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Complete List of Authors:	Hyldgård, Vibe; Aarhus Universitet, Public Health; DEFACTUM, Health Economics Laursen, Karin; Aarhus Universitet, Demartment of Public Health Poulsen, Johan; Aalborg University Hospital; Department of Urology, King's College Hospital Søgaard, Rikke; Aarhus Universitet, Demartment of Public Health and Department of Clinical Medicine
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Robot-assisted surgery in a broader health care perspective: A difference-in-difference-based cost analysis of a national cohort undergoing prostatectomy

Vibe Bolvig Hyldgård[a,b] (VBH), vibe.bolvig@ph.au.dk
Karin Rosenkilde Laursen[b] (KRL), krl@ph.au.dk
Johan Poulsen[c,d] (JP), jop@rn.dk
Rikke Søgaard[b,e] (RS), rs@ph.au.dk

[a] Health Economics, DEFACTUM, Central Denmark Region, DK
[b] Department of Public Health, Aarhus University, DK
[c] Aalborg University Hospital, DK
[d] Department of Urology, King's College Hospital, London, UK
[e] Department of Clinical Medicine, Aarhus University, DK

Corresponding author: Vibe Bolvig Hyldgård
Address: Olof Palmes Allé 15, 8200 Aarhus N, DK
Email: vibe.bolvig@rm.dk / Fax: 78414029
Phone: +45 31191504

Abstract

Objective: To estimate costs attributable to robot-assisted laparoscopic prostatectomy (RALP) as compared to open (OP) and laparoscopic (LP) prostatectomies in a national health-service perspective.

Patients and methods: Register-based study of 4309 consecutive patients who underwent prostatectomy from 2006 to 2013 (2241 RALP, 1818 OP and 250 LP). Patients were followed from 12 months before to 12 months after prostatectomy with respect to service use in primary care (general practitioners, therapists, specialists etc.) and hospitals (in- and outpatient activity related to prostatectomy and comorbidity). Tariffs of the activity-based remuneration system for primary care and the Diagnosis-Related Grouping case-mix system for hospital-based care were used to value service use. Costs attributable to RALP were estimated using a difference-in-difference analytical approach and adjusted for patient- and hospital-level risk selection using multilevel regression.

Results: No significant effect of RALP on resource-use was observed except for a marginally lower use of primary care and fewer bed days as compared with OP (not LP). The overall cost consequence of RALP was estimated at an additional €2459 (95% CI, 1377 – 3540) as compared with OP and an additional €3860 (95% CI, 559 – 7160) as compared with LP, mainly due to higher cost intensity during the index admissions.

Conclusions: No support for the argument of the additional costs of using robots for prostatectomy being outweighed by cost savings during a longer-term follow up and in a broader health care perspective was found. The policy interpretation is that the use of robots for prostatectomy should be driven by clinical superiority and that formal effectiveness analysis is required to determine whether the current and eventual new purchasing of robot capacity is best used for prostatectomy.

Keywords: Cost analysis; Economics; Prostate cancer; Prostatectomy; Robot-assisted surgery; Robotics and Laparoscopy

Strengths and limitations of this study

The wide health care sector scope and the follow-up-period of 12 months are important strengths of this study and separate it from others.

The difference in difference design also represents a clear strength as it minimizes the effect of selection bias, especially in combination with the used multilevel regression analysis.

An additional strength is the use of high quality register-data, which was further validated in connection with this study.

The main weakness of this study lies in the premises of basing it on registry data, where severity and other clinically relevant details – such as BMI – are not routinely recorded.

A proportion of patients had missing values regarding cancer stage but these patients did not seem to be different from patients with complete data.

1. Introduction

The most common cancer among men older than 50 years is prostate cancer.[1] The incidence has increased notably since the diagnostic prostate-specific antigen test was introduced and, in accordance, the incidence of prostatectomy has increased rapidly.[1–3] Internationally, the transition from open prostatectomy (OP) to laparoscopic prostatectomy (LP) was much slower than the on-going transition from LP to robot-assisted laparoscopic prostatectomy (RALP), which is today the most frequently used technique in North America and in some parts of Europe.[4] As a consequence of the rapid dissemination of RALP, the literature comparing RALP to LP is scarce.

The minimally invasive methods LP and RALP have been found to hold some peri-operational advantages over OP such as less bleeding and fewer complications of e.g. urinary incontinence.[1,5–8] The literature is, however, not definite in terms of whether these benefits of the minimally invasive approaches can be achieved equally with or without robot support.[2,4,9] It has been argued that robot technology has a particular advantage in obese patients but, again, this has been questioned by a recent study demonstrating similar oncological and pathological outcomes when comparing RALP to LP and OP in obese patients.[10]

In comparison with not using robot support, the use of robot support leads to significantly higher costs due to the capital binding in the robot, maintenance costs and surgical supplies.[4,11,12] However, there could be cost savings in the longer term and in a broader health care sector perspective that outweighs the additional cost of the surgical procedure. These could flow from the better process outcomes such as less bleeding and fewer bed days. Despite the obvious relevance of a broader perspective, the literature is characterised by focussing solely on admission costs or just operating costs. The overall consequences of the dissemination of the robot technology to health care costs are therefore to a large extent uncertain. The objective of this study is to estimate the costs attributable to RALP as compared to OP and LP in a broad health care sector perspective and using a time horizon that allows for clinical manifestation of the postoperative advantages of robot support.

2. Patients and methods

2.1. Study-design

A national-scale cohort study following patients from one year before to one year after prostatectomy. Data was collected in connection with a Danish health technology assessment (HTA) of robot-assisted surgery, which this study is a further development of.[13]

2.2. Study population

Consecutive men who underwent prostatectomy in Denmark in the period January 1st 2006 to august 1st 2013 were identified from the National Patient Registry,[14] using the procedural codes KKEC00, KKEC00A, KKEC00B, KKEC00C, KKEC01, KKEC01A, KKEC01B, KKEC01C, KZXX00 and ZPW00002. To enhance comparability of the patients an inclusion criterion was that the robot-assisted technique should be available at the given hospital at the time of the prostatectomy.

2.3. Data sources

Individual-level register data were extracted from national administrative registries including The Danish National Patient Register,[14] The Danish Civil Registration System,[15] and The Danish National Health Service Register.[16] Costs were drawn from the registries for the diagnose related grouping system (DRG) and the Danish outpatient grouping system (DAGS).[17]

2.4. Costs

A health care sector perspective was applied in this study. Thus the study included service use within the primary sector (general practitioners, medical specialists, therapists and other privately practicing specialists) and within the hospital sector (in- and outpatient hospital-based activity). Primary care service was valuated via the activity-based fees and hospital-based care via the DRG/DAGS-tariffs that were used at the time of service provision (see supplementary Table S1 for DRG tariffs of prostatectomy over the years studied). These tariffs represent long-term mean costs of the given surgical procedures. The influence of the lack of person-individual variation in the DRG tariff as a cost estimate for the admission for prostatectomy was informed by conducting sensitivity analysis where the number of bed days was added as a proxy for cost intensity. Other sensitivity analysis included adjustment for experience with robot and patient volume. Costs are reported in Euros (2014 price year).

