Robotic-assisted laparoscopic mesh sacrocolpopexy

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Abstract: The current ‘gold standard’ surgical repair for apical prolapse is the abdominal mesh sacrocolpopexy. Use of a robotic-assisted laparoscopic surgical approach has been demonstrated to be feasible as a minimally invasive approach and is gaining popularity amongst pelvic floor reconstructive surgeons. Although outcome data for robotic-assisted sacrocolpopexy (RASC) is only just emerging, several small series have demonstrated anatomic and functional outcomes, as well as complication rates, comparable to those reported for open surgery. The primary advantages thus far for RASC over open surgery include decreased blood loss and shorter hospital stay.

Keywords: mesh sacrocolpopexy, robotic surgery, pelvic prolapse

Introduction

Pelvic organ prolapse (POP) is a common problem among women, and given the aging of the US population, complaints related to pelvic floor disorders are increasing. A recent forecasting study predicted that by the year 2050, 43.8 million women, or nearly one-third of the adult female population in the US, would be affected by at least one troublesome pelvic floor disorder [Wu *et al.* 2009]. As a consequence, surgical correction of prolapse has become increasingly common. It is estimated that nearly 200,000 surgical procedures are performed annually in the US [Boyles *et al.* 2003].

The surgical repair of POP continues to evolve from the traditional, transvaginal ‘suture’ repair, including anterior colporrhaphy and posterior plication techniques, to newer approaches, including incorporation of graft material placed via a transvaginal approach. However, the high failure rate of vaginal repairs, estimated to be approximately 25% and likely much higher, suggests that poor apical support was the reason for failure of vaginal surgical techniques. This led to the use of graft interposition via an abdominal approach. Lane first reported on the use of an intervening graft to anchor the vaginal apex or uterus to the sacral promontory, leading eventually to the advent of the sacrocolpopexy as we now know it [Lane, 1962]. As of 2010, open mesh sacrocolpopexy is still widely considered to

be the ‘gold standard’ for the repair of high-grade POP, and can address POP involving the anterior, apical, and posterior vagina.

The introduction of laparoscopy has provided a minimally invasive option to open pelvic surgery. The female pelvis lends nicely to laparoscopy, and recent advances in technology led to the advent of robotic-assisted laparoscopic surgery, in particular robotic-assisted sacrocolpopexy (RASC). In this review article we describe the evolution of these minimally invasive approaches, focusing on RASC, techniques, surgical outcomes, and complications.

Open abdominal mesh sacrocolpopexy

History

There is strong evidence that abdominal sacral colpopexy is an effective and reliable procedure for the correction of apical vaginal prolapse [Nygaard *et al.* 2004]. Existing evidence in the form of randomized clinical trials supports the position that sacral colpopexy is superior to other approaches to apical resupport including sacrospinous ligament fixation [Maher *et al.* 2004; Benson *et al.* 1996] and vaginal hysterectomy with anterior and posterior colporrhaphy [Roovers *et al.* 2004]. The struggle with correction of apical uterine and vaginal prolapse is longstanding, but it was not until the late 1950s that surgeons first began using the anterior

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longitudinal ligament of the sacrum as a fixation point for support [Arthure, 1949]. There was initial debate regarding the level at which such fixation should occur, with some advocating for placement at the S-3–S-4 level to approximate normal anatomic planes [Birnbaum, 1973], while others recommended higher placement at S-1–S-2 to better visualize the middle sacral artery and avoid bleeding from that vessel [Sutton *et al.* 1981].

Techniques

A variety of techniques were initially attempted in the placement of grafts to the vagina, including placement of material along the full length of the rectovaginal septum [Snyder and Krantz, 1991] and the use of a conical configuration [Addison *et al.* 1989] to increase the amount of surface area between the tissue and the supporting graft. Currently most favor the use of two separate grafts placed anterior and posterior on the vagina and attached in concert to the sacrum. In addition some authors advocate for the concurrent performance of some form of culdoplasty [Cundiff and Addison, 1998; Addison and Timmons, 1993; Addison *et al.* 1989; Hendee and Berry, 1981], although this recommendation is not uniform or without potential complication in the form of bowel dysfunction [Nygaard *et al.* 2004; Snyder and Krantz, 1991]. While most favor closing the peritoneum over the mesh graft in order to reduce the risk of adhesions and bowel obstruction, the evidence supporting this recommendation is lacking.

