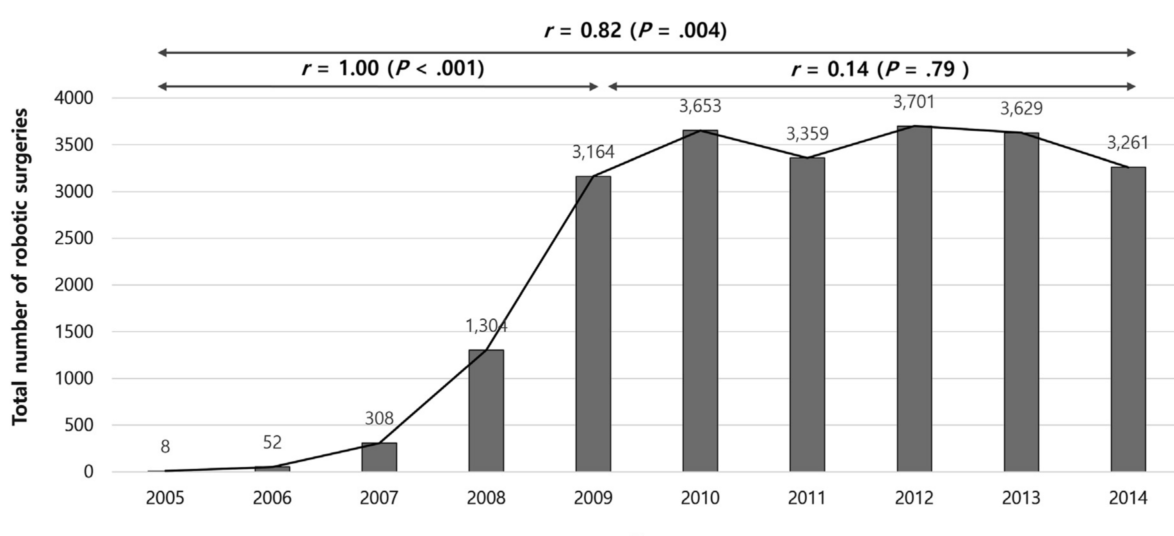

Fig. 1. Overall trend in the number of robotic cancer surgery.
r indicates Spearman's correlation coefficient during the marked period.

dominant than endoscopic thyroid surgeries since the introduction of robotic thyroid surgery in 2008 (Fig. 2A). The proportion of endoscopic thyroid surgeries to the total number of investigated thyroid surgeries decreased significantly ($r = -0.85$, $P = .007$), which was decreased from 8.8% in 2008 to 2.0% in 2014, whereas the proportions of robotic and open thyroid surgeries remained relatively constant ($r = 0.21$, $P = 0.61$ and $r = 0.24$, $P = 0.57$, respectively). In the operation-specific analysis, a significant trend was not observed for any type of operation (Fig. 2B).

The number of robotic colorectal surgeries increased significantly ($r = 0.85$, $P = 0.004$; Fig. 2C), which was 505cases in 2014; however, as a proportion of the total number of investigated colorectal surgeries, it showed no significant temporal trend ($r = 0.13$, $P = 0.73$). Of the total number of colorectal surgeries, the proportion of laparoscopic colorectal surgeries increased significantly ($r = 0.98$, $P < .001$), whereas that of open colorectal surgeries decreased significantly ($r = -0.98$, $P < .001$). The proportions of robotic inter sphincteric resection (ISR) and abdominoperineal resection (APR) showed a steady increase ($r = 0.98$, $P < .001$ and APR, $r = 0.78$, $P = 0.01$, respectively; Fig. 2D). The proportion of robotic anterior resection (AR) significantly decreased ($r = -0.77$, $P = 0.02$) whereas that of robotic low AR remained consistent by year ($P = 0.73$).