2.5. Identification of relevant aspects of risk selection

Characteristics that affect the choice of surgical method were identified in a literature review. Patient-level characteristics included age, cancer stage and comorbidity and hospital-level characteristics included organisational structure around the technology such as specialization of staff. The identified characteristics were defined for the study population based on information from national registries: age (years), tumour size and nodal involvement based on the TNM-classification,[18] comorbidity as defined by the Charlson Comorbidity Index,[19] geographical region of the treating centre, level of experience by time of surgery (to-date volume of prostatectomies using the particular technology), and organisational structure of the surgical department, referring to whether the robot is used within a single department, used across several departments or used in a robotic center. Finally, dummies for year of surgery were specified in order to be able to adjust for changes in DRG tariffs over the years.

2.6. Statistical analysis

Summary statistics including Pearson's chi-square tests for categorical variables and ANOVA for continuous variables were used to describe patient characteristics. All analysis followed a difference-in-difference (DID) design where the costs attributable to prostatectomy were estimated as the differences between comparators (OP, LP and RALP) of differences in resource use and costs between 12-month periods before and after prostatectomy. To further handle risk selection (as described in the previous section) regression models were used to adjust the DID-estimates for covariates identified to affect selection into surgical technique. Regressions were specified as multilevel regressions due to the patient-level being nested in the hospital-level (centres treating more than one patient) in order not to underestimate standard errors. The validity of regression models was visually inspected based on conventional regression diagnostic plots and found to be robust.

Results are reported as arithmetic means with 95% confidence intervals (CI) based on bootstrapping with 5000 replicates due to the skewed nature of the data. All tests were two-sided with a 5% significance level. The statistical analyses were performed in Stata SE 13.1.

2.7. Ethics

The study was conducted in accordance with The Person Data Act and hence was approved by relevant authorities (The Danish Data Protection Agency) (Journal number 2007-58-0010).

3. Results

Of the 4309 patients included in this study 52% underwent RALP, 42% underwent OP and 6% underwent LP. There were 22 conversions from either RALP or LP to OP, which were categorized according to the intended technique. The characteristics of the cohort are shown in Table 1. The treatment groups were clinically similar in age, though the RALP group was younger than the OP and LP group (median age 64 vs. 65 years) ($p<0.001$). The choice of surgical technique differed geographically and with regard to the organisation of the robot technology ($p<0.001$). Cancer severity was routinely registered for a proportion of patients only, which could be due to the fact that nodal involvement and metastases are rarely an issue for prostatectomy-candidates. However, in case of no nodal involvement patients were less likely to have received a minimally invasive technique ($p\leq0.001$).

Table 1 - Comparison of descriptive characteristics (n (% of treatment group))

Feature	RALP (n=2,241)	OP (n=1,818)	LP (n=250)	p value
Age (median (25% - 75%quartile))				<0.001
	64 (60 - 67)	65 (61 - 68)	65 (61 - 68)	
Region				<0.001
Capital Region of Denmark	1,097 (49)	1,272 (70)	120 (48)	
Region of Southern Denmark	121 (5)	123 (7)	12 (5)	
Central Denmark Region	554 (25)	264 (15)	77 (31)	
North Denmark Region	470 (21)	160 (9)	39 (16)	
Organisation type*				<0.001
Within-department	878 (39)	1,009 (55)	101 (41)	
Cross-departments	470 (21)	160 (9)	39 (16)	
Robotic centre	894 (40)	650 (36)	108 (44)	
Tumour size				0.521
T0-T2	847 (38)	649 (36)	81 (33)	
T3-T4	324 (14)	265 (15)	37 (15)	
Ta & Tis	0 (0)	1 (0)	0 (0)	
Missing data	1071 (48)	904 (50)	130 (52)	
Nodal involvement				<0.001
N0	304 (14)	489 (27)	46 (19)	
N1-N3	40 (2)	41 (2)	3 (1)	
Missing data	1898 (85)	1289 (71)	199 (80)	
Metastases				0.001
No	652 (29)	565 (31)	46 (19)	
Yes	0 (0)	1 (0)	0 (0)	
Missing data	1590 (71)	1253 (69)	202 (81)	
CCI				0.401
0	3 (0)	1 (0)	0 (0)	
1	0 (0)	1 (0)	0 (0)	
2	2,230 (99)	1,810 (100)	245 (99)	
3	4 (0)	2 (0)	2 (1)	
6	5 (0)	5 (0)	1 (0)	

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; Ta = Tumour without invasion; Tis = Carcinoma in situ; CCI = Charlson comorbidity index

*Organisation type refers to whether the robot is used within a single department, used across several departments or used in a robotic center.

Service use per patient, including length of stay, and the unadjusted mean costs of the patients' health care are depicted in Table 2 and 3, respectively. All treatment groups had statistically significant higher service use in the year following the surgery. No differences were found when comparing RALP to LP but OP was associated with 2.6 extra bed days and slightly higher primary care service use (0.5 more contacts) compared to RALP. This was, however, not reflected in the costs, as RALP was associated with the highest costs primarily caused by differences in inpatient care (Table 3).

Table 2 – Health care service use in relation to prostatectomy. Values are mean per patient with 95% CI

	Primary care	**Hospital-based care**		
		Outpatient	Inpatient	
	Number of contacts	Number of admissions	Number of admissions	Length of stay
OP				
Before	11.03	08.05	00.04	01.00
After	12.01	09.05	01.07	06.06
Difference	0.8 (0.5 – 1.0)	1.0 (0.6 – 1.4)	1.3 (1.2 – 1.4)	5.5 (5.2 – 5.9)
LP				
Before	10.03	07.08	00.03	01.00
After	11.01	08.05	01.04	04.06
Difference	0.8 (0.1 – 1.5)	0.7 (-0.3 – 1.6)	1.1 (1.0 – 1.2)	3.6 (2.7 – 4.4)
RALP				
Before	10.08	07.08	00.03	00.08
After	11.01	09.00	01.05	03.08
Difference	0.3 (0.1 – 0.5)	1.2 (0.8 – 1.5)	1.2 (1.1 – 1.2)	3.0 (2.7 – 3.3)
Robot attributable service use				
Compared to OP	-0.5 (-0.8 – 0.1)	0.2 (-0.4 – 0.7)	-0.1 (-0.2 – 0.0)	-2.6 (-3.0 – 2.1)
Compared to LP	-0.5 (-1.3 – 0.2)	0.5 (-0.5 – 1.5)	0.1 (-0.1 – 0.2)	-0.6 (-1.5 – 0.3)
RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval				

Table 3 – Health care costs in relation to prostatectomy. Values are mean costs (2014-€) per patient with 95% CI

Costs	Primary care	Hospital-based care		Total
		Outpatient	Inpatient	
OP				
Before	442	2720	1551	4714
After	429	3432	11429	15286
Difference	-13 (-29 – 3)	712 (493 – 931)	9878 (9532 – 10224)	10572 (10135 – 11010)
LP				
Before	415	2753	1271	4440
After	416	2584	10856	13856
Difference	0 (-46 – 46)	-169 (-624 – 285)	9585 (8663 – 10507)	9416 (8343 – 10489)
RALP				
Before	421	2724	1242	4392
After	392	2878	14700	17978
Difference	-29 (-43 – -15)	154 (-18 – 325)	13458 (13057 – 13859)	13586 (13132 – 14041)
Robot attributable costs				
Compared to OP	-16 (-37 – 5)	-558 (-832 – -284)	3580 (3054 – 4107)	3014 (2380 – 3648)
Compared to LP	-29 (-77 – 18)	323 (-178 – 823)	3873 (2865 – 4882)	4170 (2986 – 5354)

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval

Figure 1 illustrates the cost patterns over time. The process of getting referred by the general practitioner to the hospital for diagnosis and later treatment seems to be reflected as a rise of costs in the primary care sector, is followed by a rise in outpatient care and later in inpatient care at the time of the prostatectomy. Outpatient follow-up is clearly evident but is not set at a fixed time. No clear differences stood out except for higher inpatient costs of RALP at the time of the index prostatectomy. Both in the year prior to and after the prostatectomies included in this study the patterns are rather similar especially for OP and RALP while LP fluctuates more due to fewer patients having received this surgical technique.