Concern regarding concomitant hysterectomy at the time of colpopexy relates to the potential increased risk for graft erosion or infection due to surgical field contamination from vaginal flora in the setting of graft placement. There have been no randomized trials focused on this issue and the existing data are inconsistent. Some small studies have suggested an increased risk for erosion in the setting of hysterectomy [Culligan *et al.* 2002; Imparato *et al.* 1992] while others have not [Brizzolara and Pillai-Allen, 2003; Fedorkow and Kalbfleisch, 1993]. Given the diversity of the materials used in these studies, it seems likely that the choice of graft may play some role in the risk of erosion [Cundiff *et al.* 2008; Wu *et al.* 2006]. Good practice recommendation would also encourage the placement of multiple sutures for attachment of the graft to the vagina in order to diffuse tension across a wider surface

area and consequently reduce the likelihood of erosion.

Characteristics of the graft material to consider include durability, accessibility, and risk of infection, erosion or inflammation. In general, either biologic or synthetic materials have been used. The former reduces problems associated with immunogenic response, inflammation and erosion, but there is some concern with regards to the availability (allografts) and durability (xenografts) [FitzGerald *et al.* 2004]. In addition, there can be morbidity associated with the use of autologous tissue, in the form of incisional hernias or leg pain at the harvest site if rectus fascia or fascia lata, respectively, are used. Conversely synthetic grafts are widely available and offer a variety of options with regard to pore size, filament structure, reactivity, and stiffness. While there have been reports regarding the use of non-mesh graft materials [Cundiff *et al.* 2008; Culligan *et al.* 2005; Lansman, 1984], the present standard of care favors the utilization of non-absorbable, type I polypropylene mesh for fixation [Ridgeway *et al.* 2008]. There have been a number of reports linking the use of other types of nonabsorbable graft materials including Teflon, Gore-Tex, and silicone-coated polyester with higher rates of mesh erosion [Cundiff *et al.* 2008; Wu *et al.* 2006; Govier *et al.* 2005; Nygaard *et al.* 2004].

Outcomes

A recent comprehensive review of sacral colpopexy delineates the issues associated with attempting to evaluate the overall success of this procedure [Nygaard *et al.* 2004]. Efficacy studies vary with regard to definitions of outcome success or failure. Objective, anatomic measures range from standardized scales such as the Baden–Walker and Pelvic Organ Prolapse Quantification systems to nonvalidated modifiers (mild, moderate, severe) and independently defined terms such as ‘optimal’ or ‘satisfactory’. Similarly subjective measures of success often include nonvalidated symptom scales. Of the randomized trials that compare colpopexy to vaginal apical resupport (sacrospinous ligament fixation), two favor sacral colpopexy based on defined outcome measures [Benson *et al.* 1996], while one shows no statistically significant differences in outcome variables [Maher *et al.* 2004], although the vaginal group had higher percentages of subjects with postoperative anterior vaginal prolapse and prolapse to the level of the introitus. The

most recent comprehensive review looking at efficacy outcomes evaluated 64 studies published between January 1966 and January 2004. Long-term success rates for sacral colpopexy ranged from 78% to 100% when success was defined as no postoperative apical prolapse and from 58% to 100% when defined as no postoperative in any compartment [Nygaard *et al.* 2004].

Despite correction of prolapse, postoperative bladder and bowel function can both present problems. It is not uncommon for women with advanced prolapse to demonstrate abnormal bladder function in the form of either voiding dysfunction/retention or urinary stress incontinence. While restoration of the bladder base and urethra to a more anatomically correct position can often help resolve emptying dysfunction, pre-operative urodynamic evaluation is of questionable value given the limitations inherent in artificially reducing prolapse while the patient is voiding. Similarly, while the demonstration of stress incontinence pre-operatively supports the use of a concomitant anti-incontinence procedure, formal urodynamics are of limited use. The presence of studies validating the use of abdominal leak point pressures or maximal urethral closure pressures in the setting of prolapse are lacking. A further consideration is the individual with prolapse who does not complain of incontinence. No effective means of estimating postoperative incontinence has been established and the incidence of incontinence ranges from 8% to 60% in studies [Gallentine and Cespedes, 2001; Rosenzweig *et al.* 1992; Bergman *et al.* 1988]. A recent randomized, prospective trial of women undergoing sacral colpopexy without complaints of stress urinary incontinence demonstrated a near 50% reduction in postoperative incontinence in the group undergoing retropubic urethropexy as compared with the group that did not [Brubaker *et al.* 2003]. While it is also common for women to report defecatory dysfunction prior to undergoing colpopexy [Spence-Jones *et al.* 1994], the impact of surgical correction of prolapse on these symptoms remains unclear. There are few studies that explore this issue and the data that exist are mixed. Several studies suggest an improvement in constipation levels [Maher *et al.* 2004; Baessler and Schuessler, 2001], while others demonstrated a worsening in symptoms or a significant degree of new-onset constipation [Geomini *et al.* 2001; Pilsgaard and Mouritsen, 1999; Virtanen *et al.* 1994].

