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INVITED REVIEW

Learning curves in laparoscopic and robot-assisted prostate surgery: a systematic search and review

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Abstract

Purpose To perform a systematic search and review of the available literature on the learning curves (LCs) in laparoscopic and robot-assisted prostate surgery.

Methods Medline was systematically searched from 1946 to January 2021 to detect all studies in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement, reporting on the LC in laparoscopic radical prostatectomy (LRP), laparoscopic simple prostatectomy (LSP), robot-assisted radical prostatectomy (RARP) and robot-assisted simple prostatectomy (RSP).

Results In total, 47 studies were included for qualitative synthesis evaluating a single technique (LRP, RARP, LSP, RSP; 45 studies) or two techniques (LRP and RARP; 2 studies). All studies evaluated outcomes on real patients. RARP was the most widely investigated technique (30 studies), followed by LRP (17 studies), LSP (1 study), and RSP (1 study). In LRP, the reported LC based on operative time; estimated blood loss; length of hospital stay; positive surgical margin; biochemical recurrence; overall complication rate; and urinary continence rate ranged 40–250, 80–250, 58–200, 50–350, 110–350, 55–250, 70–350 cases, respectively. In RARP, the corresponding ranges were 16–300, 20–300, 25–200, 50–400, 40–100, 20–250, 30–200, while LC for potency rates was 80–90 cases.

Conclusions The definition of LC for laparoscopic and robot-assisted prostate surgery is not well defined with various metrics used among studies. Nevertheless, LCs appear to be steep and continuous. Implementation of training programs/standardization of the techniques is necessary to improve outcomes.

Keywords Laparoscopy · Learning curve · Prostate · Robotic surgical procedures · Systematic review

Introduction

Learning curve (LC) is considered the period during which there is an improvement of surgical performance, referring to a process of gaining knowledge/improving skills in performing specific surgical tasks/procedures, and is generally quantified by the minimum number of cases needed for a surgeon to perform an intervention in a proficient way [1]. Nevertheless, there is no evidence-based definition or standardized platform to measure LCs of the various surgical procedures and there is a great reporting variability, depending among others on the setting of the evaluating studies [2, 3]. LC is related to several surgeon- and patient-dependent factors and, therefore, specific LCs may vary among surgeons and may also be affected by the investigated outcome measure [1, 2]. High-volume compared to low-volume centers are generally associated with more favorable surgical outcomes [4, 5], but outcomes can be also different among high-volume surgeons within the same hospital since proficiency level is not similar among all surgeons [6] and even experienced ones may repeat similar errors [7]. Studies investigating surgical LCs are becoming increasingly important, since LCs may have substantial impact on surgical metrics, clinical outcomes and cost–benefit decisions [8]. In line with

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other surgical specialties, LCs of urological procedures such as laparoscopic and robotic-assisted prostate surgery have been a matter of continuous debate and there appears to be no standard definition of the minimum number of cases to achieve optimal outcomes [1, 2, 8].

Systematic reviews addressing LCs of laparoscopic and robotic-assisted prostate surgery are scarce [1, 8]. The aim of the present work is to provide a comprehensive overview of LCs in laparoscopic and robot-assisted prostate surgery based on a systematic search and review of the available literature.

Methods

Medline Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) 1946 to January 30, 2021 were systematically searched to detect all relevant studies in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement [9], based on the following literature search strategy: (laparoscopy OR robot) AND (prostate OR prostatectomy) AND (learning curve). The reference lists of selected studies, systematic reviews and meta-analyses were screened for other potentially eligible studies. After excluding citations in abstract form and non-English citations, titles/abstracts of full papers were screened for relevance, defined as original research studies reporting on the LC in laparoscopic radical prostatectomy (LRP), laparoscopic simple prostatectomy (LSP), robot-assisted radical prostatectomy (RARP) and robot-assisted simple prostatectomy (RSP). Review articles, editorial letters comments, bulletins and studies describing non-technical skills were excluded. Two review authors (NG and IZ) independently scanned the titles, abstracts or both of every record retrieved, to determine which studies should be further assessed and extracted all data. Disagreements were resolved through consensus or after consultation with a third review author (CM).

Results

In total, 47 studies were included for qualitative synthesis (Fig. 1) evaluating a single technique (LRP, RARP, LSP, RSP; 45 studies) or two techniques (LRP and RARP; 2 studies). Seventeen studies (four prospective and 13 retrospective) including 19,681 patients investigated the LC in LRP (Table 1) [10–26]. Thirty studies (13 prospective and 17 retrospective) including 30,822 patients investigated the LC in RARP (Table 2) [23, 25, 27–54]. The study outcomes based on which LC was evaluated included peri-operative outcomes (operative time, estimated blood loss (EBL), length of hospital stay (LOS)), oncological outcomes (positive surgical margin rate (PSM), biochemical recurrence rate (BCR)), safety (overall complication rate) and functional outcomes (urinary continence and potency rates).