Consistent with robotic colorectal surgeries, the number of robotic stomach surgeries significantly increased ($r = 0.87$, $P = .001$; Fig. 2E). The proportion of robotic stomach surgeries of the total number of stomach surgeries also increased significantly ($r = 0.64$, $P = .048$), which was decreased from 4.9% in 2008 to 7.1 in 2014, that of laparoscopic stomach surgeries of the total number of stomach surgeries markedly increased ($r = 0.98$, $P < 0.001$), and that of open stomach surgeries of the total number of stomach surgeries consistently decreased ($r = -0.95$, $P < 0.001$). The proportion of robotic pylorus-preserving gastrectomy (PPG) significantly increased ($r = 0.86$, $P = 0.007$), and the proportions of other types of operations showed no significant trends (distal gastrectomy: $r = 0.42$, $P = 0.23$; total gastrectomy: $r = -0.07$, $P = 0.86$; proximal gastrectomy: $r = 0.24$, $P = 0.56$; Fig. 2F).

In contrast to the number of robotic colorectal and stomach surgeries, the number of robotic HBP surgeries was almost consistent ($r = -0.13$, $P = 0.75$; Fig. 2G). The proportion of laparoscopic HBP surgeries of the total number of HBP surgeries increased significantly ($r = 0.74$, $P = 0.04$), whereas the proportions of robotic and open HBP surgeries of the total number of HBP surgeries did not show a significant temporal trend ($r = -0.61$, $P = 0.11$ and $r = -0.48$, $P = 0.23$, respectively). The proportion of robotic distal pancreatectomy showed a significant decrease ($r = -0.71$, $P = .047$), and no significant trend was found in other types of operations (Fig. 2H).

3.3. *Odds of performing Robotic Surgeries instead of laparoscopic surgeries*

Year was significantly associated with a decreased odds of performing robotic colorectal, stomach, and HBP surgeries (odds ratio [OR]: 0.95, 95% confidence interval [CI]: 0.93–0.97, $P < .001$; OR: 0.90, 95% CI: 0.88–0.92, $P < 0.001$; and OR: 0.71, 95% CI: 0.65–0.78, $P < 0.001$, respectively; Fig. 3). By contrast, year was associated with an increased odds of performing robotic thyroid surgeries (OR: 1.28, 95% CI: 1.25–1.30, $P < 0.001$). Therefore, in the case of thyroid surgeries, the odds of performing robotic surgery increased, whereas that decreased for all other types of surgery after being established for 10 years in those independent subdivisions.

4. Discussion

We examined the nationwide trends of robotic cancer surgeries for the first time since the worldwide introduction of the robotic surgical system in South Korea. Our study is unique in that it compared the trends of robotic and laparoscopic surgeries and assessed the utilization of robotic surgery in the field of minimally invasive treatments. The analysis enabled us to identify operative procedures for which robotic surgery is actively expanding and to identify potential qualitative benefits of robotic surgery compared to laparoscopic surgery in clinical practice.

The rapid growth of all robotic cancer surgeries for the first 5 years reflects a high social interest and optimism toward the adoption of new, innovative technologies in the medical field. The cessation of the overall growth seems to be largely associated with

Table 1
Numbers of participating institutions in the study and types of operations included in each surgical department.

Type of operation	Robotic surgery, no. (%)	Laparoscopic (endoscopic)[a] surgery, no. (%)	Open surgery, no. (%)	Total, no.
Total (n = 21)[b]	22,439 (11)	35,670 (18)	139,783 (71)	197,892
Colorectal (n = 12)	2835 (9)	18,085 (61)	8969 (30)	29,889
Anterior resection	180 (2)	8239 (72)	2948 (26)	11,367
Low anterior resection	1905 (12)	8760 (57)	4718 (31)	15,383
Intersphincteric resection	640 (33)	674 (35)	636 (33)	1950
Abdominoperineal resection	110 (9)	412 (35)	667 (56)	1189
Stomach (n = 7)	1926 (6)	11,846 (37)	17,931 (57)	31,703
Distal gastrectomy	1381 (6)	9377 (41)	11,935 (53)	22,693
Total gastrectomy	352 (5)	1423 (19)	5709 (76)	7484
Proximal gastrectomy	49 (9)	286 (54)	190 (36)	525
Pylorus-preserving gastrectomy	144 (14)	760 (76)	97 (10)	1001
HBP (n = 3)	94 (1)	761 (12)	5511 (87)	6366
Limited hepatectomy	28 (1)	277 (14)	1684 (85)	1989
Major hepatectomy	9 (0)	211 (10)	1970 (90)	2190
Distal pancreatectomy	48 (5)	174 (20)	667 (75)	889
Pancreaticoduodenectomy	9 (1)	99 (8)	1190 (92)	1298
Thyroid (n = 16)	17,584 (14)	4928 (4)	107,372 (83)	129,884
Total thyroidectomy	4522 (10)	954 (2)	40,141 (88)	45,617
Partial thyroidectomy	5158 (15)	2934 (9)	25,578 (76)	33,670
Central compartment neck dissection	7489 (17)	1032 (2)	35,546 (81)	44,067
Radical neck dissection	415 (6)	8 (0)	6107 (94)	6530

