Long term resource consequences of a nationwide introduction of robotic surgery for women with early stage endometrial cancer

Malene Korsholm [a,b,c,d,*], Dorte Gyrd-Hansen [d], Ole Mogensen [e], Sören Möller [b,c], Liza Sopina [d], Siv L. Joergensen [a,b,c], Pernille T. Jensen [b,e]

[a] Research Unit of Gynecology and Obstetrics, Odense University Hospital, Kloevervaenget 10, 10th Floor, 5000 Odense C, Denmark
[b] Faculty of Health Sciences, Department of Clinical Research, University of Southern Denmark, J.B. Winsloews Vej 19, 5000 C, Denmark
[c] Odense Patient Data Explorative Network (OPEN), Department of Clinical Research, University of Southern Denmark and Odense University Hospital, J.B. Winsloews Vej 9, 3rd Floor, 5000 Odense C, Denmark
[d] Danish Centre for Health Economics (DaCHE), Department of Public Health, University of Southern Denmark, J.B. Winsloews Vej 9B, 1st Floor, 5000 Odense C, Denmark
[e] Faculty of Health Institute for Clinical Medicine, Aarhus University and Department of Gynecology, Aarhus University Hospital, Palle Juul-Jensens Blvd. 99, 8200 Aarhus N, Denmark

HIGHLIGHTS

- Robotic minimally invasive surgery in early stage endometrial cancer generates no cost savings one year post surgery.
- Robotic surgery generates higher costs related to the surgical procedure compared with open and laparoscopic surgery.
- When controlling for time trends robotic surgery did not generate bed day savings.
- Robotic surgery does not reduce women's sickness leave or exit from the labor market.

ARTICLE INFO

ABSTRACT

Objective. The majority of cost-studies related to robotic surgery has a short follow-up and primarily report the costs from the index surgery. The aim of this study was to evaluate the long-term resource consequences of introducing robotic surgery for early stage endometrial cancer in Denmark.

Methods. The study included all women with early stage endometrial cancer who underwent robotic, laparoscopic and open access surgery from January 2008 to June 2015. Data was linked from national databases to determine resource consumption and costs from hospital treatments, outpatient contacts, primary health care sector visits, labor market affiliation and prescription of medication. Each patient was observed in a period of 12 months before- and after surgery. The key exposure variable was women who were exposed to robotic surgery compared to those who were not.

Results. A total of 4133 women underwent surgery for early stage endometrial cancer. The study found additional costs of $7309 (95% confidence interval [CI] 2100–11,620, P = 0.001) per patient in the group exposed to robotic surgery including long-term costs post-surgery compared to the non-exposed group (non-robotic group). When controlling for time trends, the introduction of robotic surgery did not reduce the number of bed days (mean diff −0.42, 95% CI −3.03–2.19, P = 0.752).

Conclusions. The introduction of robotic surgery for early stage endometrial cancer did not generate any long-term cost savings. The additional costs of robotic surgery were primarily driven by the index surgery. Any reduction in bed days could be explained by time trends.

© 2019 Elsevier Inc. All rights reserved.

1. Introduction

The robotic platform has been rapidly adopted for gynecological procedures in the US and Europe thereby reducing the use of Open Access Surgery (OAS) [1]. The establishment of robotic surgical availability is associated with high initial purchase costs of the platform and additional maintenance and surgical supply costs [2,3]. In a recent review, we compared the methodological design in 32 cost studies within the

* Corresponding author at: Research Unit of Gynecology and Obstetrics, University of Southern Denmark, Odense University Hospital, Kloevervaenget 10, 10th Floor, 5000 Odense C, Denmark.
E-mail addresses: malene.korsholm@rsyd.dk (M. Korsholm), dgh@sdu.dk (D. Gyrd-Hansen), olemog@rm.dk (O. Mogensen), soren.moller@rsyd.dk (S. Möller), lsopina@sdu.dk (L. Sopina), siv.lykke.joergensen@rsyd.dk (S.L. Joergensen), pernille_jensen@dadlnet.dk (P.T. Jensen).

gynecological field [2]. Most studies suffered from selection bias, as they were not able to control for data on tumor stage, comorbidities and/or unobservable patient characteristics [2,4–8], nor did they control for prior levels of health care service use. The majority of these studies had a short follow-up reporting the costs from the index surgery without investigating the long-term resource implications of Robotic Minimally Invasive Surgery (RMIS) [2]. There is currently insufficient evidence as to whether the immediate costs of introducing RMIS are offset by long term savings due to e.g. reduced need for rehabilitation services, reduced utilization of primary care services, fewer outpatient visits and/or faster return to the labor market, compared to other surgical procedures. Previous studies comparing RMIS with OAS for women with endometrial cancer have shown shorter length of stay from the index surgery [9–11], fewer readmissions [9] and reduced risk of severe complications [12].

The present study aims to evaluate the long-term resource consequences of introducing RMIS for early stage endometrial cancer in Denmark. The evaluation strategy has three major strengths. Firstly, we took advantage of the fact that RMIS was introduced in the regions of Denmark at different points in time and at different paces between 2008 and 2013. This allowed assessment of exposed and non-exposed individuals simultaneously, and minimization of potential patient selection bias as exposure to RMIS depended on RMIS introduction patterns and not women's characteristics. Secondly, we applied an analytical approach where the patient acted as her own control. We controlled for use of health care resources one year prior to surgery, which allowed us to isolate the resource use associated with surgery. Thirdly, we operated with a follow-up period of one-year post-surgery, and used high quality registry data to monitor the long-term resource consequences of RMIS in the primary and secondary health care sector. We also measured production losses due to sickness leave or earlier exit from the labor market.

2. Materials and methods

2.1. Study design

RMIS was gradually introduced in Denmark over a five-year period from 2008 to 2013. We included all women in Denmark who underwent surgery for early stage endometrial cancer FIGO stage I-II from January 1st, 2008 to June 30th, 2015. Women operated before the date of the first RMIS performed in their region were allocated to the non-exposed group. The non-exposed group (non-robotic group) mainly underwent open access surgery and a minor proportion had conventional laparoscopy. Women in the exposed group were operated after the date of the first RMIS performed in their region and were considered as exposed to RMIS. The majority in the exposed group underwent robotic surgery and a minor proportion underwent laparoscopy and open access surgery.