Table 4 illustrates DID-estimates similar to those of table 3 except that multivariate modelling is used to adjust for eventual residual risk selection not handled by the DID-analytical strategy. Results support the unadjusted results as significant differences are revealed when RALP is held against OP and LP respectively. The adjusted costs attributable to RALP varied as RALP was associated with an extra € 3860 (95% CI, 559 – 7160) when held against LP and € 2459 (95% CI, 1377 – 3540) when compared to OP.

Costs were significantly higher when patients were operated in Region of Southern Denmark or North Denmark Region ($p<0.05$), and when they were operated in hospitals with a robotic centre ($p<0.05$).

An extended model was applied to assess the role of informative missings on cancer severity. Adding cancer severity to the model did not substantially affect the cost attributable to RALP. Tumours categorized as T3-T4 were associated with significant additional costs for all surgical techniques and having missing data with respect to nodal involvement was associated with decreased costs but there was no significant interaction between either tumour size or nodal involvement and surgical technique.

Table 4 – Adjusted estimates of the costs attributable to RALP: Main model compared to extended model, which includes adjustment for tumour size and nodal involvement. Values are mean costs (2014-€) with 95% CI.

Feature	Main model		Extended model	
	Coefficient	p value	Coefficient	p value
Treatment				
RALP (reference)				
OP	-2459 (-3540 – -1377)	0.003	-2756 (-3965 – -1548)	0.003
LP	-3860 (-7160 – - 559)	0.031	-3990 (-7073 – -906)	0.023
Age	14 (-43 – 71)	0.541	7 (-66 – 80)	0.815
Region				
Central Denmark Region (reference)				
Capital Region of Denmark	85 (-689 – 860)	0.775	881 (-833 – 2594)	0.227
Region of Southern Denmark	1907 (610 –3204)	0.015	1882 (-13 – 3777)	0.051
North Denmark Region	241 (156 – 327)	0.001	404 (-288 – 1096)	0.181
Organisation type				
Within-speciality (reference)				
Robotic centre	1028 (460 – 1595)	0.007	978 (-181 – 2136)	0.079
Year of surgery				
2006 (reference)				
2007	376 (-264 – 1016)	0.178	304 (-253 – 861)	0.204
2008	1386 (-41 – 2813)	0.054	1222 (-51 – 2496)	0.056
2009	-688 (-1627 – 250)	0.111	-919 (-1870 – 32)	0.055
2010	910 (-540 – 2361)	0.156	668 (-734 – 2070)	0.257
2011	1244 (–226 – 2714)	0.079	971 (-552 – 2494)	0.151
2012	1423 (205 – 2641)	0.032	1371 (433 – 2309)	0.015
2013	3036 (1338 – 4734)	0.008	3058 (1591 – 4525)	0.004
Tumour size				
T0-T2 (reference)				
T3-T4			1172 (683 – 1660)	0.003
Missing data			1599 (-1270 – 4469)	0.197
Nodal involvement				
N0 (reference)				
N1-N3			-2676 (-5796 – 444)	0.076
Missing data			-1219 (-2102 – -335)	0.019
Constant	10803 (7643 – 13964)	0.001	11136 (7111 – 15161)	0.002
n		4309		4309
R^2		0.041		0.046
Root mean standard error		10232		10213

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval

4. Discussion

Practically all prostatectomies performed in Danish hospitals over a period of 8 years were included in this analysis, which focussed on the broad health care sector consequences of using robot technology. The costs of RALP were found to be higher than the costs of both OP and LP but only to an extent that corresponds to the difference in DRG tariffs across these surgical techniques. Thus, no evidence was found of RALP impacting service use in primary care or readmissions to hospitals. Hence, the main contribution of this study is an important first piece of evidence that, when considering a broad health care sector perspective and a longer time horizon than the index admission, the use of RALP does not seem to generate cost consequences apart from the additional cost associated with the index surgery.

A recent study by Hughes et al. estimated the resource use in the postoperative phase after prostatectomy in a hospital perspective and found that RALP led to costs savings, when the cost of the index surgery was excluded from the equation.[20] This study is in many ways similar to the present in that it is based on a large sample and considers extra-index-surgery consequences of using robot technology. It has however a couple of weaknesses that is circumvented in the present study. First, it includes patients who were referred to centres not offering robot technology and who could have different profiles than those referred to centres offering robot technology. Second, the investigators did not analytically handle the fact that patients were selected into surgical technique. It thus remains unclear whether the difference between the present results of no cost saving and Hughes et al.s' finding of a cost saving is due to these weaknesses or whether they are simply do to differences between the British and the Danish context.

Previous studies have assessed the costs of robot technology in an analytical perspective restricted to hospital costs of the index surgery. Kim et al. found that RALP, despite shorter hospital stays, was associated with higher operation costs than OP by an average that more or less corresponds to the difference in Danish DRG tariffs between surgical techniques (mean \$11932 vs. \$9390; $p < 0.001$).[21] Similarly, Bolenz et al. found hospital costs to be higher for RALP compared to LP and OP, which was a bit lower but still within the level of the difference in the Danish DRG tariffs (median \$6752 for RALP, \$5687 LRP and \$4437 for OP; $p < 0.001$).[12] These studies were conducted in the United States that is not normally considered to be comparable as a setting due to different system structures and price levels. The strengths of this study relates to the design where a cohort of consecutive patients are observed and where appropriate analytical effort is made into handling selection for surgical techniques. The use of the DID-design serves to minimize the effect of selection bias, which can be an important issue in observational designs that may have been chosen as the only option or in priority of external validity. This design has the ability to cleanse out exogenous factors such as time and to isolate the costs related to the prostatectomy from the costs related to e.g. chronic comorbidities or other time invariant patient characteristics.[22] The design is particularly powerful when combined with extra means for handling selection and multilevel multivariate regression was here used to adjust for hospital-level characteristics as well as patient-level characteristics that could have caused confounding. It should also be mentioned that, we were able to validate the consecutiveness of data and the coding of surgical techniques by comparing register data to the independent clinical database UroLap, which supported that data were truly representing consecutive patients and which gave no reason to suspect misclassification.[23]

In the early stages of this work we suspected that the cost implications of robot technology would be affected by centre volume and experience with the technology. We thus included variables in the regression model for these organisational-level covariates but they appeared to be insignificant contributors and were thus excluded from the reported main model. Also, we sought to assess whether there was any effect modification from point at the learning curve by including interaction terms between the dummies of year of surgery and the cost consequences of robot technology but again, these turned out to be insignificant and were thus left out in the main model. The geographical variations found could reflect patient heterogeneity caused by both cultural and structural variations such as different waiting times and referral practice.