Laparoscopic radical prostatectomy

Regarding peri-operative outcomes, it was reported that operative time reduces significantly after 100–200 cases with a reported plateau at 40–250 cases. Similarly, EBL was found to be significantly reduced after 100–200 cases with a plateau ranging between 80 and 250 cases. Nevertheless, a single series of 110 cases reported that no EBL plateau was

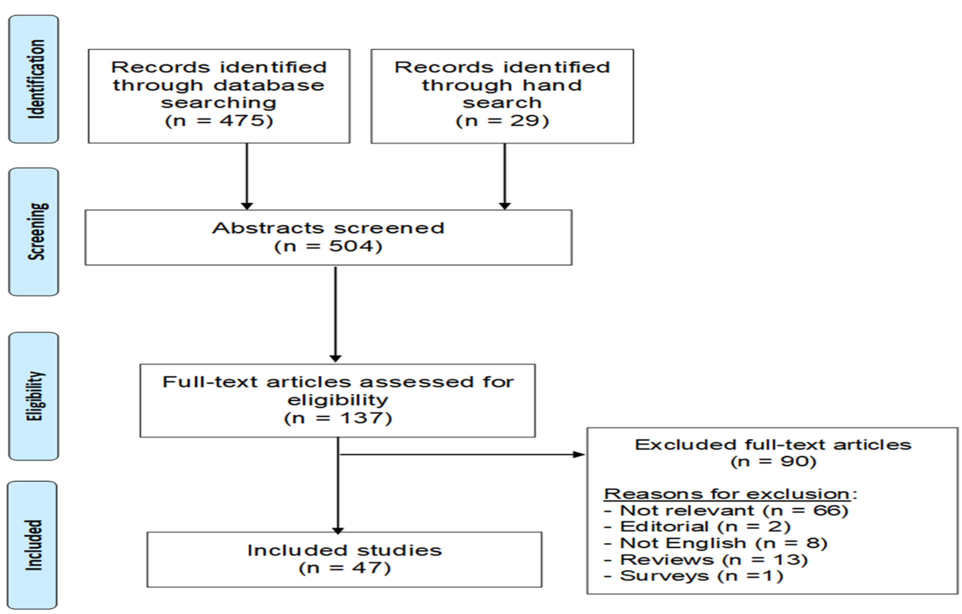

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flowchart

Table 1 Main characteristics and results of studies evaluating LC of LRP

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Main oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate	Potency rate	Transfusion rate	Conversion to open	Duration of catheterization (days)
Baumert (2004) [10]	100	1	20 LRP	N/A	N/A	N/A	Less than 50 cases: 10% PSM rate More than 50 cases: 2% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Eden (2008) [11]	1000	1	NR	Plateau: 100–150 cases	Plateau: 100–150 cases	N/A	N/A	N/A	Overall complication rates Plateau: 150—200 cases	Overall continence rates Plateau: 150—200 cases	N/A	N/A	N/A	N/A
Vickers (2009) [12]	4702	29	RRP (65% of surgeons)	N/A	N/A	N/A	N/A	10 cases: 17% BCR rate 250 cases: 16% BCR rate 750 cases: 9% BCR rate	N/A	N/A	N/A	N/A	N/A	N/A
Secin (2010) [13]	1862	51	RRP (60% of surgerons)	N/A	N/A	N/A	Less than 50 cases: 26% PSM rate 50–99 cases: 23% PSM rate 100–249 cases: 21% PSM rate 250–1100: 21% PSM rate PSM rate plateau: 250 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hruza (2010) [14]	2200	5	< 20 LRP	N/A	N/A	N/A	N/A	N/A	Overall complication rates Plateau: 250 cases (for 3rd generation surgeons)	N/A	N/A	N/A	N/A	N/A
Rodriguez (2010) [15]	400	1	NR	Less than 100 cases: 350 min OP time More than 100 cases: 222–291 min OP time	N/A	N/A	Less than 200 cases: 28.4–31.9% PSM rate More than 200 cases: 11.5–11.6% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 1 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Main oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate	Potency rate	Transfusion rate	Conversion to open	Duration of catheterization (days)
So (2011) [16]	100	1	NR	Less than 40 cases: 226.8 min OP time	N/A	N/A	Less than 40 cases: 17.5% PSM rate	N/A	N/A	12- month continence rate Less than 40 cases: 65.6% continence	N/A	N/A	N/A	N/A
				40–70 cases: 198.2 min OP time			40- 70 cases: 16.7% PSM rate			40- 70 cases: 54.7% continence				
				71–100 cases: 186.1 min OP time			71–100 cases: 10% PSM rate			71–100 cases: 78.2% continence				
Vasdev (2012) [17]	300	3	Proficient upper tract laparoscopic surgeon	Less than 100 cases: 231 ± 55.6 min	Less than 100 cases: 728 ± 427.5 ml	Less than 100 cases: 5.2 ± 3.3 days	N/A	N/A	Overall complication rate (Clavien–Dindo) classification (I–V) Less than 100 cases: 12% complication rate	N/A	N/A	Less than 100 cases: 7% transfusion rate	Less than 100 cases: 2% conversion rate	Less than 100 cases: 19.5 ± 15 days
				101–200 cases: 204 ± 49.2 min	101–200 cases: 536 ± 384.6 ml	101–200 cases: 3.7 ± 2 days			101–200 cases: 8% complication rate			101- 200 cases: 6% transfusion rate	101–200 cases:	101–200 cases:
													1% conversion rate	11.4 ± 5.1 days
				201–300 cases: 181 ± 47.3 min	201- 300 cases: 511 ± 353.7 ml	201–300 cases: 3.2 ± 1.2 days			201–300 cases: 5% complication rate			201–300 cases: 1% transfusion rate	201–300 cases: 0% conversion rate	201–300 cases 9.9 ± 5.2 days