The treatment of endometrial cancer in Denmark is conducted in accordance with national guidelines from the Danish gynecological cancer group [13] and revised every 3-4th year. The gold standard of surgery consists of total hysterectomy and bilateral salpingo-oophorectomy. Women with increased risk of metastatic disease undergo additional staging lymphadenectomy (pelvis +/− para-aortic) and omentectomy for certain histological subtypes [14]. To estimate the resource consequences of introducing RMIS we utilized the gradual phase-in of this new technology and constructed a quasi-experimental design comparing women who were exposed to robotic surgery with those who were not. We assume that the time and place at which a woman undergoes surgery for endometrial cancer is random and independent of patient characteristics such as age, BMI and comorbidity. Our key exposure variable is the fraction of women who had RMIS out of the total number of women receiving surgery for early stage endometrial cancer in a given region and at a specific time. Our primary outcomes are changes in resource use and costs, as well as labor market affiliation, in the first year after surgery compared to the year before surgery.
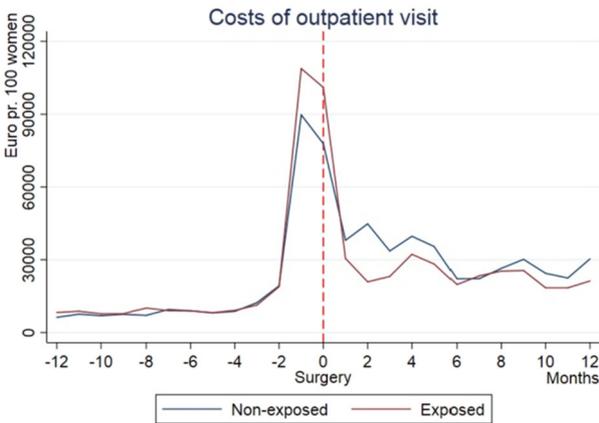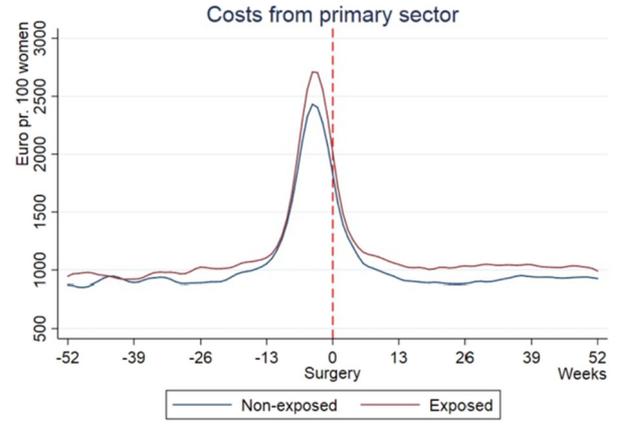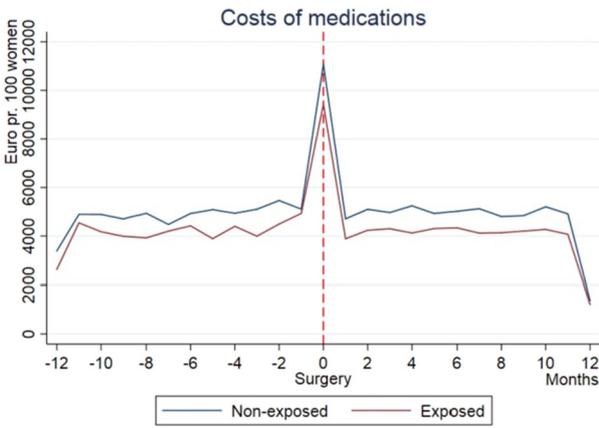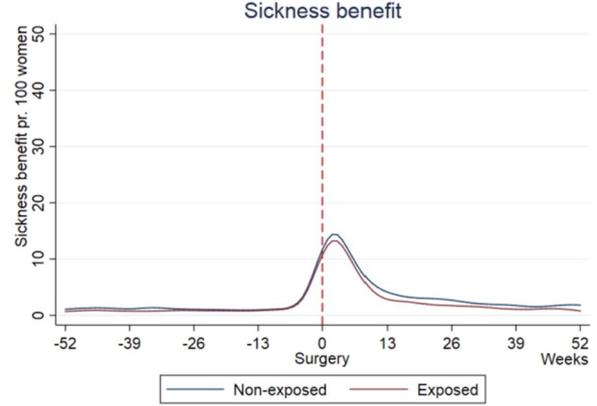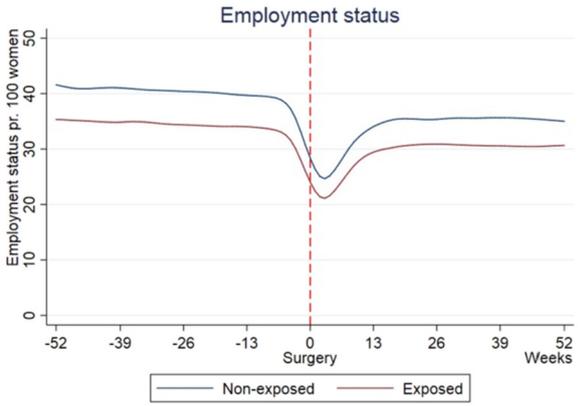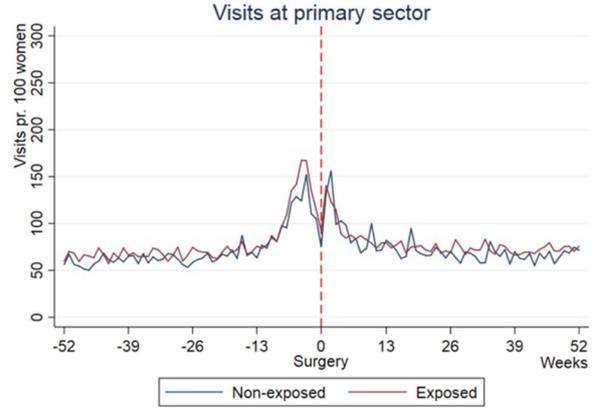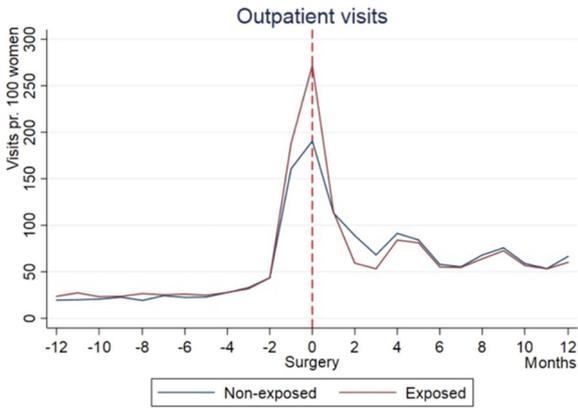
2.2. Data sources

The study population was extracted from the Danish Gynecological Cancer Database (DGCD) which covers clinical, surgical, and pathology data. Data are registered mandatory by gynecologists specialized in gynecological cancer surgery and pathologists [15]. The DGCD is a nationwide, clinical quality registry that covers 97% of women diagnosed with endometrial cancer [15]. From this database we extracted information on the surgical modality, date of surgery, location of the hospital, Body Mass Index (BMI), histological type, grade, FIGO stage, and information on whether lymphadenectomy was performed.