No., number; HBP, hepato-biliary-pancreatic.
[a] Cases of endoscopic surgery were included as thyroid surgery.
[b] n indicates the number of participating institutions.

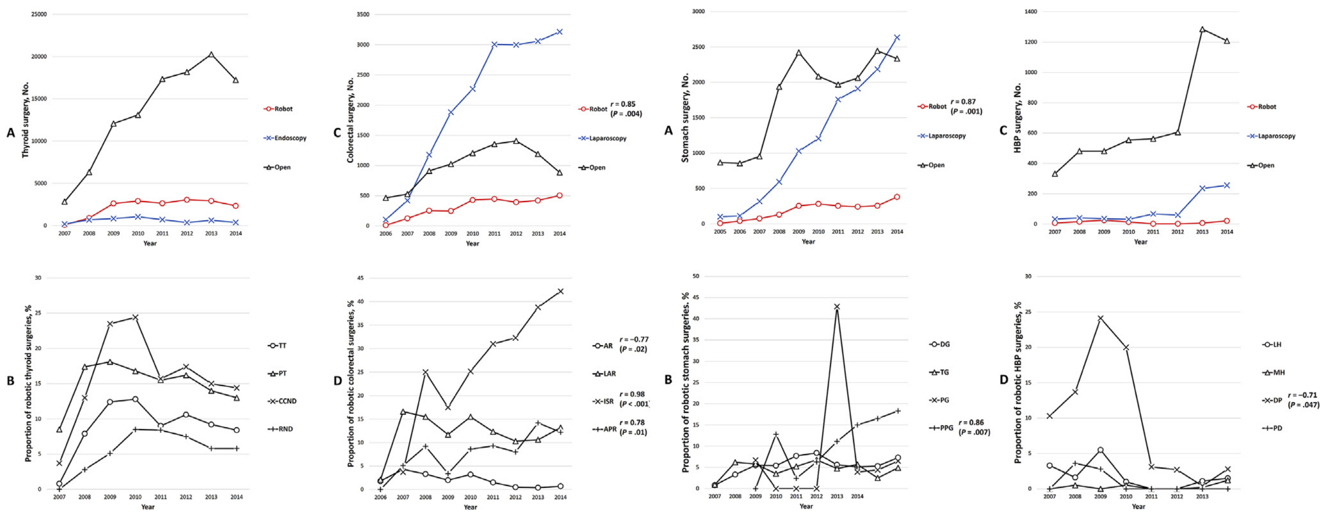

Fig. 2. Organ- and operation-specific trends in thyroid, colorectal surgeries, stomach and HBP surgeries.
(A) The total number of thyroid surgery (cases)
(B) The proportion of robotic thyroid surgery (%)
(C) The total number of colorectal surgery (cases)
(D) The proportion of robotic colorectal surgery (%), The proportions in (B) and (D) indicate the proportions of the types of operative procedures performed by robots to the total number of procedures performed. For robotic surgeries in (A) and (C), Spearman's correlation analysis was conducted.*r* indicates Spearman's correlation coefficient; no., number; TT, total thyroidectomy; PT, partial thyroidectomy; CCND, central compartment neck dissection; RND, radical neck dissection; AR, anterior resection; LAR, low anterior resection; ISR, intersphincteric resection; APR, abdominoperineal resection.(E) The total number of stomach surgery (cases), (F) The proportion of robotic stomach surgery (%), (G) The total number of hepato-biliary-pancreatic surgery (cases), (H) The proportion of robotic hepato-biliary-pancreatic surgery (%), The proportions in (F) and (H) indicate the proportions of the types of operative procedures performed by robots to the total number of procedures performed. For robotic surgeries in (E) and (G), Spearman's correlation analysis was conducted.