Table 1 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Main oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate	Potency rate	Transfusion rate	Conversion to open	Duration of catheterization (days)
Di Gioia (2013) [18]	240	1	RRP and upper tract lapa-roscopy experience	Less than 80 cases: 210 min OP time	Less than 80 cases: 400 ml EBL	Less than 80 cases: 2 days	N/A	N/A	Minor complication rate (Clavien–Dindo classification) Less than 80 cases: 26.25% complication rate	N/A	N/A	N/A	N/A	N/A
				81–160 cases: 150 min OP time	81–160 cases: 250 ml EBL	81–160 cases: 2 days			81–160 cases: 11.25% complication rate					
				161–240 cases: 150 min OP time OP time plateau: 80 cases	161–240 cases: 250 ml EBL EBL plateau: 80 cases	161–240 cases: 2 days			161–240 cases: 11.25% complication rate					
									Major complication rate (Clavien– Dindo classification) Less than 80 cases: 7.5% complication rate					
									81–160 cases: 2.5% complication rate					
									161–240 cases: 2.5% complication rate					
Mitre (2013) [19]	165	1	NR	Less than 55 cases: 267 min OP time	Less than 55 cases: 328 ml EBL	N/A	Less than 55 cases: 29.1% PSM rate	Less than 55 cases: 14.5% BCR rate	Overall complication rate Less than 55 cases:	N/A	N/A	N/A	N/A	N/A
				56–110 cases: 230 min OP time	56–110 cases: 254 ml EBL		56–110 cases: 21.8% PSM rate	56–110 cases: 7.2% BCR rate	40% complication rate 56–110 cases:					
				111–165 cases: 159 min OP time	111–165 cases: 206 ml EBL		111–165 cases: 5.5% PSM rate	111–165 cases: 1.8% BCR rate	23.6% complication rate 111–165 cases: 3.6% complication rate					
Good (2014) [20]	550	1	Modular training (25 cases)	N/A	N/A	N/A	Plateau: 250 cases	Plateau: 250 cases	Overall complication rate Plateau: 250 cases	Plateau: 250 cases	Plateau: 250 cases	N/A	N/A	N/A

Table 1 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Main oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate	Potency rate	Transfusion rate	Conversion to open	Duration of catheterization (days)
Good (2015) [25]	550	1	Upper tract laparoscopy experience	Plateau: 250 cases	Plateau: 250 cases	N/A	Plateau: 200 cases	N/A	Overall complication rate Plateau: 250 cases	Continence rate Plateau: 350 cases	N/A	N/A	N/A	N/A
Mason (2016) [21]	500	2	NR	N/A	N/A	LOS (days) Surgeon A Plateau: 100 cases Surgeon B Plateau: No plateau	T2 PSM rate Surgeon A Plateau: 150 cases Surgeon B Plateau: No plateau	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Barbosa (2016) [22]	115	1	NR	Less than 57 cases: 139.5 min OP time 58–165 cases: 132.3 min OP time	Less than 57 cases: 200.7 ml EBL 58–165 cases: 156.4 ml EBL	Less than 57 cases: 2.3 days 58–165 cases: 2 days	Less than 57 cases: 16.4% PSM rate 58–165 cases: 17.9% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sivaraman (2017) [23]	3846	9	NR	N/A	N/A	N/A	Less than 50 cases: 25% PSM rate 51–350 cases: 20% PSM rate More than 350 cases: 17% PSM rate PSM rate plateau: 350 cases	Less than 50 cases: 30% BCR rate 51–350 cases: 20% BCR rate More than 350 cases: 16.7% BCR rate BCR rate plateau: 350 cases	N/A	N/A	N/A	N/A	N/A	N/A
Dias (2017) [26]	110	2	RARP	Plateau: 40 cases	Uniform distribution	N/A	No plateau	N/A	Overall complications Uniform distribution	Continence rate Plateau: 70 cases	N/A	N/A	N/A	N/A
Handmer (2018) [24]	2943	9	NR	Less than 100 cases: 193 min OP time 101–200 cases: 163 min OP time	Less than 100 cases: 413 ml EBL 101–200 cases: 378 ml EBL	Less than 100 cases: 2.7 days 101–200 cases: 2.4 days	Less than 100 cases: 18.4% PSM rate 101–200 cases: 17.5% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A

BCR biochemical recurrence, *EBL* estimated blood loss, *LC* learning curve, *LOS* length of hospital stay, *LRP* laparoscopic radical prostatectomy, *NR* not reported, *OP* operative, *PSM* positive surgical margin, *RARP* robot-assisted radical prostatectomy, *RRP* retropubic radical prostatectomy reached. LOS was significantly reduced after 58–200 cases, while a plateau was reported to be reached at 100 cases. Regarding oncological outcomes, significantly lower PSM rates were reported after 50–60 cases, reaching a plateau at 150–350 cases. BCR rate was reported to decrease after 110 cases with a plateau reached at 350 cases. Prior laparoscopic experience decreased the BCR rate by 8% according to a single study. Regarding safety and functional outcomes, it was reported that the complication rate was significantly lower after 55–200 cases with a plateau reached at 100–250 cases. Nevertheless, a single series of 110 cases reported that no plateau was reached for overall complication rate. A significant increase in 12-month urinary continence rate was reported after 70 cases (78.2% vs 65.6%), with a plateau reached at 70–350 cases. No study reported on LC based on potency rate.