All Danish residents have a unique personal identification number (CPR-number) which enables accurate linkage between all national registers [16]. The study population was linked with individual-level register data from the Danish National Patient Register (NPR) [17], The Danish National Health Service Register [18], and The Danish Education register [19]. The NPR holds information on dates of all hospital admissions and discharges, hospital in-patient treatments, and operations including re-operations, outpatient contacts, and diagnoses [17]. The National Health Service Register holds data from the primary health care sector, accounting for health services [18]. Any production losses due to changes in job market affiliation were measured by comparing individual-level labor market data and sickness benefit data before and after surgery [20]. The DREAM database includes weekly information for all Danish citizens who have received social benefit or any other transfer benefit [21].

Costs of hospital admissions were estimated using unit costs derived from the Diagnosis Related Grouping system (DRG) for somatic inpatients [22], the Danish Ambulatory Grouping System (DAGS) for ambulatory patients [22], The National Health Service Register for primary health contacts [18], and The Danish National Prescription Registry. The Danish National Prescription Registry provides information on the costs for prescription medication handed out from pharmacies [23]. The national DRG-tariffs for surgery for endometrial cancer included activities from hospital admission to discharge. Outpatient visits and reoperations associated with the index hospitalization were reimbursed separately. DRG tariffs are based on annual detailed costing reporting's from all public hospitals in Denmark, and reflect the national average operating costs within each DRG group [22]. The DRG tariffs thus represent reimbursement fees that do not reflect the precise cost of treating the individual patient. DRG-tariffs are adjusted each year and published by the Danish Health Authority [22]. All costs were adjusted to price index 2015 [24] and converted into USD ($).

2.3. Statistical methods

Each patient was observed in a pre-treatment period of 12 months before the date of the index surgery and a post-treatment period of 12 months after the date of the index surgery. To control for potential pre-surgery differences in health care service utilization, and to isolate the costs associated with surgery, we applied a Difference-in-Difference (DiD) design. In the DiD design, the patient acts as her own control and the outcome variable is change in resource use post-surgery versus pre-surgery [25–27]. In the analyses, the focus is to estimate whether the introduction of RMIS, measured by level of exposure (proportion of patients being treated with RMIS out of the total number of patients in a given region and calendar year), was associated with changes in the primary outcome variables measuring resource use and

Fig. 1. Resource use and costs one year before and after the index hospitalization. Resource use and costs are reported as year totals, while employment status and sickness benefit are reported as number of weeks per year.

costs as obtained from registers. Underlying the DiD design lies the common trends assumption to ensure internal validity of the approach. For ease of presentation the exposure variable was dichotomized (exposed; non-exposed) in the descriptive analyses but modelled as a continuous variable in the regression models. The common trends assumption requires the exposed and non-exposed group to have the same parallel trends in outcomes the year before index surgery. Time series in resource use were plotted graphically for outpatient visits, primary sector visits, employment status and sickness benefit and the pattern of costs were plotted for primary sector visits, outpatient visits, and prescription of drugs per woman to evaluate whether the common trends assumption was fulfilled in the one-year period prior to surgery (Fig. 1).

To ensure that potential differences in baseline characteristics did not drive differences in trends, a linear regression was performed. We adjusted for potential time trends by including fixed effects for calendar year, and for potential differences in resource use across regions by including fixed effects for each region.

This resulted in the fully adjusted model in which our exposure variable was defined as the proportion of patients being treated with RMIS out of the total number of patients receiving surgery for early stage endometrial cancer by calendar year and region:

$$\Delta C_i = C_{i1} - C_{i0} = c + \beta_1 p_{RMISi} + \sum_k \beta_k \times X_{ik} + \varepsilon_i$$

here ΔC_i indicates the difference in costs per patient the year after surgery (C_{i1}) relative to the year prior to surgery (C_{i0}), c denotes the model intercept, β_1 is the key result denoting the association between the outcome variable ΔC_i and our exposure variable p_{RMISi}, X_{ik} represents covariates (age, BMI, Charlson comorbidity index, ASA score, histopathological risk groups, lymphadenectomy, education level, socioeconomic group) including region-of-surgery and year-of-surgery fixed effects, and ε_i denotes the residuals in the linear regression model. To investigate any possible over adjustment in time trends a sensitivity analysis

was performed in which we analyzed data for a short time period only (2011–2012).

We performed a further sensitivity analysis excluding patients who underwent surgery in the region of Southern Denmark due to potentially confounding research projects related to the postoperative follow-up visits taking place in the region during the time of observation.

Results are reported as mean differences with 95% confidence intervals (CI) based on bootstrapping with 5000 replicates to take into account the skewed nature of cost and resource use data. The difference-in-difference mean estimates for resource use and costs one year postoperatively (contacts/costs per patient) are reported in three models, 1) an unadjusted model, 2) a model adjusted for patient characteristics and region of surgery and 3) a model that is further adjusted for surgical year. Resource use and costs are compared between 12 months before and 12 months after the index surgery. Resource use and costs of bed days were analyzed both including and excluding the index surgery stay to investigate if potential differences were driven by the index surgery stay. Resource use and costs are reported as year totals, while employment status and sickness benefit are reported as number of weeks per year.

A two-sided p-value below 0.05 was considered statistically significant. All analyses were performed using Stata version 15.1. Data was pseudo-anonymized and administered by Statistics Denmark.

2.4. Ethical consideration

The study was approved by the Data Protection Agency (18/43728).

3. Results

During the study period, 4133 women with early stage endometrial cancer underwent surgery in Denmark (Fig. 2). Before RMIS was introduced 78% of women underwent open access surgery (Fig. 2). During

Fig. 2. Flowchart of included patients. OAS: Open Access Surgery. LMIS: Laparoscopic Minimally Invasive Surgery. RMIS: Robotic Minimally Invasive Surgery.