*r* indicates Spearman's correlation coefficient; no., number; HBP, hepato-biliary-pancreatic; DG, distal gastrectomy; TG, total gastrectomy; PG, proximal gastrectomy; PPG, pylorus-preserving gastrectomy; LH, limited hepatectomy; MH, major hepatectomy; DP, distal pancreatectomy; PD, pancreaticoduodenectomy.

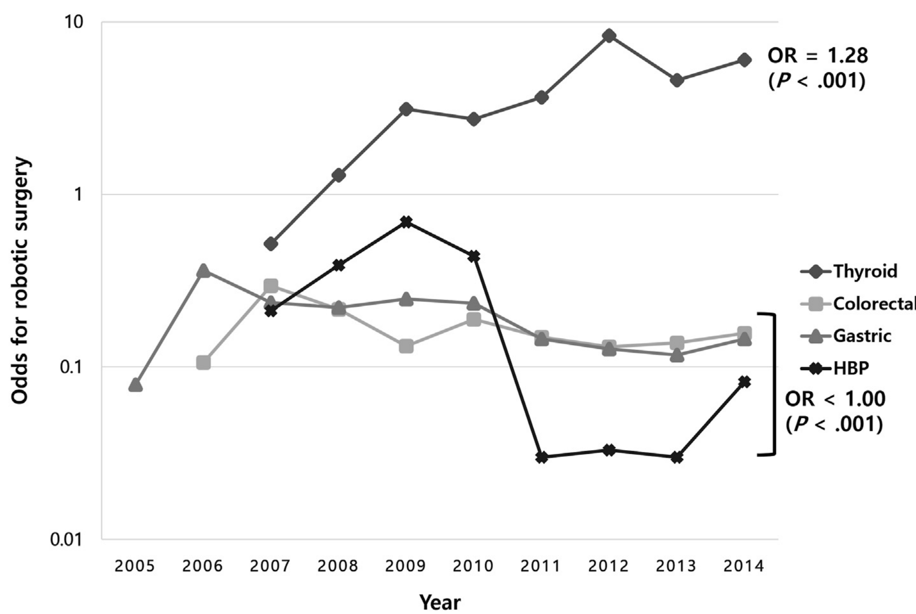

Fig. 3. Odds of performing robotic surgery versus laparoscopic surgery from 2005 to 2014.
Logistic regression was used to compare robotic surgery to laparoscopic surgery as a minimally invasive surgery.
OR indicates odds ratio; HBP, hepato-biliary-pancreatic.

the high costs of robotic procedures in comparison with laparoscopic approaches and partly with the policies developed by the National Healthcare Systems in Korea and worldwide. In Korea, most patients can personally cover only 5% of the entire cost of cancer surgery; therefore, if patients patient desire to undergo robotic surgery, they would have to pay the overall cost for the robotic surgery by themselves and provide consent preoperatively. Robotic surgeries are approximately three times more expensive than laparoscopic surgeries.[5–7] Moreover, several previous studies designed to identify the long-term oncological benefits of robotic surgeries did not prove an apparent superiority of robotic surgery over conventional laparoscopic surgeries.[8–10] Thus, surgeons now seem to have developed a tendency to seek clear patient benefits when choosing robotic surgeries, compared to the initial period of robotic surgery when robotics were used aggressively for marketing purposes.