Robot-assisted laparoscopic radical prostatectomy

Regarding peri-operative outcomes, it was reported that operative time reduces significantly after 20–300 cases and reached a plateau at 16–300 cases. Similarly, EBL was significantly reduced after 20–300 cases with a plateau reached at 90–250 cases. No statistically significant difference between the case groups were reported in four studies. LOS was found to be significantly reduced after 30–200 cases and according to the results of a single study it reached a plateau at > 25 cases. No statistically significant difference between the case groups were reported in two studies. Regarding oncological outcomes, a significant decrease in PSM rate was reported after 67–80 cases with a plateau reached at 50–400 cases. No statistically significant difference between the case groups were reported by eight studies. BCR rate was reported to decrease after 40 cases and the plateau was 100 cases. After salvage RARP, BCR rate was increased after 90 cases compared to the initial 30 cases (36% vs 23%) according to one study. Regarding safety, it was reported that the complication rate was significantly lower after 20–125 cases and reached a plateau at 50–250 cases. Nevertheless, a single series of 120 cases reported that no plateau was reached for overall complication rate. No statistically significant difference between the case groups were reported in two studies. Regarding functional outcomes, a significant increase in urinary continence rate was reported after 30–70 cases. The plateau for early and 12-month urinary continence was reached at 100 and 100–200 cases, respectively. A large series of 1477 cases reported that no plateau was reached for 12-month urinary continence rate. No statistically significant difference between the case groups were reported by two studies. A significant increase in 12-month potency rates was reported after 80 cases (76.6% vs 60.5%) in one study. Following salvage RARP, an increase in 12-month potency rate from 3.3% in the first 30 cases to 23% after 90 cases was reported in one study. No statistically significant difference between the case groups were reported in two studies.

Laparoscopic retropubic simple prostatectomy and robotic simple prostatectomy

A single retrospective study evaluating the LC of LSP on 11 cases with benign prostate hyperplasia was detected [55]. The evaluation of LC was based on conversion-to-open rate, operative time and EBL. No conversion was performed. Operative time and EBL were reported to be significantly reduced with increasing experience. Similarly, a single retrospective study evaluating the LC of RSP on 120 cases with benign prostate hyperplasia was detected [56]. Operative time was significantly reduced from 162 min in the first 10 cases to 134 min in the last 10 cases. For the first ten cases, hematocrit drop had logarithmic improvement, showing linear transitioning thereafter. Regarding overall complication rate and catheterization time no statistically significant difference between the case groups were reported.

Discussion

To the best of our knowledge, this is the first review providing a comprehensive overview of LCs focusing on laparoscopic and robot-assisted prostate surgery based on a systematic search of the available literature. It can therefore provide a useful guide for urologists starting with these procedures regarding the number of cases needed for reaching proficiency.

RARP was found to be the most widely investigated technique (30 studies), followed by LRP (17 studies), LSP (1 study), and RSP (1 study). According to our findings, the definition and assessment method of LC for laparoscopic and robot-assisted prostate surgery is not well defined with various metrics used among studies. Nevertheless, LCs appear to be steep and continuous with the required number of cases for reaching proficiency showing intra-technical variability and outcome-dependent inter-technical variability. In LRP, the reported LC based on operative time; EBL; LOS; PSM; BCR; overall complication rate and urinary continence rate ranged 40–250, 80–250, 58–200, 50–350, 110–350, 55–250, 70–350 cases, respectively. In RARP, the corresponding ranges were 16–300, 20–300, 25–200, 50–400, 40–100, 20–250, 30–200, while LC for potency rates was 80–90 cases.

The outcomes of radical prostatectomy have become a great topic for discussion. Initially, the outcomes focused on cancer control, urinary continence and potency rates, the so- called trifecta. But such reporting system has failed to meet the increasing expectations of patients that need to undergo radical prostatectomy, especially those that choose