The main weakness of this study lies in the premises of basing it on registry data, where severity and other clinical details are not routinely recorded. One variable of relevance to choice of surgical technique would be body mass index (BMI).[24] Another weakness concerns the missing values on cancer stage, as it appeared that doctors are not routinely registering TNM status in relation to prostatectomy. Tumour size was registered for about 50% of patients while nodal involvement and metastasis were registered for around 25% of patients only. Whether this reflects irrelevance of registration in relation to the choice of surgical technique and expected outcome or other reasons is unclear but conducting parallel analysis with and without TNM status did not substantially affect results. And more importantly, patients with missing values on the TNM status did not seem to be different from patients with complete data. A number of sensitivity analyses were undertaken to address limitations of the study. First, the use of national DAGS and DRG tariffs as an expression for the patient-level cost of hospital service ignores patient- and hospital level variation. E.g. differences in coefficient of utilization are not reflected in the tariffs. A sensitivity analysis where the number of bed days was included in the model was therefore undertaken and confirmed that variation captured in bed days had no influence on the main result. This analysis is however no full compensation for the lack of patient-level variation and this limits the interpretation of the analysis to the broad-sector consequences of using robot technology as opposed to the technical efficiency or productivity that characterises the operation of the robot technology. Also it should be noted that time dummies were included in the base-case model in order to take out variation that was due to changes in the DRG tariffs over time. If centres in the future administer the robot technology (and other surgical techniques for that sake) in a more of less efficient way, e.g. by operating more patients per robot this will affect the cost of index surgery (and should lead to an adjustment of the DRG tariff) whereas the main focus of this analysis, the broader-sector cost consequences, should be unaffected if the quality level is kept.

Further research seems warranted as RALP is here found to be overall more costly than its alternatives while there appears to be limited evidence for a clinical benefit to the patients. At best, a randomised controlled trial comparing RALP to both LP and OP should be conducted and followed by a cost effectiveness evaluation. LP is a relatively rare choice of surgical approach in Denmark although it has been found to create health- and functional outcomes comparable to those of RALP.[3,9,25] However, there is evidence that RALP is a superior choice with regards to the risk of erectile dysfunction.[26] If this was also the case in the present cohort it was not reflected in the number of visits to neither hospitals nor the primary health care sector.

5. Conclusions

No support for the argument of the additional costs of using robots for prostatectomy being outweighed by cost savings during a longer-term follow up and in a broader health care perspective was found. The policy interpretation is that the use of robots for prostatectomy should be driven by clinical superiority and that formal effectiveness analysis is required to determine whether the current and eventual new purchasing of robot capacity is best used for prostatectomy.

6. Acknowledgements

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7. Conflicts of Interest statement

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9. Data sharing statement

Unfortunately no additional data are available

10. Contributors

Drafting the manuscript: VBH. Analysis and interpretation: VBH+RS. Statistical analysis: VBH+KRL. Concept and design: JP+RS. Acquisition of data: RS+KRL+LST. Critical revision of manuscript: JP+RS+KRL+VBH. Supervision: RS.

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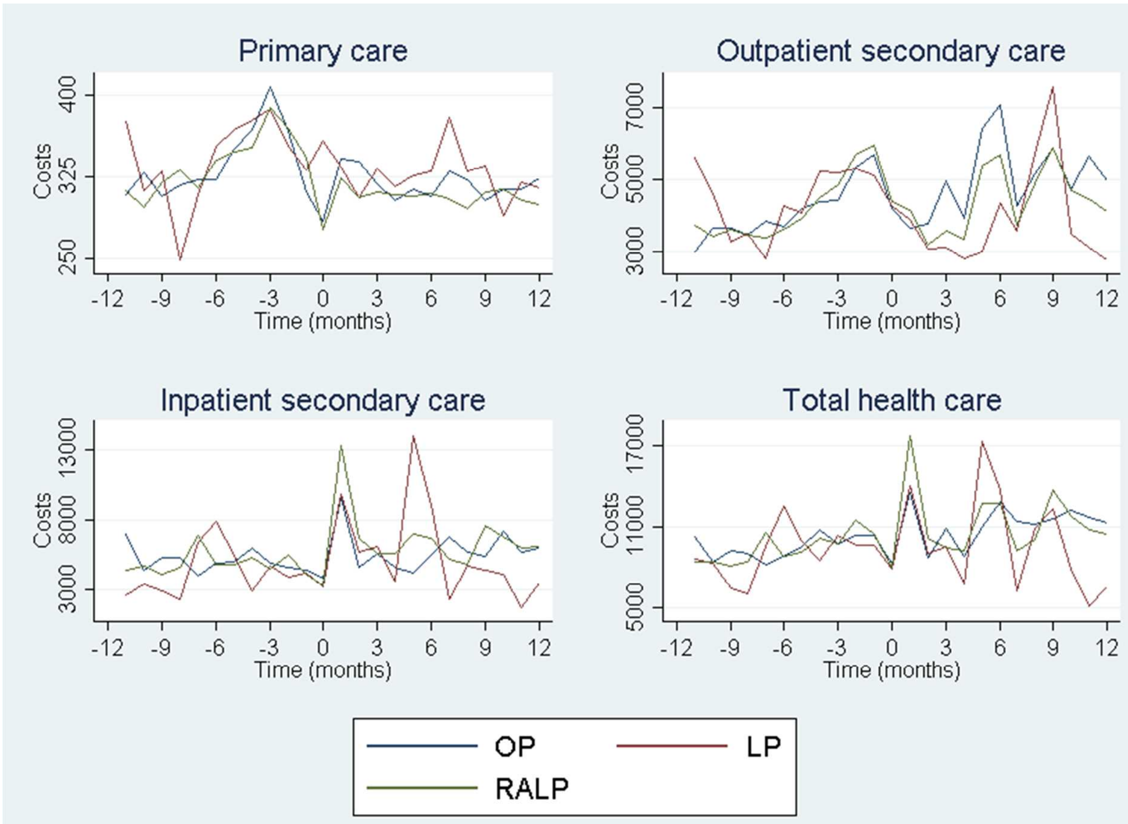

Figure 1 – Time series graphics for the unadjusted mean costs (€). Month zero marks the time of prostatectomy, price year 2014.
RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy

Supplementary material

Table S1 – DRG tariffs over the study period (2014-€)

Year of operation	DRG tariff		Difference
	RALP	OP & LP	
2006	13.666	10.746	2.920
2007	13.291	10.260	3.031
2008	13.218	10.101	3.118
2009	11.397	8.087	3.310
2010	13.082	7.751	5.331
2011	13.362	8.316	5.046
2012	13.547	8.732	4.815
2013	14.250	8.779	5.471

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Complete List of Authors:	Hyldgård, Vibe; Aarhus Universitet, Public Health; DEFACTUM, Health Economics Laursen, Karin; Aarhus Universitet, Demartment of Public Health Poulsen, Johan; Aalborg University Hospital; Department of Urology, King's College Hospital Søgaard, Rikke; Aarhus Universitet, Demartment of Public Health and Department of Clinical Medicine

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Robot-assisted surgery in a broader health care perspective: A difference-in-difference-based cost analysis of a national prostatectomy cohort

Vibe Bolvig Hyldgård[a,b] (VBH), vibe.bolvig@ph.au.dk
Karin Rosenkilde Laursen[b] (KRL), krl@ph.au.dk
Johan Poulsen[c,d] (JP), jop@rn.dk
Rikke Søgaard[b,e] (RS), rs@ph.au.dk

[a] Health Economics, DEFACTUM, Central Denmark Region, DK
[b] Department of Public Health, Aarhus University, DK
[c] Aalborg University Hospital, DK
[d] Department of Urology, King's College Hospital, London, UK
[e] Department of Clinical Medicine, Aarhus University, DK

Corresponding author: Vibe Bolvig Hyldgård
Address: Olof Palmes Allé 15, 8200 Aarhus N, DK
Email: vibe.bolvig@rm.dk / Fax: 78414029
Phone: +45 31191504

Abstract

Objective: To estimate costs attributable to robot-assisted laparoscopic prostatectomy (RALP) as compared to open (OP) and laparoscopic (LP) prostatectomies in a national health-service perspective.