In organ-specific cases, early establishment of indications for robotic thyroid surgery likely contributed to the stable trend in the application of robotics in thyroid surgery. Although the intraoperative conversion rate of the thyroid gland is negligible, robotic thyroid surgery has a clear advantage over conventional laparoscopic thyroid surgery in terms of excellent cosmetic satisfaction.[9,11,12] As most patients with thyroid cancer in Korea are relatively young women who culturally feel more sensitive to anterior neck scars.[11] robotic thyroid surgery carries an absolute advantage for patients and surgeons, without long-term clinical complications. In contrast to robotic colorectal and stomach surgeries, robotic thyroid surgery was adopted in clinical practices before sufficient maturation of conventional endoscopic thyroid surgery, possibly because of the long learning curve for endoscopic thyroid surgery.[9] Therefore, robotic thyroid surgery was likely adopted earlier, and given the rapid accumulation of sufficient surgical experience, robotic thyroid surgery would have matured more promptly.[9,13,14]

Although the proportion of colorectal surgeries did not increase significantly, the trend for colorectal surgeries was almost consistent with the significantly increasing trend in the number of robotic colon-rectum surgeries. This supports the idea that robotic colorectal surgery in the clinical field has several advantages. Our findings are in line with those of a single-institution study that reported a similarly increasing trend in the number of robotic colorectal surgeries.[15] These trends seem to account for better functional outcomes of robotic colorectal surgery, such as earlier recovery of voiding and sexual function.[16,17] Several studies have hypothesized that robotic colorectal surgery provides better oncological outcomes because the intraoperative conversion rate of the robotic colorectal surgery was significantly lower than that of the laparoscopic colorectal surgery.[18] However, published data for establishing convincing evidence are sparse.[8]

The increased use of robotic stomach surgery in our study seems to manifest surgeons' expectation of the benefits of robotic approaches. Significant short-term outcomes of robotic stomach surgery over laparoscopic stomach surgery have been proven, such as a decreased risk of pancreatic fistula formation and reduced estimated blood loss.[19–21] Studies that demonstrated faster learning curves for robotic stomach surgery may also have encouraged surgeons to shift to robotic gastric surgery.[22,23] A recent multicenter prospective study comparing robotic and laparoscopic gastric surgery found no significant difference in the intraoperative conversion rates between the two, and robotic surgery has no clear advantage over laparoscopic surgery.[24] The authors suggested that future studies should focus more on technically demanding procedures to prove the benefits of robotic surgery over laparoscopic surgery.

The number of robotic HBP surgeries showed a negative correlation without statistical significance. However, analysis of the trend of robotic HBP surgeries had little implication in our study owing to the limited number of investigated cases of robotic HBP surgery compared to that in other surgical departments. Systematic reviews have reported that robotic hepatectomy has no perioperative benefit over laparoscopic approaches, and because of higher cost, is less advantageous than laparoscopic surgeries.[25,26] Several studies agree on the safety and feasibility of robotic pancreatectomy, including pancreaticoduodenectomy,[27–30] but the superiority of any surgical method has not been established.

In the operation-specific analysis, robotic surgery was increasingly utilized in procedures conducted in limited surgical fields or those that require functional preservation. This finding is in line with the previously suggested advantages of robotic surgery over laparoscopic surgery, such as three-dimensional visualization and a higher degree of freedom.[2] As ISR requires fine manipulation of tissues in a limited surgical field with function preservation, only few studies have recommended laparoscopic approaches for ISR.[31–33] Laparoscopic ISR warranted longer operation times and showed high conversion to open surgery rates in these studies. By contrast, robotic ISR has shown several benefits over laparoscopic ISR. Park et al reported favorable outcomes of robotic ISR compared with laparoscopic ISR, including better functional outcomes and reduced adaptation time.[16] For APR, the robotic approach exhibited favorable perioperative and short-term oncological outcomes.[34,35] Similar to robotic ISR, robotic APR had a significantly lower conversion rate in another study,[36] and the relative proportion of robotic APR to the total number of performed APRs increased during the study period, which is congruent with our results. The proportion of robotic PPG also increased significantly in our study, but robotic PPG has been rarely discussed. Given the increasing prevalence of early gastric cancer and its concerns on improving of quality of life after surgery, function-preserving surgeries has steadily increased as adequate postoperative nutritional status and appropriate surgical methods are becoming more important. Han et al compared robotic and laparoscopic PPG by propensity score matching and concluded that robotic PPG has no superiority over laparoscopic PPG.[37] Nevertheless, this finding supports our point that robotics are being increasingly applied to function-preserving surgeries. In this regard, the decreasing trend in the proportion of robotic AR can be easily understood because AR is a relatively less complicated surgery.