Table 2 Main characteristics and results of studies evaluating LC of RARP

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
Atug (2006) [27]	100	3	Advanced laparoscopic techniques	N/A	N/A	N/A	Less than 33 cases: 45.4% PSM rate 34–76 cases: 21.2% PSM rate 77–100 cases: 11.7% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Artibani (2008) [28]	41	1	Expertise in RRP, limited laparoscopic skills	Less than 10 cases: 270 min OP time 11–20 cases: 222.5 min OP time 21–41 cases: 195 min OP time	Less than 10 cases: 700 ml EBL 11–20 cases: 400 ml EBL 21–41 cases: 300 ml EBL	Less than 10 cases: 7 days 11–20 cases: 7.5 days 21–41 cases: 7 days	N/A	N/A	Overall complications rate Less than 10 cases: 33% complication rate 11–20 cases: 10% complication rate 21–41 cases: 0% complication rate	N/A	N/A	N/A	Less than 10 cases: 7 days 11–20 cases: 7 days 21–41 cases: 7 days	N/A
Doumerc (2010) [29]	300	1	Experience in RRP	N/A	N/A	N/A	PSM rate plateau: 205 cases p T2 PSM plateau: 130 cases pT3 PSM plateau: 170 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sharma (2011) [30]	500	2	Surgeon 1: experience in RRP, Surgeon 2: little previous RPP experience, considerable laparoscopic expertise	Surgeon 1 OP time (min) Less than 50 cases: 185 min OP time 51–100 cases: 180 min OP time 101–150 cases: 149 min OP time	Surgeon 1 EBL (ml) Less than 50 cases: 288 ml EBL 51–100 cases: 225 ml EBL 101–150 cases: 150 ml EBL	N/A	Surgeon 1 Overall: 23% PSM rate Last 50 cases: 8.0% PSM rate pT2 Last 50 cases 19.1% PSM rate pT3a	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
				151–200 cases: 150 min OP time	151–200 cases: 100 ml EBL		Surgeon 2 Overall: 26% PSM rate							
				201–250 cases: 163 min OP time	201–250 cases: 250 ml EBL		Last 50 cases: 12.9% PSM rate pT2							
				251–300 cases: 135 min OP time	251–300: 150 ml EBL		Last 50 cases: 23.5% PSM rate pT3a							
				301–330 cases: 131 min OP time	301–330 cases: 100 ml EBL									
				Surgeon 2 OP time (min) Less than 50 cases: 237 min OP time	Surgeon 2 EBL (ml) Less than 50 cases: 250 ml EBL									
				51–100 cases: 201 min OP time	51–100 cases: 250 ml EBL									
				101–150 cases: 180 min OP time	101–150 cases: 200 ml EBL									
				151–170 cases: 177 min OP time	151 -170 cases: 225 ml EBL									
Sammon (2010) [31]	235	3	Experience in RRP	Surgeon 1 1–25 cases: 345.4 min OP time	Surgeon 1 1–25 cases: 149 ml EBL	Surgeon 1 1–25 cases: 2.2 days	Surgeon 1 1–25 cases: 8% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A
				26–75 cases: 247.7 min OP time	26–75 cases: 182 ml EBL	26–75 cases: 1.66 days	26–75 cases: 24% PSM rate							
				Surgeon 2 1–25 cases: 298 min OP time	Surgeon 2 1–25 cases: 252 ml EBL	Surgeon 2 1–25 cases: 2.12 days	Surgeon 2 1–25 cases: 24% PSM rate							

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
				26–75 cases: 203.7 min OP time	26–75 cases: 203 ml EBL	26–75 cases: 1.38 days	26–75 cases: 22% PSM rate							
				Surgeon 3 1–25 cases: 265.8 min OP time	Surgeon 3 1–25 cases: 122 ml EBL	Surgeon 3 1–25 cases: 2.04 days	Surgeon 3 1–25 cases: 28% PSM rate							
				26–75 cases: 189.5 min OP time	26–75 cases: 139 ml EBL	26–75 cases: 1.18 days	26–75 cases: 16% PSM rate							
				Plateau: more than 25 cases		Plateau: more than 25 cases								
Ou (2010) [32]	100	1	NR	Less than 30 cases: 3.75 h OP time	Less than 30 cases: 314.83 ml EBL	Less than 30 cases: 7.33 days	Less than 30 cases: 50% PSM rate	N/A	N/A	3-month continence rate Less than 30 cases: 76.7% continence	N/A	Less than 30 cases: 13.3% transfusion rate	N/A	N/A
				31–60 cases: 3.15 h OP time	31–60 cases: 227.33 ml EBL	31–60 cases: 3.93 days	31–60 cases: 43.3% PSM rate			31–60 cases: 95% continence		31–60 cases: 0% transfusion rate		
				61–100 cases: 3.01 h OP time	61–100 cases: 161.75 ml EBL	61–100 cases: 3 days	61–100 cases: 42.5% PSM rate			61–100 cases: 96.6% continence		61–100 cases: 5% transfusion rate		
Ou (2011a) [33]	200	1	NR	Less than 50 cases: 207.7 min OP time	Less than 50 cases: 275.3 ml EBL	N/A	N/A		Overall complications rate Plateau: more than 150 cases	N/A	N/A	Plateau: more than 150 cases	N/A	N/A
				51–100 cases: 184.1 min OP time	51–100 cases: 179.4 ml EBL				Less than 50 cases: 19% complication rate			Less than 50 cases: 9% transfusion rate		
				101–150 cases: 168.1 min OP time	101–150 cases: 145.5 ml EBL				51–100 cases: 12% complication rate			51–100 cases: 4% transfusion rate		
				151–200 cases: 145.9 min OP time	151–200 cases: 102.6 ml EBL				101–150 cases: 18% complication rate			101–150 cases: 2% transfusion rate		
									151–200 cases: 0% complication rate			151–200 cases: 0% transfusion rate		

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
Ou (2011b) [34]	60	1	NR	N/A	Less than 30 cases: 314.8 ml EBL	Less than 30 cases: 7.33 days	N/A	N/A	Overall complications rate Less than 30 cases: 16.7% complication rate	3-month continence rate Less than 30 cases: 76.7% continence rate	N/A	Less than 30 cases: 13.3% transfusion rate	N/A	N/A
					31–60 cases: 227.3 ml EBL	31–60 cases: 3.93 days			31–60 cases: 10% complication rate	31–60 cases: 97.6% continence rate		31–60 cases: 0% transfusion rate		
Gumus (2011) [35]	120	1	Standard Intuitive Surgical accreditation course	1–40 cases: 182 min OP time	1–40 cases: 287 ml EBL	1–40 cases: 5.1 days	1–40 cases: 22% PSM rate	1–40 cases: 17.5% BCR rate	N/A	12-month continence rate 1–40 cases: 72.5% continence rate	12-month potency rate 1–40 cases: 60.5% potency rate	N/A	N/A	N/A
				41–80 cases: 168 min OP time	41–80 cases: 238 ml EBL	41–80 cases: 4 days	41–80 cases: 17% PSM rate	41–80 cases: 5% BCR rate		41–80 cases: 85% continence rate	41–80 cases: 66.7% potency rate			
				81–120 cases: 139 min OP time	81–120 cases: 170 ml EBL	81–120 cases: 3.1 days	81–120 cases: 6% PSM rate	81–120 cases: 0% BCR rate		81–120 cases: 92.5% continence rate	81–120 cases: 76.6% potency rate			
				All measured outcomes are similar to high volume centers: 80—120 cases										
Dal Moro (2012) [36]	257	NR	NR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Port placement and docking of da Vinci Surgical System Plateau: 60 cases
Al-Hathal (2013) [37]	250	1	Fellowship trained	Plateau: more than 50 cases	N/A	N/A	Plateau: more than 50 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A
				1–50 cases: 260 min OP time			1–50 cases: 38% PSM rate							