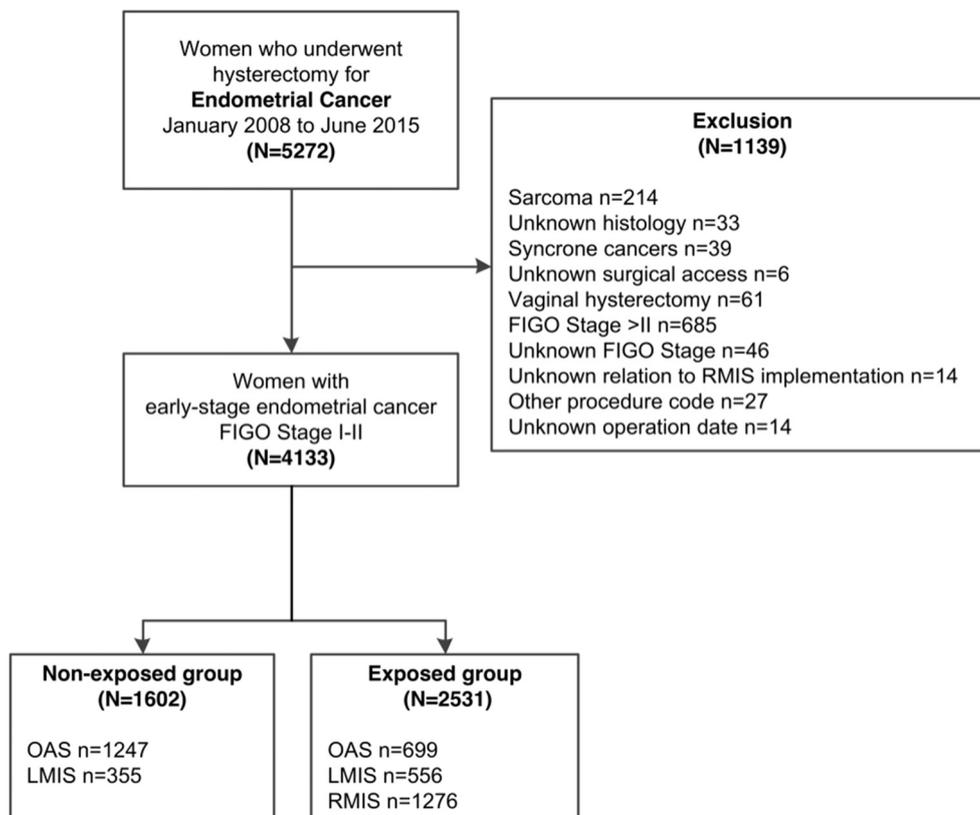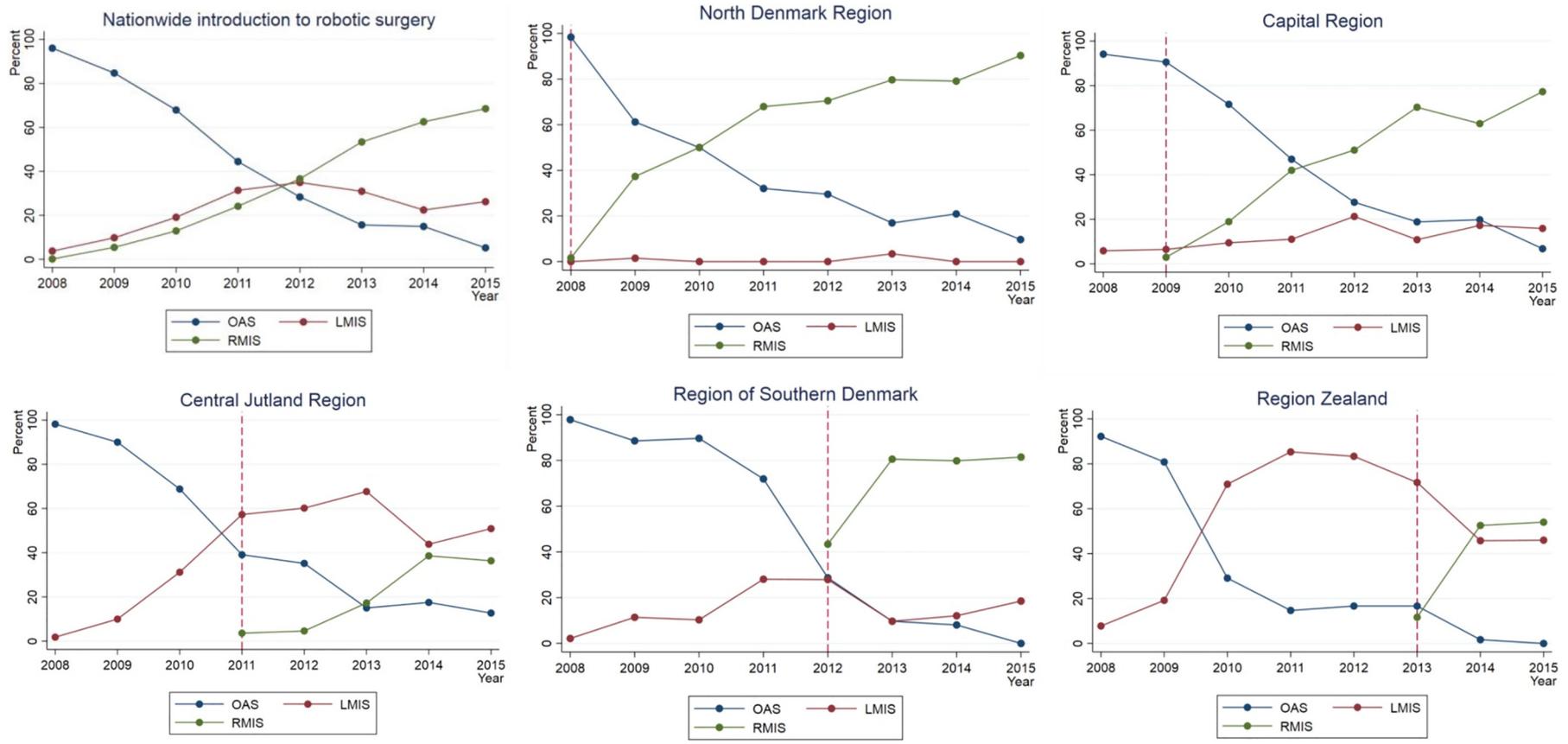**Fig. 3.** The introduction to robotic surgery in DK and each region Jan. 2008–July 2015. OAS: Open Access Surgery. LMIS: Laparoscopic Minimally Invasive Surgery. RMIS: Robotic Minimally Invasive Surgery. Red dotted line: The year of introducing robotic surgery in each region.

the 7.5 years of observation while robotic surgery was introduced nationwide, 72% of the women underwent minimally invasive surgery (laparoscopy and RMIS). In the present study these women are nominated "exposed" vs. "non-exposed" but modelled as proportions in the regression models. Fig. 3 illustrates the introduction of RMIS nationwide and separately for each region. Conventional laparoscopy was used in 22% of the women in the exposed and the non-exposed group. As it appears, the use of conventional laparoscopy increased before the introduction of RMIS and decreased slightly during the RMIS period (Fig. 3). Sociodemographic characteristics between the groups are given in Table 1.