Patients and methods: Register-based cohort study of 4309 consecutive patients who underwent prostatectomy from 2006 to 2013 (2241 RALP, 1818 OP and 250 LP). Patients were followed from 12 months before to 12 months after prostatectomy with respect to service use in primary care (general practitioners, therapists, specialists etc.) and hospitals (in- and outpatient activity related to prostatectomy and comorbidity). Tariffs of the activity-based remuneration system for primary care and the Diagnosis-Related Grouping case-mix system for hospital-based care were used to value service use. Costs attributable to RALP were estimated using a difference-in-difference analytical approach and adjusted for patient- and hospital-level risk selection using multilevel regression.

Results: No significant effect of RALP on resource-use was observed except for a marginally lower use of primary care and fewer bed days as compared with OP (not LP). The overall cost consequence of RALP was estimated at an additional €2459 (95% CI 1377 – 3540, p = 0.003) as compared with OP and an additional €3860 (95% CI 559 – 7160, p = 0.031) as compared with LP, mainly due to higher cost intensity during the index admissions.

Conclusions: In this study from the Danish context, the use of RALP generates a factor 1.3 additional cost when compared with OP and a factor 1.6 additional cost when compared with LP, on average, based on 12 months follow-up. The policy interpretation is that the use of robots for prostatectomy should be driven by clinical superiority and that formal effectiveness analysis is required to determine whether the current and eventual new purchasing of robot capacity is best used for prostatectomy.

Keywords: Cost analysis; Economics; Prostate cancer; Prostatectomy; Robot-assisted surgery; Robotics and Laparoscopy

Strengths and limitations of this study

- A broad health care sector perspective with 12 months follow-up of a national cohort.
- A strong analytical approach including a quasi-experimental difference-in-difference design in combination with the use of regression-based adjustment for selection..
- Adjustment for body mass index could not be undertaken due to this information not being available in national register data.
- A proportion of patients had missing values regarding cancer stage but these patients did not seem to be different from patients with complete data.

1. Introduction

The most common cancer among men older than 50 years is prostate cancer.[1] The incidence has increased notably since the diagnostic prostate-specific antigen test was introduced and, in accordance, the incidence of prostatectomy has increased rapidly.[1–3] Internationally, the transition from open prostatectomy (OP) to laparoscopic prostatectomy (LP) was much slower than the on-going transition from LP to robot-assisted laparoscopic prostatectomy (RALP), which is today the most frequently used technique in North America and in some parts of Europe.[4] As a consequence of the rapid dissemination of RALP, the literature comparing RALP to LP is scarce.

The minimally invasive methods LP and RALP have been found to hold some peri-operational advantages over OP such as less bleeding and fewer complications of e.g. urinary incontinence.[1,5–8] The literature is, however, not definite in terms of whether these benefits of the minimally invasive approaches can be achieved equally with or without robot support.[2,4,9] It has been argued that robot technology has a particular advantage in obese patients but, again, this has been questioned by a recent study demonstrating similar oncological and pathological outcomes when comparing RALP to LP and OP in obese patients.[10]

In comparison with not using robot support, the use of robot support leads to significantly higher costs due to the capital binding in the robot, maintenance costs and surgical supplies.[4,11,12] However, there could be cost savings in the longer term and in a broader health care sector perspective that outweighs the additional cost of the surgical procedure. These could flow from the better process outcomes such as less bleeding and fewer bed days. Despite the obvious relevance of a broader perspective, the literature is characterised by focussing solely on admission costs or just operating costs. The overall consequences of the dissemination of the robot technology to health care costs are therefore to a large extent uncertain. The objective of this study is to estimate the costs attributable to RALP as compared to OP and LP in a broad health care sector perspective and using a time horizon that allows for clinical manifestation of the postoperative advantages of robot support.

2. Patients and methods

2.1. Design

A national-scale cohort was followed from one year before to one year after prostatectomy. A quasi-experimental difference-in-difference design [13] was combined with regression to adjust for pre-treatment covariates (risk selection into surgical technique) [14]. Data was collected in connection with a Danish health technology assessment (HTA) of robot-assisted surgery, which this study is a further development of.[15]

2.2. Study population

Consecutive men who underwent prostatectomy in Denmark in the period January 1st 2006 to august 1st 2013 were identified from the National Patient Registry,[16] using the procedural codes KKEC00, KKEC00A, KKEC00B, KKEC00C, KKEC01, KKEC01A, KKEC01B, KKEC01C, KZXX00 and ZPW00002. To enhance comparability of the patients an inclusion criterion was that the robot-assisted technique should be available at the given hospital at the time of the prostatectomy.

2.3. Data sources

Individual-level register data were extracted from national administrative registries including The Danish National Patient Register [16], The Danish Civil Registration System [17], and The Danish National Health Service Register.[18] Costs were drawn from the registries for the diagnosis related grouping system (DRG) and the Danish outpatient grouping system (DAGS).[19]

2.4. Costs

A health care sector perspective was applied in this study. Thus the study included service use within the primary sector (general practitioners, medical specialists, therapists and other privately practicing specialists) and within the hospital sector (in- and outpatient hospital-based activity). Primary care service was valuated via the activity-based fees and hospital-based care via the DRG/DAGS-tariffs that were used at the time of service provision. The DRG tariffs for prostatectomy cover the activity from the day of admission to the day of discharge (preparation, surgery, remobilisation and discharge) whereas follow-up visits and other events after discharge, e.g. caused by complications, are therefore separately reimbursed. The specific tariffs for prostatectomy are shown in supplementary material Table S1. The higher tariff of the robot-assisted surgery (on average € 4525) thus refers to the rather expensive instrument kit required for each surgery, robot maintenance costs and longer operating time. The theoretical interpretation of the DRG tariff is an average long-term cost. The influence of the lack of person-individual variation in the DRG tariff as a cost estimate for the admission for prostatectomy was informed by conducting sensitivity analysis where the number of bed days was added as a proxy for cost intensity. Other sensitivity analyses included adjustment for experience with robot and patient volume, as well as restrictions to the two most recent years and exclusion of the tariffs from the costs. Costs are reported in Euros (2014 price year).

2.5. Identification of relevant aspects of risk selection

Characteristics that affect the choice of surgical method were identified in a literature review. Patient-level characteristics included age, cancer stage and comorbidity and hospital-level characteristics included organisational structure around the technology such as specialization of staff. The identified characteristics were defined for the study population based on information from national registries: age (years), tumour size and nodal involvement based on the TNM-classification [20], comorbidity as defined by the Charlson Comorbidity Index [21], geographical region of the treating centre, level of experience by time of surgery (to-date volume of prostatectomies using the particular technology), and organisational structure of the surgical department, referring to whether the robot is used within a single department, used across several departments or used in a robotic center. Finally, dummies for year of surgery were specified in order to be able to adjust for changes in DRG tariffs over the years.

2.6. Statistical analysis

Summary statistics including Pearson's chi-square tests for categorical variables and ANOVA for continuous variables were used to describe patient characteristics. All analysis followed a difference-in-difference (DID) design where the costs attributable to prostatectomy were estimated as the differences between comparators (OP, LP and RALP) of differences in resource use and costs between 12-month periods before and after prostatectomy.[13] To further handle risk selection (as described in the previous section) regression models were used to adjust the DID-estimates for covariates identified to affect selection into surgical technique.[14] Regressions were specified as multilevel regressions due to the patient-level being nested in the hospital-level (centres treating more than one patient) in order not to underestimate standard errors. The validity of regression models was visually inspected based on conventional regression diagnostic plots and found to be robust.