In logistic regression analysis, the odds of performing robotic surgery were found to have temporally decreased, except in thyroid surgeries, for which the use of robots instead of conventional laparoscopes increased annually. This finding implies that although the absolute numbers of robotic surgeries steadily grew annually, utilization of robotic surgery has failed to surpass that of laparoscopic surgery because of the stronger expansion of laparoscopic surgeries in most fields of general surgery. With the advent of minimally invasive surgery, conventional laparoscopic methods have actively extended to various fields of surgery as a first-line approach for minimally invasive surgeries. By contrast, robotic surgery failed to maintain its early aggressive expansion as it faced many cost- and benefit-related controversies.[2,38–42] Notably, the odds for performing robotic thyroid surgeries have grown. The number of robotic thyroid surgeries did not show significant trends, but the decreased number of endoscopic thyroid surgeries in our data would have contributed to enhanced utilization of robotic surgeries in the field of minimally invasive thyroid surgeries.

For HBP surgeries, although some studies indicate that the conversion rate of robotic surgery is significantly lower than that of laparoscopic surgery in pancreatic resection, our study only includes data from three institutions.[43] and 94 cases of robotic surgeries were investigated. This is markedly fewer than the number of cases in other departments, which are at least over 1000; hence, it is questionable whether our results can accurately reflect the actual trend in robotic HBP surgery. Moreover, as robotic surgery is not covered by the national healthcare system, decision-making processes on patient selection vary among surgical departments. In terms of guaranteeing the rights of patients, instead of recommending robotic surgery or laparoscopic surgery to the patient, the patient can choose either surgery. Patients can choose between laparoscopic or robotic surgery based on their financial situation and personal preferences. Except for robotic surgeries for rectal and thyroid cancers, which possess relatively clear clinical benefits, patient selection in other departments depends mainly on the patients' current economic status. In a prospective study that compared robotic and laparoscopic gastrectomy in Korea, the mean patient age in the robotic gastrectomy group was 52 years, which is the most socioeconomically active age, and it was significantly younger than that in the laparoscopic gastrectomy group.[24] This suggests that factors other than clinical advantages could have possibly influenced our results. Another limitation of this study was that we could not collect all national data because we recruited volunteer institutions, but data of hospitals that were actively performing robotic surgery were mostly collected. Thus, we expect that our data are sufficient to reflect the national trend of robotic cancer surgery in Korea.

5. Conclusions

Initially, the overall number of robotic cancer surgeries in Korea increased steadily, but this growth has now ceased because of unresolved cost-related concerns and unclear clinical merits of robotic surgery compared to laparoscopic surgery. Among the surgical departments, robotic colorectal and stomach surgeries have maintained their expansion into the field of minimally invasive surgery, although they did not preponderate laparoscopic surgery. Robotic thyroid surgery rapidly matured in the initial period; the long-term trend has not significantly changed. However, odds for choosing robotic thyroid surgery have increased because of the decline in endoscopic thyroid surgeries. Robotics have been increasingly utilized in limited fields and complex surgeries, but their use in relatively simple surgeries has declined.

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Author contributions

Liang An and Kyo Sun Hwang contributed equally to this work. All authors made substantial contributions to the design and analysis of this work, which included drafting and assessing the manuscript. All authors approved the final manuscript for submission and agreed to be accountable for the work.

Data statement

The research data is confidential.

Declaration of competing interest

None.

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