3.1. Resource use

Patients assigned to the exposed group had almost four fewer bed days the year following surgery compared to the non-exposed group, when adjusting for patient characteristics only (Table 2). After further adjustment for surgical year no statistically significant difference was observed in bed days between the exposed and non-exposed group (Table 2). This was true for both index surgery and subsequent hospitalizations. Also, no statistically significant difference in resource use was observed for primary sector- or outpatient visits between the exposed and the non-exposed group (Table 2).

3.2. Costs

The total costs one-year post-surgery from hospitalization, primary sector visits, outpatient visits and prescription drugs were $7309 higher per patient in the exposed group compared to the non-exposed group ($p = 0.001$) (Table 3). The costs related to the hospitalization including the index surgery and subsequent hospitalizations were $7434 higher per person in the exposed group vs. non-exposed group ($p = 0.001$) (Table 3). No statistically significant cost difference was found between the exposed and the non-exposed group for the other cost categories (Table 3).

A sensitivity analysis, which included a smaller sample based on a shorter time period showed results consistent with the main analysis, indicating no signs of over-adjustment for time trend. The sensitivity analysis excluding patients from the Region of Southern Denmark did not change any results significantly.

4. Discussion

This study included all women with early stage endometrial cancer who underwent surgery at Danish hospitals over a period of 7.5 years. Long-term resource use and costs related to their index surgery and the year following surgery were evaluated. The introduction of robotic surgery did not generate any long-term cost savings related to primary sector, outpatient visits, or prescription of medicine in this population of gynecological cancer patients. The introduction of robotic surgery was associated with additional costs of $7309 per patient in the exposed group compared to non-exposed and the extra costs were mainly attributable to the index surgery. Our findings are in line with other cost studies reporting RMIS to be more costly than open and conventional laparoscopic surgery in women with endometrial cancer [4,7,28–31]. Smith et al. reported that the overall hospital charge was 40% higher with RMIS compared to laparoscopy and open access surgery [31]. In contrast to our findings, Laursen et al. found that RMIS generated cost savings of $3861 per women when compared with open access surgery and increased costs of €3749 when compared with laparoscopy in Danish cancer patients [32]. Important differences between the study of Laursen and the present study concern the selection of the patient population and the data source. Further, our study applied an intention to treat approach thus minimizing the risk of selection bias due to non-random allocation to treatment modalities. Importantly, our findings relate to the particular patient group of women with early stage

endometrial cancer who are comparatively unaffected by their cancer when diagnosed. Hence, our results cannot be used to generalize about resource use and costs related to robotic surgery in other patient groups with e.g. a greater need of longer rehabilitation or sick leave. However, the evaluation method used in the present study can be applied to other patient groups for a valid non-biased evaluation of resource use and costs related to the introduction of a new technology.

In a recent study, we showed that a Danish nationwide introduction of robotic surgery for early stage endometrial cancer is associated with

Table 1
Demographic characteristics of included women.

	Non-exposed group $N = 1602$ No (%)	Exposed group $N = 2531$ No (%)	P-value
Age			0.282
Mean (std. dev.)	67.2 (10.4)	67.6 (10.5)	
Median (range)	67 (41–90)	67 (44–90)	
Age group[a]			0.159
≤59 years	369 (23.0)	574 (22.7)	
60–66 years	429 (26.8)	610 (24.1)	
67–74 years	398 (24.8)	690 (27.2)	
≥75 years	406 (25.4)	657 (26.0)	
BMI group[b] (kg/m²)			0.027
<25.0	515 (32.9)	779 (32.1)	
25.0–29.9	500 (32.0)	700 (28.8)	
30.0–34.9	295 (18.8)	473 (19.5)	
≥35.0	255 (16.3)	476 (19.6)	
Unknown	37	103	
CCI[c]			0.564
0	1050 (65.5)	1640 (64.8)	
1	267 (16.7)	454 (17.9)	
≥2	285 (17.8)	437 (17.3)	
ASA score[d]			<0.001
I	602 (37.7)	774 (31.0)	
II	840 (52.6)	1432 (57.2)	
≥III	155 (9.7)	295 (11.8)	
Unknown	5	30	
Histopathological risk[e]			0.138
Low-risk	856 (54.5)	1424 (57.4)	
Intermediate low-risk	296 (18.8)	401 (16.2)	
Intermediate high-risk	51 (3.2)	78 (3.1)	
High-risk	369 (23.5)	577 (23.3)	
Unknown	30	51	
Lymphadenectomy			0.196
No	1061 (66.5)	1602 (64.5)	
Yes	534 (33.5)	880 (35.5)	
Unknown	7	49	
Educations[f]			<0.001
Grade school	715 (45.9)	970 (39.2)	
Short education	561 (36.0)	915 (36.9)	
Medium-further education	282 (18.1)	592 (23.9)	
Unknown	44	54	
Socioeconomy[g]			<0.001
I	193 (12.0)	388 (15.3)	
II	576 (36.0)	1008 (39.9)	
III	832 (52.0)	1132 (44.8)	
Unknown	<3	3	
Region[h]			<0.001
North Denmark	57 (3.6)	442 (17.5)	
Capital	282 (17.6)	1055 (41.7)	
Central Jutland	357 (22.3)	491 (19.4)	
Southern Denmark	516 (32.2)	405 (16.0)	
Zealand	390 (24.3)	138 (5.4)	

[a] Age group was reported for the year of surgery and grouped in quartiles.
[b] BMI group was ranked according to the World Health Organization classification.
[c] CCI: Charlsons Comorbidity Index: 10 years before surgery. All diagnosis-codes unless referral diagnosis.
[d] ASA score: American Society of Anesthesiologists physical status classification system.
[e] Histopathological risk groups: Low-risk: EAC Stage IA Grade I–II, Intermediate low-risk: EAC Stage IB Grade I–II, Intermediate high-risk: EAC Stage IA Grade III, High-risk: EAC Stage IB grade III/EAC Stage II/non-EAC.
[f] Educations: Highest completed educations.
[g] Socioeconomic status was categorized by income the year before surgery and the highest achieved educational level.
[h] The hospital location was categorized according to the five regions in Denmark.