Results are reported as arithmetic means with 95% confidence intervals (CI) based on bootstrapping with 5000 replicates due to the skewed nature of the data. All tests were two-sided with a 5% significance level. The statistical analyses were performed in Stata SE 13.1.

2.7. Ethics

The study was conducted in accordance with The Person Data Act and hence was approved by relevant authorities (The Danish Data Protection Agency) (Journal number 2007-58-0010). *Consent is not required for register-based studies according the Danish Ethical Committee system.*

3. Results

Of the 4309 patients included in this study 52% underwent RALP, 42% underwent OP and 6% underwent LP (cf. supplementary Table S2 for procedure volume over time). There were 22 conversions from either RALP or LP to OP, which were categorized according to the intended technique. The characteristics of the cohort are shown in Table 1. The treatment groups were clinically similar in age, though the RALP group was younger than the OP and LP group (median age 64 vs. 65 years) ($p<0.001$). The choice of surgical technique differed geographically and with regard to the organisation of the robot technology ($p<0.001$). Cancer severity was routinely registered for a proportion of patients only, which could be due to the fact that nodal involvement and metastases are rarely an issue for prostatectomy-candidates.

However, in case of no nodal involvement patients were less likely to have received a minimally invasive technique ($p \leq 0.001$).

Table 1 - Comparison of descriptive characteristics (n (% of treatment group))

Feature	RALP (n=2,241)	OP (n=1,818)	LP (n=250)	p value
Age (median (25% - 75%quartile))				<0.001
	64 (60 - 67)	65 (61 - 68)	65 (61 - 68)	
Region				<0.001
Capital Region of Denmark	1,097 (49)	1,272 (70)	120 (48)	
Region of Southern Denmark	121 (5)	123 (7)	12 (5)	
Central Denmark Region	554 (25)	264 (15)	77 (31)	
North Denmark Region	470 (21)	160 (9)	39 (16)	
Organisation type*				<0.001
Within-department	878 (39)	1,009 (55)	101 (41)	
Cross-departments	470 (21)	160 (9)	39 (16)	
Robotic centre	894 (40)	650 (36)	108 (44)	
Tumour size				0.521
T0-T2	847 (38)	649 (36)	81 (33)	
T3-T4	324 (14)	265 (15)	37 (15)	
Ta & Tis	0 (0)	1 (0)	0 (0)	
Missing data	1071 (48)	904 (50)	130 (52)	
Nodal involvement				<0.001
N0	304 (14)	489 (27)	46 (19)	
N1-N3	40 (2)	41 (2)	3 (1)	
Missing data	1898 (85)	1289 (71)	199 (80)	
Metastases				0.001
No	652 (29)	565 (31)	46 (19)	
Yes	0 (0)	1 (0)	0 (0)	
Missing data	1590 (71)	1253 (69)	202 (81)	
CCI				0.401
0	3 (0)	1 (0)	0 (0)	
1	0 (0)	1 (0)	0 (0)	
2	2,230 (99)	1,810 (100)	245 (99)	
3	4 (0)	2 (0)	2 (1)	
6	5 (0)	5 (0)	1 (0)	

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; Ta = Tumour without invasion; Tis = Carcinoma in situ; CCI = Charlson comorbidity index
*Organisation type refers to whether the robot is used within a single department, used across several departments or used in a robotic center.

Service use per patient, including length of stay, and the unadjusted mean costs of the patients' health care are depicted in Table 2 and 3, respectively. All treatment groups had statistically significant higher service use in the year following the surgery. No differences were found when comparing RALP to LP but OP was associated with 2.6 extra bed days and slightly higher primary care service use (0.5 more contacts) compared to RALP. This was, however, not reflected in the costs, as RALP was associated with the highest costs primarily caused by differences in inpatient care (Table 3).

Table 2 – Health care service use in relation to prostatectomy. Values are mean per patient with 95% CI

		Hospital-based care		
	Primary care	Outpatient	Inpatient	
	Number of contacts	Number of admissions	Number of admissions	Length of stay
OP				
Before	11.0	08.1	00.0	01.0
After	12.0	09.1	01.1	06.1
Difference	0.8 (0.5 – 1.0)	1.0 (0.6 – 1.4)	1.3 (1.2 – 1.4)	5.5 (5.2 – 5.9)
LP				
Before	10.0	07.1	00.0	01.0
After	11.0	08.1	01.0	04.1
Difference	0.8 (0.1 – 1.5)	0.7 (-0.3 – 1.6)	1.1 (1.0 – 1.2)	3.6 (2.7 – 4.4)
RALP				
Before	10.1	07.1	00.0	00.1
After	11.0	09.0	01.1	03.1
Difference	0.3 (0.1 – 0.5)	1.2 (0.8 – 1.5)	1.2 (1.1 – 1.2)	3.0 (2.7 – 3.3)
Robot attributable service use				
Compared to OP	-0.5 (-0.8 – 0.1)	0.2 (-0.4 – 0.7)	-0.1 (-0.2 – 0.0)	-2.6 (-3.0 – 2.1)
Compared to LP	-0.5 (-1.3 – 0.2)	0.5 (-0.5 – 1.5)	0.1 (-0.1 – 0.2)	-0.6 (-1.5 – 0.3)

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval. Before refers to the 12 months prior to the index surgery and after refers to the 12 months after the index surgery including the day of surgery.

Table 3 – Health care costs in relation to prostatectomy. Values are mean costs (2014-€) per patient with 95% CI

Costs	Primary care	Hospital-based care		Total
		Outpatient	Inpatient	
OP				
Before	442	2720	1551	4714
After	429	3432	11429	15286
Difference	-13 (-29 – 3)	712 (493 – 931)	9878 (9532 – 10224)	10572 (10135 – 11010)
LP				
Before	415	2753	1271	4440
After	416	2584	10856	13856
Difference	0 (-46 – 46)	-169 (-624 – 285)	9585 (8663 – 10507)	9416 (8343 – 10489)
RALP				
Before	421	2724	1242	4392
After	392	2878	14700	17978
Difference	-29 (-43 – -15)	154 (-18 – 325)	13458 (13057 – 13859)	13586 (13132 – 14041)
Robot attributable costs				
Compared to OP	-16 (-37 – 5)	-558 (-832 – -284)	3580 (3054 – 4107)	3014 (2380 – 3648)
Compared to LP	-29 (-77 – 18)	323 (-178 – 823)	3873 (2865 – 4882)	4170 (2986 – 5354)

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval. Before refers to the 12 months prior to the index surgery and after refers to the 12 months after the index surgery including the day of surgery.

Figure 1 illustrates the cost patterns over time. The process of getting referred by the general practitioner to the hospital for diagnosis and later treatment seems to be reflected as a rise of costs in the primary care sector, is followed by a rise in outpatient care and later in inpatient care at the time of the prostatectomy. Outpatient follow-up is clearly evident but is not set at a fixed time. No clear differences stood out except for higher inpatient costs of RALP at the time of the index prostatectomy. Both in the year prior to and after the prostatectomies included in this study the patterns are rather similar especially for OP and RALP while LP fluctuates more due to fewer patients having received this surgical technique.