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
				51–250 cases: 170–190 min OP time			51–250 cases: 26–32% PSM rate							
Hashimoto (2013) [38]	200	1	Experience in RRP	Plateau: 20 cases	No plateau	N/A	Plateau: 50 cases	N/A	Overall complications rate Plateau: 50 cases	Continence rate 3-month continence rate plateau: 50 cases	N/A	N/A	N/A	N/A
										6-month continence rate plateau: 100 cases				
										12-month continence rate plateau: 100 cases				
	100	1	No experience	N/A	1–10 cases: 725 ml EBL	N/A	1–10 cases: 42.9% PSM rate	N/A	N/A	12-month continence rate 1–10 cases: 88.9% continence rate	N/A	1–10 cases: 50% transfusion rate	N/A	N/A
					11–40 cases: 471 ml EBL		11–40 cases: 20% PSM rate					11–40 cases: 23.7% transfusion rate		
					41–70 cases: 312 ml EBL		41–70 cases: 33.3% PSM rate			11–40 cases: 95.7% continence rate		41–70 cases: 13.3% transfusion rate		
					71–100 cases: 285.1 ml EBL		71–100 cases: 22.7% PSM rate			41–70 cases: 89.3% continence rate		71–100 cases: 3.3% transfusion rate		
										71–100 cases: 100% continence rate				
Vasdev (2013) [40]	300	3	Laparoscopic and open experience	Less than 100 cases: 272 min OP time	Less than 100 cases: 251 ml EBL	Less than 100 cases: 2.58 days	Less than 100 cases: 22% PSM rate	N/A	Overall complications rate (Clavien–Dindo classification I–V) Less than 100 cases: 21% complication rate	N/A	N/A	Less than 100 cases: 1% transfusion rate	N/A	N/A
				101–200 cases: 228 min OP time	101–200 cases: 247 ml EBL	101–200 cases: 2.57 days	101–200 cases: 32% PSM rate		101–200 cases: 13% complication rate			101–200 cases: 2% transfusion rate		
				201–300 cases: 171 min OP time	201–300 cases: 248 ml EBL	201–300 cases: 1.86 days	201–300 cases: 26% PSM rate		201–300 cases: 5% complication rate			201–300 cases: 1% transfusion rate		

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
Di Pierro (2014) [41]	233	1	Laparoscopic and open experience	N/A	N/A	N/A	N/A	N/A	Overall complications rate Plateau: more than 175 cases Less than 60 cases: 31% complication rate 60–117 cases: 29% complication rate 118–175 cases: 29% complication rate 176–233 cases: 7% complication rate	N/A	N/A	N/A	N/A	N/A
Thompson (2014) [42]	866	1	Experience in RRP	N/A	N/A	N/A	Plateau: 400–500 cases	N/A	N/A	Incontinence score Plateau: 200–300 cases Function score Plateau: 50–100 cases Bother score Plateau: 200–300 cases Irritation- obstruction score Plateau: 200–300 cases	N/A	N/A	N/A	N/A
Ou (2014) [43]	500	1	NR	N/A	N/A	N/A	pT3 PSM Significant decrease 250 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Davis 2014 [53]	17,034	325	NR	Less than 25 cases: 5.0 h OP time 26–50 cases: 4.5 h OP time 51–75 cases: 4.3 h OP time 76–100 cases: 4.1 h OP time 101–125 cases: 4.0 h OP time 126–150 cases: 3.9 h OP time	N/A	Less than 25 cases: 2.4 days 26–50 cases: 2.2 days 51–75 cases: 2.1 days 76–100 cases: 2.0 days 101–125 cases: 1.9 days 126–150 cases: 2.0 days	N/A	N/A	Overall complication rate Less than 25 cases: 11.75% complication rate 26–50 cases: 10.05% complication rate 51–75 cases: 9.06% complication rate 76–100 cases: 8.93% complication rate 101–125 cases: 8.62% complication rate 126–150 cases: 8.95% complication rate	N/A	N/A	N/A	N/A	N/A

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
Good (2015) [25]	531	1	Open, laparoscopic, dry and cadaveric training	Plateau: 250 cases	Plateau: 250 cases	N/A	Plateau: 300 cases	N/A	Overall complication rate Plateau: 250 cases	Continence rate Plateau: 100 cases	N/A	NN	N/A	N/A
Chang (2016) [44]	355	3	Surgeon A: open; surgeon B: open and laparoscopic; surgeon C: laparoscopic	Surgeon A Plateau: 90 cases Surgeon B No Plateau Surgeon C No Plateau	Surgeon A Plateau: 90 cases Surgeon B Plateau: 50 cases Surgeon C Plateau: 50 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lovegrove (2016) [45]	426	15 trainees	Simulator, laboratory, cadaver	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Anterior bladder neck transection Plateau: 16 cases Posterior bladder neck transection Plateau: 18 cases Posterior dissection Plateau: 9 cases Prostatic pedicle and seminal vesicles dissection Plateau: 15 cases Anastomosis Plateau: 17 cases Other technical skills No plateau
Sivaraman (2017) [23]	3846	9	NR	N/A	N/A	N/A	Plateau: 100 cases	Plateau: 100 cases	N/A	N/A	N/A	N/A	N/A	N/A