Table 2

Resource use associated with the introduction of robotic minimally invasive surgery for women with early stage endometrial cancer.

	Unadjusted model		Adjusted model I patient characteristics		Adjusted model II patient characteristics and surgical date	
	Additional number per patient[a]	P value[b]	Additional number per patient[a]	P value[b]	Additional number per patient[a]	P value[b]
No. of contacts						
Bed days (index hospitalization)[c]	−2.83 (−3.34 to −2.32)	<0.001	−3.55 (−4.15 to −2.96)	<0.001	−0.16 (−1.28 to 0.96)	0.781
Bed days (subsequent hospitalizations)[d]	−0.18 (−1.17 to 0.81)	0.721	−0.25 (−1.46 to 0.96)	0.683	−0.36 (−2.52 to 1.80)	0.745
Bed days (all hospitalizations)[e]	−2.97 (−4.16 to −1.79)	<0.001	−3.74 (−5.15 to −2.33)	<0.001	−0.42 (−3.03 to 2.19)	0.752
Outpatient visits	0.01 (−0.89 to 0.92)	0.975	0.27 (−0.87 to 1.42)	0.638	0.66 (−1.62 to 2.95)	0.570
Primary sector	−1.15 (−4.72 to 2.41)	0.526	1.41 (−2.71 to 5.53)	0.502	3.96 (−5.54 to 13.46)	0.414
Employment status[f]	1.28 (0.36 to 2.21)	0.006	0.98 (−0.05 to 2.01)	0.062	−0.53 (−2.69 to 1.63)	0.630
Sickness benefit[f]	−0.57 (−1.11 to −0.03)	0.038	−0.55 (−1.20 to 0.09)	0.092	−0.40 (−1.71 to 0.91)	0.551

No. of contacts are per patient with 95% CI.

[a] Additional number of contact/bed days of RMIS compared to the non-robotic group.

[b] P value in relation to additional contact/bed days.

[c] Number of bed days from index hospitalization stay.

[d] Bed days without the hospital stay.

[e] Bed days including the hospital stay related to the surgery.

[f] Results are reported in week's one-year post-surgery.

reduced risk of severe complications and improved survival independent of histopathological risk group [12,33]. However, taking time trends as well as patient characteristics into account, the present study was unable to demonstrate that the introduction of RMIS was associated with a significant reduction in bed days as would be expected in case of fewer re-admissions due to severe complications after minimally invasive surgery. Scrutinizing the graphical presentation of the RMIS introduction in the different regions in Denmark reveals different trends of robotic introduction in two regions (the region of central Jutland and the Zealand region). These regions had a very slow introduction of RMIS compared to the other regions while the proportion of women undergoing conventional laparoscopy increased dramatically. This led to an increased use of conventional laparoscopy already before the introduction of RMIS in these regions and contributed to the decrease in bed days in the non-exposed group. Further, during the time period with robotic introduction another time trend arose; even women who underwent open surgery had fewer bed days compared to earlier time periods. This was likely due to emerging evidence regarding the importance of early mobilization and faster recovery at home. It may be looked at as a paradigm shift and is likely to influence on the results when including a comparatively large time period in the analyses. This emphasizes the importance of adjusting for potential time trends when including patients over several years. In the present

study, length of stay was driven by time trends rather than surgical modality.

Using the Danish DRG-tariffs, all gynecological procedures were listed as more expensive when involving robotic surgery i.e. a simple hysterectomy with bilateral salpingo-oophorectomy without lymph node dissection is valued at $11,259 using robotic surgery versus $7722 without the robotic assistance for the same procedure. The in-hospital costs of RMIS is likely to decrease in the years to come due to increased surgeon experience and hence reduction in procedure- and operating room time. This prediction is supported by Avondstondt et al. who found a reduction in total costs attributable to a decrease in the operating room costs and costs of anesthesia after five years of experience with RMIS [34]. In addition, present patents related to the robotic platform will expire in the near future. The lack of market competition is highly related to the high costs of robotic instrument supplies. Same-day discharge may be another cost-saving procedure for RMIS. Several studies have found this safe and feasible for the majority of women undergoing minimally invasive surgery [35–38]. According to the literature, Enhanced Recovery After Surgery (ERAS) protocols decreased length of stay by 30% to 50% thereby lowering hospital costs [39]. ERAS, a comprehensive program with multimodal approaches of perioperative pathways, has resulted in early recovery after surgery and has shown to improve outcomes in almost all major surgical specialties

Table 3

Costs associated with the introduction of robotic minimally invasive surgery for women with early stage endometrial cancer.

	Unadjusted model		Adjusted model I patient characteristics		Adjusted model II patient characteristics and surgical date	
	Additional cost per patient (USD)[a]	P value[b]	Additional cost per patient (USD)[a]	P value[b]	Additional cost per patient (USD)[a]	P value[b]
Costs						
Index hospitalization[c]	5803 (5241 to 6364)	<0.001	6622 (5992 to 7252)	<0.001	4438 (3232 to 5644)	<0.001
Subsequent hospitalizations[d]	1226 (−328 to 2782)	0.122	1155 (−678 to 2986)	0.217	2747 (−755 to 6251)	0.124
All hospitalizations[e]	7072 (5391 to 8752)	<0.001	7853 (5829 to 9877)	<0.001	7434 (3605 to 11,263)	0.001
Outpatient visits	−1378 (−1991 to −763)	<0.001	−1493 (−2270 to −715)	<0.001	−127 (−1740 to 1504)	0.878
Primary sector	44 (−9 to 89)	0.055	105 (48 to 161)	<0.001	34 (−82 to 150)	0.568
Medications	−6 (−57 to 46)	0.829	17 (−46 to 81)	0.592	−31 (−157 to 94)	0.627
All costs[f]	−112 (−1893 to 1588)	0.864	−216 (−2250 to 1765)	0.835	2624 (−1319 to 6566)	0.192
All costs[g]	5732 (3838 to 7627)	<0.001	6482 (4262 to 8703)	<0.001	7309 (2100 to 11,620)	0.001

Costs are per patient using 2015 prize index (USD) with 95% confidence interval.

[a] Additional costs of RMIS compared to the non-robotic group.

[b] P value in relation to additional costs.

[c] Costs from the index hospitalization stay.

[d] Hospitalizations in bed days without the costs from the hospital stay related to the surgery.

[e] Hospitalizations in bed days including costs from the hospital stay related to the surgery.

[f] Costs reported from subsequent hospitalization, primary sector visits, outpatient visits and medication.

[g] Costs reported from all hospitalizations, primary sector visits, outpatient visits and medication.