Table 4 illustrates DID-estimates similar to those of table 3 except that multivariate modelling is used to adjust for eventual residual risk selection not handled by the DID-analytical strategy. Results support the unadjusted results as significant differences are revealed when RALP is held against OP and LP respectively. The adjusted costs attributable to RALP varied as RALP was associated with an extra € 3860 (95% CI 559 – 7160) when held against LP and € 2459 (95% CI 1377 – 3540) when compared to OP.

Costs were significantly higher when patients were operated in Region of Southern Denmark or North Denmark Region ($p<0.05$), and when they were operated in hospitals with a robotic centre ($p<0.05$).

An extended model was applied to assess the role of informative missings on cancer severity. Adding cancer severity to the model did not substantially affect the cost attributable to RALP. Tumours categorized as T3-T4 were associated with significant additional costs for all surgical techniques and having missing data with respect to nodal involvement was associated with decreased costs but there was no significant interaction between either tumour size or nodal involvement and surgical technique.

Restricting the main model to activity during the two most recent years (2012 and 2013) does not significantly alter the findings (the average attributable costs increases from € 2459 to € 3889 compared with OP and reduces from € 3860 to € 3359 compared with LP).

In order to directly analyse the contribution of the index admission versus the after-period for the costs attributable to RALP, sensitivity analyses restricting the costs to the after-period alone show comparable after-periods for LP and RALP whereas the after-period for OP is characterised by significantly more activity (€ 2332 (95% CI 1287 – 2777)).

Table 4 – Adjusted estimates of the costs attributable to RALP: Main model compared to extended model, which includes adjustment for tumour size and nodal involvement. Values are mean costs (2014-€) with 95% CI.

Feature	Main model		Extended model	
	Coefficient	p value	Coefficient	p value
Treatment				
RALP (reference)				
OP	-2459 (-3540 – -1377)	0.003	-2756 (-3965 – -1548)	0.003
LP	-3860 (-7160 – - 559)	0.031	-3990 (-7073 – -906)	0.023
Age	14 (-43 – 71)	0.541	7 (-66 – 80)	0.815
Region				
Central Denmark Region (reference)				
Capital Region of Denmark	85 (-689 – 860)	0.775	881 (-833 – 2594)	0.227
Region of Southern Denmark	1907 (610 –3204)	0.015	1882 (-13 – 3777)	0.051
North Denmark Region	241 (156 – 327)	0.001	404 (-288 – 1096)	0.181
Organisation type				
Within-speciality (reference)				
Robotic centre	1028 (460 – 1595)	0.007	978 (-181 – 2136)	0.079
Year of surgery				
2006 (reference)				
2007	376 (-264 – 1016)	0.178	304 (-253 – 861)	0.204
2008	1386 (-41 – 2813)	0.054	1222 (-51 – 2496)	0.056
2009	-688 (-1627 – 250)	0.111	-919 (-1870 – 32)	0.055
2010	910 (-540 – 2361)	0.156	668 (-734 – 2070)	0.257
2011	1244 (–226 – 2714)	0.079	971 (-552 – 2494)	0.151
2012	1423 (205 – 2641)	0.032	1371 (433 – 2309)	0.015
2013	3036 (1338 – 4734)	0.008	3058 (1591 – 4525)	0.004
Tumour size				
T0-T2 (reference)				
T3-T4			1172 (683 – 1660)	0.003
Missing data			1599 (-1270 – 4469)	0.197
Nodal involvement				
N0 (reference)				
N1-N3			-2676 (-5796 – 444)	0.076
Missing data			-1219 (-2102 – -335)	0.019
Constant	10803 (7643 – 13964)	0.001	11136 (7111 – 15161)	0.002
n		4309		4309
R^2		0.041		0.046
Root mean standard error		10232		10213

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval

4. Discussion

Practically all prostatectomies performed in Danish hospitals over a period of eight years were included in this analysis, which focussed on the broad health care sector consequences of using robot technology. The cost of RALP was found to be higher than the costs of both OP and LP due to the difference in DRG tariffs across these surgical techniques. No evidence was found of RALP impacting service use when compared to LP, however, some reduction in bed days in the after-period was found when compared to OP. Hence, the main contribution of this study is an important piece of evidence that, when considering a broad health care sector perspective and a longer time horizon than the index admission, the use of RALP does not seem to generate cost consequences that can outweigh the additional cost associated with the index surgery.

A recent study by Hughes et al. estimated the resource use in the postoperative phase after prostatectomy in a hospital perspective and found that RALP led to costs savings, when the cost of the index surgery was excluded from the equation.[22] This study is in many ways similar to the present in that it is based on a large sample and considers extra-index-surgery consequences of using robot technology. It has however a couple of weaknesses that is circumvented in the present study. First, it includes patients who were referred to centres not offering robot technology and who could have different profiles than those referred to centres offering robot technology. Second, the investigators did not analytically handle the fact that patients were selected into surgical technique. It thus remains unclear whether the difference between the present results of no cost saving and Hughes et al.s' finding of a cost saving is due to these weaknesses or whether they are simply do to differences between the British and the Danish context.

Previous studies have assessed the costs of robot technology in an analytical perspective restricted to hospital costs of the index surgery. Kim et al. found that RALP, despite shorter hospital stays, was associated with higher operation costs than OP by an average that more or less corresponds to the difference in Danish DRG tariffs between surgical techniques (mean \$11932 vs. \$9390; $p < 0.001$).[23] Similarly, Bolenz et al. found hospital costs to be higher for RALP compared to LP and OP, which was a bit lower but still within the level of the difference in the Danish DRG tariffs (median \$6752 for RALP, \$5687 LP and \$4437 for OP; $p < 0.001$).[12] These studies were conducted in the United States that is not normally considered to be comparable as a setting due to different system structures and price levels. The strengths of this study relates to the design where a cohort of consecutive patients are observed and where appropriate analytical effort is made into handling selection for surgical techniques. The hybrid DID-design in combination with regression-based adjustment for pre-treatment covariates serves to minimize the effect of selection bias, which can be an important issue in observational designs that may have been chosen as the only option or in priority of external validity. This design has the ability to cleanse out exogenous factors such as time and to isolate the costs related to the prostatectomy from the costs related to e.g. chronic comorbidities or other time invariant patient characteristics.[24] The design is particularly powerful when combined with extra means for handling selection and multilevel multivariate regression was here used to adjust for hospital-level characteristics as well as patient-level characteristics that could have caused confounding. It should also be mentioned that, we were able to validate the consecutiveness of data and the coding of surgical techniques by comparing register data to the independent clinical database UroLap, which supported that data were truly representing consecutive patients and which gave no reason to suspect misclassification.[25]

In the early stages of this work we suspected that the cost implications of robot technology would be affected by centre volume and experience with the technology. We thus included variables in the regression model for these organisational-level covariates but they appeared to be insignificant contributors and were thus excluded from the reported main model. Also, we sought to assess whether there was any effect modification from point at the learning curve by including interaction terms between the dummies of year of surgery and the cost consequences of robot technology but again, these turned out to be insignificant and were thus left out in the main model. The geographical variations found could reflect patient heterogeneity caused by both cultural and structural variations such as different waiting times and referral practice.