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
Adili (2017) [46]	400	1	600 LRP	Less than 100 cases: 207.4 min OP time 101–200 cases: 184.4 min OP time 201–300 cases: 177.6 min OP time 301–400 cases: 179.2 min OP time	Less than 100 cases: 255.1 ml EBL 101–200 cases: 246.4 ml EBL 201–300 cases: 248.6 ml EBL 301–400 cases: 213.6 ml EBL	Less than 100 cases: 2 days 101–200 cases: 2 days 201–300 cases: 2 days 301–400 cases: 2 days	Less than 100 cases: 29% PSM rate 301–400 cases: 19% PSM rate	N/A	N/A	N/A	N/A	Less than 100 cases: 1% transfusion rate 101–200 cases: 0% transfusion rate 201–300 cases: 1% transfusion rate 301–400 cases: 1% transfusion rate	N/A	N/A
Fossati (2017) [54]	1477	4	NR	N/A	N/A	N/A	N/A	N/A	N/A	12-months continence rate Less than 100 cases: 70% continence More than 500 cases: 90% continence	N/A	N/A	N/A	N/A
Jaulim (2018) [47]	300	3	NR	N/A	N/A	N/A	PSM rate Surgeon 1 Less than 50 cases: 12% PSM rate 51–100 cases: 32% PSM rate Surgeon 2 Less than 50 cases: 20% PSM rate 51–100 cases: 36% PSM rate Surgeon 3 Less than 50 cases: 23% PSM rate	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
							51–100 cases: 21% PSM rate							
Ucar (2019) [48]	91	1	RRP and LRP	N/A	N/A	N/A	Less than 45 cases: 16% PSM rate	N/A	Overall complication rate Less than 45 cases: 17.7% complication rate	12-month continence rate Less than 45 cases: 92.1% continence	12-month potency rate Less than 45 cases: 39.5% potency	N/A	N/A	N/A
							46–91 cases: 12% PSM rate		46–91 cases: 15.5% complication rate	46–91 cases: 87.9% continence	46–91 cases: 27.3% potency			
Slusarenco (2020) [49]	145	1	Laparoscopic experience	Less than 50 cases: 293.5 min OP time	Less than 50 cases: 290.2 ml EBL	Less than 50 cases: 12 days	N/A	N/A	Clavien I-II complications Less than 50 cases: 26.5% complication rate	N/A	N/A	N/A	N/A	N/A
				50–88 cases: 204.2 min OP time	50–88 cases: 189.7 ml EBL	50–88 cases: 11 days			50–88 cases: 23.1% complication rate					
				89–145 cases: 178.1 min OP time	89–145 cases: 127.2 ml EBL	89–145 cases: 10 days			89–145 cases: 7.0% complication rate					
									Clavien III complications Less than 50 cases: 16.3% complication rate					
									50–88 cases: 5.1% complication rate					
									89–145 cases: 3.5% complication rate					
Song (2020) [50]	329	1	RRP and laparoscopic experience	N/A	Plateau: 230 cases	Plateau: 200 cases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tamhankar (2020) [51]	1406	1 surgical team	RRP and laparoscopic experience	Plateau: 308 cases	N/A	N/A	No plateau	N/A	Overall complication rate No plateau	N/A	N/A	N/A	N/A	N/A
Bonet (2020) [52]	120	1	NR	1–30 cases: 139.5 min OP time	1–30 cases: 124 ml EBL	N/A	N/A	1–30 cases: 23% BCR rate	N/A	12-months continence rate 1–30 cases: 38.7% continence rate	12-months potency rate 1–30 cases: 3.3% potency rate	N/A	N/A	N/A

Table 2 (continued)

Author (year)	Number (patients)	Number (surgeons)	Prior experience	Main peri-operative outcomes			Oncological outcomes		Safety outcomes	Main functional outcomes		Other outcomes		
				Operative time	Estimated blood loss	Length of stay	PSM rate	BCR rate	Complications	Continence rate/other functional scores	Potency rate	Transfusion rate	Duration of catheterization (days)	Technical aspects
				91–120 cases: 121 min OP time	91–120 cases:69 ml EBL			91–120 cases: 36% BCR rate		91–120 cases: 36% continence rate	91–120 cases: 23% potency rate			

BCR biochemical recurrence, *EBL* estimated blood loss, *LC* learning curve, *LOS* length of hospital stay, *LRP* laparoscopic radical prostatectomy, *NR* not reported, *OP* operative, *PSM* positive surgical margin, *RARP* robot-assisted radical prostatectomy, *RRP* retropubic radical prostatectomy

less invasive and more advanced treatment options such as LRP and RARP. Therefore, the pentafecta entity has been suggested. This incorporates the trifecta outcomes (BCR, urinary continence and potency), peri-operative complications and surgical margin status. At present, this comprehensive reporting method is utilized to counsel patients prior to offering treatment options for prostate cancer, to estimate the efficiency of the modality and patients' satisfaction [57].