[39–41]. A recent study reported that ERAS was feasible and safe in older patients undergoing gynecologic oncological surgery as in younger patients [42]. ERAS protocols have not been implemented systematically in this population. However, Fast-Track principle has been used to optimizing patient outcomes in Denmark outlined in the national guidelines from the Danish gynecological cancer group. This is likely to influence on the observed effect of time-trend adjustment.

To our knowledge, this is the first detailed investigation of job market affiliation related to treatment of endometrial cancer. No statistically significant effect was observed regarding women's return to the labor market and their use of sickness benefits. A plausible explanation for this is that we included a population with a median age of 67 years at the time of surgery which meant that the majority of the women received pension both before and after the index surgery. Only 40.2% of the women were working at least one week the year before surgery. Further, endometrial cancer is often diagnosed in an early stage and the operation therefore often leads to a rather short sick leave. Since only periods of leave longer than 14 days are observable in the Danish registries, our estimate of total days of leave may be underestimated.

An important strength of our study is the use of the gradual implementation of RMIS as the basis of a quasi-experimental design, thus minimizing patient selection bias. We also controlled for differences in baseline characteristics, time trends and differences in resource consumption across regions. Another strength of this study relates to the large population and the DiD design evaluating differences in resource use and cost patterns one-year pre- versus one-year post-surgery. A further advantage is the use of high-quality national databases, thereby allowing for systematic and objective measurement of resource use at an individual patient level.

An inherent limitation in the study design is the use of retrospective data and a comparatively long time period. Using registry data some clinical details are not routinely recorded e.g. surgeon experience and we cannot completely preclude some institutional selection bias. A further limitation is the use of DRG-tariffs as an approximation of the costs of hospital admissions. The Danish DRG-tariffs do not include the purchase or the maintenance cost of the robot. Another Danish study reported costs for instruments and disposals to be $2500 for each procedure and the purchase cost of the robotic platform was estimated to cost $2.4 million which amounts to $800 per operation with an amortization over 10 years [10].

5. Conclusion

The introduction of robotic surgery in Denmark did not generate any long-term cost savings in women with early stage endometrial cancer. The additional costs of robotic surgery are primarily driven by the index surgery. The introduction of robotic surgery decreased the number of bed days but adjusting for time trends outweighed any difference between the group exposed to robotic surgery and those who were not.

Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

Acknowledgments

Funding

Author contribution

MK, DGH, SM, PTJ: Contributed to the conception and design, processing of data, statistical analysis and interpretation of data; drafting the article, revising it critically for important intellectual content and final approval of the version to be published.

OM, SLJ, LS: Contributed to the conception and design, processing of data, interpretation of data; drafting the article, revising it critically for important intellectual content and final approval of the version to be published.

References

[1] G.I. Barbash, S.A. Glied, New technology and health care costs—the case of robot-assisted surgery, N. Engl. J. Med. 363 (2010) 701–704.

[2] M. Korsholm, J. Sorensen, O. Mogensen, C. Wu, K. Karlsen, P.T. Jensen, A systematic review about costing methodology in robotic surgery: evidence for low quality in most of the studies, Heal. Econ. Rev. 8 (2018) 21.

[3] Z. Tandogdu, L. Vale, C. Fraser, C. Ramsay, A systematic review of economic evaluations of the use of robotic assisted laparoscopy in surgery compared with open or laparoscopic surgery, Appl. Health Econ. Health Policy 13 (2015) 457–467.

[4] A.N. Fader, R.M. Weise, A.K. Sinno, E.J. Tanner 3rd, B.J. Borah, J.P. Moriarty, et al., Utilization of minimally invasive surgery in endometrial cancer care: a quality and cost disparity, Obstet. Gynecol. 127 (2016) 91–100.

[5] J.K. Chan, A.B. Gardner, K. Taylor, C.A. Thompson, K. Blansit, X. Yu, et al., Robotic versus laparoscopic versus open surgery in morbidly obese endometrial cancer patients - a comparative analysis of total charges and complication rates, Gynecol. Oncol. 139 (2015) 300–305.

[6] J.P. Shepherd, K.L. Kantartzis, K.H. Ahn, M.J. Bonidie, T. Lee, Cost analysis when open surgeons perform minimally invasive hysterectomy, JSLS 18 (2014).

[7] J.D. Wright, C.V. Ananth, A.I. Tergas, T.J. Herzog, W.M. Burke, S.N. Lewin, et al., An economic analysis of robotically assisted hysterectomy, Obstet. Gynecol. 123 (2014) 1038–1048.

[8] S.E. Kristensen, B.J. Mosgaard, M. Rosendahl, T. Dalsgaard, S.F. Bjorn, L.P. Froding, et al., Robot-assisted surgery in gynecological oncology: current status and controversies on patient benefits, cost and surgeon conditions - a systematic review, Acta Obstet. Gynecol. Scand. 96 (2017) 274–285.

[9] G. Bogani, F. Multinu, S.C. Dowdy, W.A. Cliby, T.O. Wilson, B.S. Gostout, et al., Incorporating robotic-assisted surgery for endometrial cancer staging: analysis of morbidity and costs, Gynecol. Oncol. 141 (2016) 218–224.

[10] S.F. Herling, C. Palle, A.M. Moller, T. Thomsen, J. Sorensen, Cost-analysis of robotic-assisted laparoscopic hysterectomy versus total abdominal hysterectomy for women with endometrial cancer and atypical complex hyperplasia, Acta Obstet. Gynecol. Scand. 95 (2016) 299–308.

[11] S. Eklind, A. Lindfors, P. Sjoli, P. Dahm-Kahler, A prospective, comparative study on robotic versus open-surgery hysterectomy and pelvic lymphadenectomy for endometrial carcinoma, Int. J. Gynecol. Cancer 25 (2015) 250–256.

[12] S.L.M.O. Jorgensen, C. Wu, K. Lund, M. Iachina, M. Korsholm, P.T. Jensen, Nationwide introduction of minimally invasive robotic surgery for early-stage endometrial cancer and its association with severe complications, JAMA Surg. (February 27, 2019) https://doi.org/10.1001/jamasurg.2018.5840.

[13] Danish guidelines for the management of endometrial cancer (translated) [internet]. Denmark: Danish gynecological cancer group 3. Revision of guidelines - 2016 (cited 2019 Jan 2), Available from: http://www.dgcg.dk/images/retningslinier/Corpuscancer/Revuderet/Kap.%205.%20Onkologisk%20behandling.pdf.

[14] P. Morice, A. Leary, C. Creutzberg, N. Abu-Rustum, E. Darai, Endometrial cancer, Lancet 387 (2016) 1094–1108.