The main weakness of this study lies in the premises of basing it on registry data, where severity and other clinical details are not routinely recorded. One variable of relevance to choice of surgical technique would be body mass index (BMI).[26] Another weakness concerns the missing values on cancer stage, as it appeared that doctors are not routinely registering TNM status in relation to prostatectomy. Tumour size was registered for about 50% of patients while nodal involvement and metastasis were registered for around 25% of patients only. Whether this reflects irrelevance of registration in relation to the choice of surgical technique and expected outcome or other reasons is unclear but conducting parallel analysis with and without TNM status did not substantially affect results. And more importantly, patients with missing values on the TNM status did not seem to be different from patients with complete data. A number of sensitivity analyses were undertaken to address limitations of the study. First, the use of national tariffs as an expression for the patient-level cost of hospital service ignores patient- and hospital level variation. E.g. differences in coefficient of utilization are not reflected in the tariffs. A sensitivity analysis where the number of bed days was included in the model was therefore undertaken and confirmed that variation captured in bed days had no influence on the main result. This analysis is however no full compensation for the lack of patient-level variation and this limits the interpretation of the analysis to the broad-sector consequences of using robot technology as opposed to the technical efficiency or productivity that characterises the operation of the robot technology. Also it should be noted that time dummies were included in the base-case model in order to take out variation that was due to changes in the DRG tariffs over time. If centres in the future administer the robot technology (and other surgical techniques for that sake) in a more of less efficient way, e.g. by operating more patients per robot this will affect the cost of index surgery (and should lead to an adjustment of the DRG tariff) whereas the main focus of this analysis, the broader-sector cost consequences, should be unaffected if the quality level is kept.

Further research seems warranted as RALP is here found to be overall more costly than its alternatives while there appears to be limited evidence for a clinical benefit to the patients. At best, a randomised controlled trial comparing RALP to both LP and OP should be conducted and followed by a cost effectiveness evaluation. LP is a relatively rare choice of surgical approach in Denmark although it has been found to create health- and functional outcomes comparable to those of RALP.[3,9,27] However, there is evidence that RALP is a superior choice with regards to the risk of erectile dysfunction.[28] If this was also the case in the present cohort it was not reflected in the number of visits to neither hospitals nor the primary health care sector.

5. Conclusions

In this study from the Danish context, the use of RALP generates a factor 1.3 additional cost when compared with OP and a factor 1.6 additional cost when compared with LP, on average, based on 12 months follow-up. The policy interpretation is that the use of robots for prostatectomy should be driven by clinical superiority and that formal effectiveness analysis is required to determine whether the current and eventual new purchasing of robot capacity is best used for prostatectomy.

6. Acknowledgements

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7. Conflicts of Interest statement

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Karin Rosenkilde Laursen: None

Johan Poulsen: None

Rikke Søgaard: None

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9. Data sharing statement

Unfortunately no additional data are available

10. Contributors

Drafting the manuscript: VBH. Analysis and interpretation: VBH+RS. Statistical analysis: VBH+KRL. Concept and design: JP+RS. Acquisition of data: RS+KRL+LST. Critical revision of manuscript: JP+RS+KRL+VBH. Supervision: RS.

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Figure legends:

Figure 1 – Time series graphics for the unadjusted mean costs (€). Month zero marks the time of prostatectomy, price year 2014.
RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy

Supplementary material

Table S1 – DRG tariffs for prostatectomy over the study period (2014-€)

Year of operation	DRG tariff		Difference
	RALP	OP and LP	
2006	13666	10746	2920
2007	13291	10260	3031
2008	13218	10101	3118
2009	11397	8087	3310
2010	13082	7751	5331
2011	13362	8316	5046
2012	13547	8732	4815
2013	14250	8779	5471
Volume-weighted tariff	13275	8750	4525

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval.
The volume-weighted tariff is calculated as an average tariff for the prostatectomy cohort. The tariffs show large variation over the years, which is due to regular adjustment in order not to introduce profit and thus incentivize the use of one technique over another.

Table S2 – Procedure volume over the study period

Year of operation	RALP	OP	LP	Total
2006	3	65	25	93
2007	42	68	8	118
2008	78	314	47	439
2009	289	447	33	769
2010	340	317	31	688
2011	462	229	29	720
2012	613	294	59	966
2013	415	85	16	516
Total	2242	1819	248	4309

RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy; CI=confidence interval

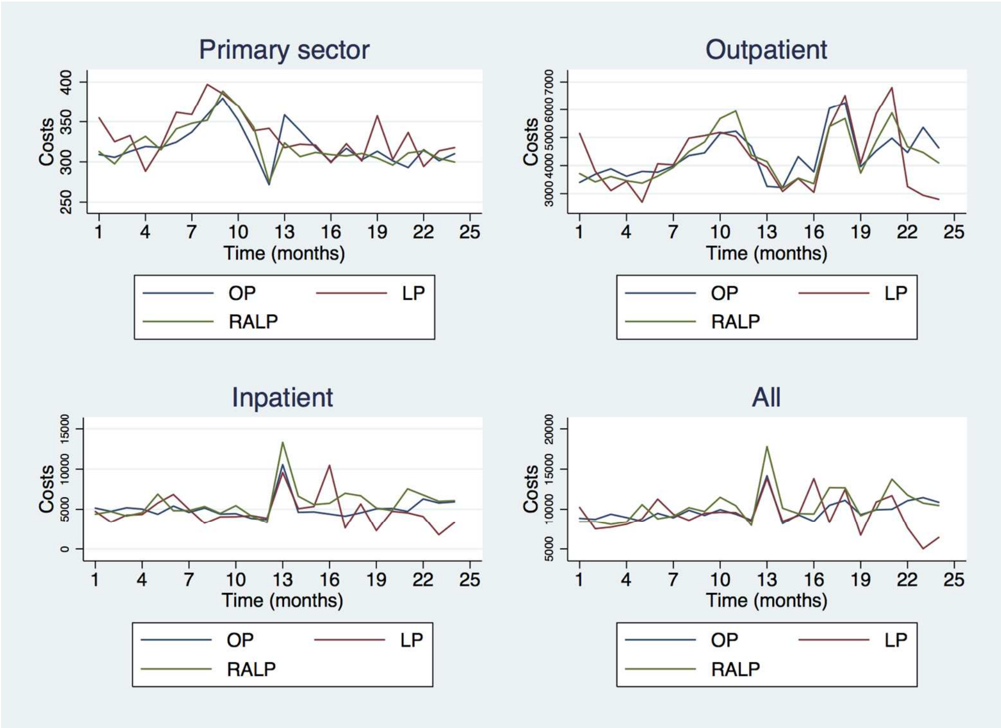

Figure 1 – Time series graphics for the unadjusted mean costs (€). Month zero marks the time of prostatectomy, price year 2014.
RALP = Robot-assisted laparoscopic prostatectomy; OP = Open prostatectomy; LP = Laparoscopic prostatectomy

139x101mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1+2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4 - 5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5 - 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5 – 6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	Na
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6 - 7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6 - 7
Bias	9	Describe any efforts to address potential sources of bias	5 + 7 - 8
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7 – 8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7 – 8
		(*b*) Describe any methods used to examine subgroups and interactions	13
		(*c*) Explain how missing data were addressed	13
		(*d*) If applicable, explain how loss to follow-up was addressed	Na
		(*e*) Describe any sensitivity analyses	6 – 7
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	Na
		(c) Consider use of a flow diagram	Na
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8 – 10
		(b) Indicate number of participants with missing data for each variable of interest	10
		(c) Summarise follow-up time (eg, average and total amount)	Na (12 months for all patients)
Outcome data	15*	Report numbers of outcome events or summary measures over time	Na
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11 – 12
		(*b*) Report category boundaries when continuous variables were categorized	Na
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Na
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13 – 14
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations			
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16 – 19
Generalisability	21	Discuss the generalisability (external validity) of the study results	16 – 19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.