The most commonly used metrics both in LC-LRP and RARP studies include PSM rate (12 and 18 studies, respectively), operative time (10 and 16 studies, respectively) and EBL (8 and 16 studies, respectively). This may be attributed to the fact that the above outcomes are more easily recorded. Nevertheless, it should be noted that PSM rate can be affected by several factors including nerve preservation and extracapsular disease, while a shorter operative time does not necessarily mean proficiency, especially if not combined with favorable oncological outcomes. Five LRP studies reported on urinary continence outcomes, while urinary continence and potency outcomes were reported in ten and three RARP studies, respectively. Despite the fact that it is generally more difficult to record functional outcomes since they necessitate a longer follow-up, they are considered equally important since they reflect the patient's quality of life. A recent systematic review focusing on LC in robotic surgery confirmed the outcome reporting heterogeneity among studies, showing that the majority of the studies uses surgical rather than patient-related metrics [2].

Abboudi et al. performed the first systematic review investigating the LCs in various urological procedures and reported a mean operative time plateau after 50–200 cases and PSM rates plateau at 50–1600 cases for surgeons with unknown experience level on RARP [1]. They also investigated experienced laparoscopic surgeons' outcomes, who achieved acceptable PSM rates after 100–300 cases. In another systematic review investigating LCs in robot-assisted surgery, early urinary continence rate and 12-month urinary continence rate plateau were reported after 100 and 112–541 cases, respectively. BCR and PSM rate plateau was reported to be reached at 100 cases [8]. A literature-based analysis on LC-LRP studies reported diverse results for EBL, operative time and complication rates; PSM and BCR rates were reported to reach a plateau at 200–250 and 150 cases, respectively; urinary continence rates were reported to reach a plateau at 250 cases; no plateau was reported to be reached for potency rates [58].

LC can be affected by various factors (Table 3). Anatomical factors such as prostate volume and pelvis diameter have been reported to be significantly correlated with operative time and EBL in RARP [59]. Furthermore, the complexity of each case and the dexterity of the surgeon play a key role [60]. Most LC studies do not take into account the low case volume urologists who usually have a limited operation time

Table 3 Factors affecting LC metrics

Metrics	Factors
PSM rate	Nerve preservation, extracapsular disease, surgeon dexterity
Operative time	Prostate volume, pelvis diameter, case complexity, case volume, surgeon dexterity, technical factors, assistants–nurses–anesthetist experience, simulator–laboratory training programs
EBL	Prostate volume, pelvis diameter, case complexity, case volume, surgeon dexterity
Complication rates	Simulator–laboratory training programs, mentored training
Urinary continence and potency rates	Long follow-up, limited report compared to oncological outcomes

EBL estimated blood loss, *LC* learning curve, *PSM* positive surgical margin

available and are forced to achieve LC with fewer cases. Case volume, institutional resources and technical factors such as instruments with improved dexterity in LRP and double console in RARP may affect LC [45]. Other factors that may affect LC include anesthetists' and surgical nurses' level of experience, as well as residents'/fellows' previous training [61, 62]. Cimen et al. reported that the higher level of experience of the bedside assistants in RARP can significantly shorten operative time, although it does not affect the oncological outcomes [63].

Furthermore, the role of surgical simulation should be considered and we should compare the LC training with traditional wet- and dry-laboratory methods, because a combination of training environments could result in most effective training [64]. An RCT reported that the tasks performed by residents in the da Vinci Surgical Skills Simulator are correlated with bladder mobilization and urethro-vesical anastomosis during RARP [65]. Three-dimensional printing has also been shown to be feasible in phase II RARP trials [66]. Nevertheless, the elasticity of normal tissue has not been replicated with these models and therefore cost-effectiveness warrants further testing [66]. A systematic review focusing on robotic surgery in urology has shown that mentored training and non-structured pathways combined with traditional laboratory training favorably affect LCs [67]. Surgical curricula including training on technical and non-technical skills, such as surgical cognitive and social skills have also been applied to improve outcomes in laparoscopic and robot-assisted surgery [68]. The role of a training program under supervision appears to result in shortening of the LC and minimization of adverse outcome rates during this period [67, 68]. Nevertheless, LRP seems to involve skills not translated well from radical retropubic prostatectomy [69] and therefore outcome improvements appear to be achieved more slowly in laparoscopic compared to open surgery [12].

A limitation of the present review is the general low quality of the available studies in the international literature and were therefore included. In addition, there was a variety of different metrics making comparison among studies difficult. Furthermore, most studies were performed in high-volume centers by surgeons with various previous level of experience. Last but not least, substantial information on the complexity of each step to overcome the beginning of the LC was lacking in many studies.

Based on the above findings, we recommend standardized data collection and outcome reporting for each procedure to have more accurate estimation of the LCs. Moreover, simulator and mentored training should be applied to shorten the LC, especially in conventional laparoscopy in which the LC is longer compared to robot-assisted procedures. Case selection can also shorten the LC, avoiding demanding nerve-sparing procedures and complex cases such as bulky prostates or cases with extracapsular disease. Finally, experienced surgical assistants can contribute to improved intra-operative outcomes during the LC.

Conclusions

LC for laparoscopic and robot-assisted prostate surgery is not well defined with various metrics used among studies. Nevertheless, LCs appear to be steep and continuous. Implementation of training programs/standardization of the techniques is necessary to improve outcomes.

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