[15] S.M. Sorensen, S.F. Bjorn, K.M. Jochumsen, P.T. Jensen, I.R. Thranov, H. Hare-Bruun, et al., Danish gynecological cancer database, Clin. Epidemiol. 8 (2016) 485–490.

[16] C.B. Pedersen, The Danish civil registration system, Scand. J. Public Health 39 (2011) 22–25.

[17] E. Lynge, J.L. Sandegaard, M. Rebolj, The Danish national patient register, Scand. J. Public Health 39 (2011) 30–33.

[18] L.C. Thygesen, C. Daasnes, I. Thaulow, H. Bronnum-Hansen, Introduction to Danish (nationwide) registers on health and social issues: structure, access, legislation, and archiving, Scand. J. Public Health 39 (2011) 12–16.

[19] V.M. Jensen, A.W. Rasmussen, Danish education registers, Scand. J. Public Health 39 (2011) 91–94.

[20] M. Baadsgaard, J. Quitzau, Danish registers on personal income and transfer payments, Scand. J. Public Health 39 (2011) 103–105.

[21] N.H. Hjollund, F.B. Larsen, J.H. Andersen, Register-based follow-up of social benefits and other transfer payments: accuracy and degree of completeness in a Danish interdepartmental administrative database compared with a population-based survey, Scand. J. Public Health 35 (2007) 497–502.

[22] A. Ankjaer-Jensen, P. Rosling, L. Bilde, Variable prospective financing in the Danish hospital sector and the development of a Danish case-mix system, Health Care Manag. Sci. 9 (2006) 259–268.

[23] A. Pottegard, S.A.J. Schmidt, H. Wallach-Kildemoes, H.T. Sorensen, J. Hallas, M. Schmidt, Data resource profile: the Danish national prescription registry, Int. J. Epidemiol. 46 (2017) 798–f.

[24] S. Denmark, Consumer Price Index, Statistics Denmark, 2018.

[25] A. A., Semiparametric difference-in-difference estimators, Rev. Econ. Stud. 72 (2005) 1–19.

[26] S. O'Neill, N. Kreif, R. Grieve, M. Sutton, J.S. Sekhon, Estimating causal effects: considering three alternatives to difference-in-differences estimation, Health Serv. Outcome Res. Methodol. 16 (2016) 1–21.

[27] K.R. Olsen, D. Gyrd-Hansen, A. Boegh, S.H. Hansen, GPs as citizens' agents: prescription behavior and altruism, Eur. J. Health Econ. 10 (2009) 399–407.

[28] L. El Hachem, V. Andikyan, S. Mathews, K. Friedman, J. Poeran, K. Shieh, et al., Robotic single-site and conventional laparoscopic surgery in gynecology: clinical outcomes and cost analysis of a matched case-control study, J. Minim. Invasive Gynecol. 23 (2016) 760–768.

[29] C. Teljeur, M. O'Neill, P.S. Moran, P. Harrington, M. Flattery, L. Murphy, et al., Economic evaluation of robot-assisted hysterectomy: a cost-minimisation analysis, BJOG 121 (2014) 1546–1553.

[30] H. Desille-Gbaguidi, T. Hebert, J. Paternotte-Villemagne, C. Gaborit, E. Rush, G. Body, Overall care cost comparison between robotic and laparoscopic surgery for endometrial and cervical cancer, Eur. J. Obstet. Gynecol. Reprod. Biol. 171 (2013) 348–352.

[31] X. Yu, D. Lum, T.K. Kiet, K.C. Fuh, J. Orr Jr., R.A. Brooks, et al., Utilization of and charges for robotic versus laparoscopic versus open surgery for endometrial cancer, J. Surg. Oncol. 107 (2013) 653–658.

[32] K.R. Laursen, V.B. Hyldgard, P.T. Jensen, R. Sogaard, Health care cost consequences of using robot technology for hysterectomy: a register-based study of consecutive patients during 2006–2013, J. Robot. Surg. 12 (2018) 283–294.

[33] S.L. Jorgensen, O. Mogensen, C.S. Wu, M. Korsholm, K. Lund, P.T. Jensen, Survival after a nationwide introduction of robotic surgery in women with early-stage endometrial cancer: a population-based prospective cohort study, Eur. J. Cancer 109 (2019) 1–11.

[34] A.M. Avondstondt, M. Wallenstein, C.R. D'Adamo, R.M. Ehsanipoor, Change in cost after 5 years of experience with robotic-assisted hysterectomy for the treatment of endometrial cancer, J. Robot. Surg. 12 (2018) 93–96.

[35] M. Korsholm, O. Mogensen, M.M. Jeppesen, V.K. Lysdal, K. Traen, P.T. Jensen, Systematic review of same-day discharge after minimally invasive hysterectomy, Int. J. Gynaecol. Obstet. 136 (2017) 128–137.

[36] N. Madden, M.K. Frey, L. Joo, J. Lee, K. Musselman, J.Y. Chern, et al., Safety of robotic-assisted gynecologic surgery and early hospital discharge in elderly patients, Am. J. Obstet. Gynecol. 220 (3) (2018) 253.e1–253.e7.

[37] S. Nahas, T. Feigenberg, S. Park, Feasibility and safety of same-day discharge after minimally invasive hysterectomy in gynecologic oncology: a systematic review of the literature, Gynecol. Oncol. 143 (2016) 439–442.

[38] K.R. Penner, N.D. Fleming, L Barlavi, A.E. Axtell, S.E. Lentz, Same-day discharge is feasible and safe in patients undergoing minimally invasive staging for gynecologic malignancies, Am. J. Obstet. Gynecol. 212 (2015) (186.e1–8).

[39] O. Ljungqvist, M. Scott, K.C. Fearon, Enhanced recovery after surgery: a review, JAMA Surg. 152 (2017) 292–298.

[40] S. Nazzani, F. Preisser, E. Mazzone, Z. Tian, F.A. Mistretta, S.F. Shariat, et al., In-hospital length of stay after major surgical oncological procedures, Eur. J. Surg. Oncol. 44 (2018) 969–974.

[41] ACOG Committee Opinion No. 750, Perioperative pathways: enhanced recovery after surgery, Obstetrics and Gynecology, vol. 132, , 2018 , (e120-e30).

[42] A. de Nonneville, C. Jauffret, C. Braticevic, M. Cecile, M. Faucher, C. Pouliquen, et al., Enhanced recovery after surgery program in older patients undergoing gynaecologic oncological surgery is feasible and safe, Gynecol. Oncol. 151 (2018) 471–476.