Disadvantages

Relative to less-invasive approaches to apical resupport, abdominal sacral colpopexy is generally associated with greater intraoperative blood loss, longer hospital stay, delayed return of bowel function, increased postoperative pain and higher rates of postoperative febrile morbidity and wound complication.

Laparoscopic mesh sacrocolpopexy

The initial goals of laparoscopic sacrocolpopexy (LSC) were to reproduce the steps of open sacrocolpopexy, while providing a similar anatomic outcome via a minimally invasive approach. One early series described a four-port approach, using a 10-mm umbilical port, two 5-mm ports lateral to the rectus abdominis muscles and 3 cm medial from the anterior superior iliac spine, and a 10-mm port in the suprapubic position. [Cosson *et al.* 2002]. The vesicovaginal and rectovaginal spaces are dissected to allow the surgeon to suture a Y-shaped piece of synthetic mesh to the vagina, with a single arm extending to the anterior longitudinal ligament. The mesh is often secured to the ligament with staples or a tacker, as suture passage in the promontory with laparoscopic instruments may be challenging [Wattiez *et al.* 2003]. One of the earliest robotic sacrocolpopexy series describes use of laparoscopy to perform the dissection, using the robot only to assist with passage of the suture [DiMarco *et al.* 2004].

If a hysterectomy is performed in the same setting, the uterus can be delivered through an extended abdominal or vaginal incision. If the uterus is being preserved, the mesh can be passed between the uterus and bladder. Similar to the open approach, the peritoneum is closed over the entire mesh to protect the enteric contents from the mesh.

Outcomes

There are no randomized, controlled studies comparing LSC with the open abdominal counterpart, and long-term data for outcome are still lacking. However, reported series with early to intermediate follow up after laparoscopic sacrocolpopexy currently outnumber those following RASC. Overall rates of success range from 75% to 98% with follow up mostly around 1 year. Table 1 summarizes outcomes with operative parameters. The largest series of 363 patients demonstrated 96% success with a mean operative time of only 97 minutes [Rozet *et al.* 2005].

Table 1. Outcomes from laparoscopic and robotic mesh sacrocolpopexy series.

Author (year)	Mean age (years)	Mean OT (min)	Mean LOS (days)	Mean follow up (months)	Success rate	Definition of success	Complications/notes
LAPAROSCOPIC SACROCOLPOPEXY							
Akladios <i>et al.</i> [2010] (<i>n</i> =48)	56 [36–78]	237	4 [3–15]	16	96%	No recurrent prolapse	33 supracervical hyst, 3 transobturator slings; 4.1% complication rate
Antiphon <i>et al.</i> [2004] (<i>n</i> =108)	59 [36–79]	261 ± 79	7 [2–32]	17	75%	POP ≥ grade 2	2.8% complication rate; comparison of 33 anterior only vs. 71 ant/post; concomitant SU1 surgery 74.1%
Claerhout <i>et al.</i> [2009] (<i>n</i> =132)	65 ± 10	180	5.7	13	78% (2% apical)	POP-Q ≥ –1 any point	18% posterior failure; 11% complication rate (6 mesh erosions); Q follow-up in multiple domains
Cosson <i>et al.</i> [2002] (<i>n</i> =77)	47 [28–66]	276	3.5 [2–7]	11	94%	No recurrent prolapse	Burch in 74; SCH in 60; 7.2% conversion rate; 5% complication rate
Gadonneix <i>et al.</i> [2004] (<i>n</i> =46)	59 [41–76]	171 ± 37	4.0 ± 2.1	??	83%	No recurrence ≥ grade 2	Bladder injury 7%; mesh erosion 2%; recurrent rectocele in 12%
Granese <i>et al.</i> [2009] (<i>n</i> =165)	67 [58–76]	NR	3 [2–7]	43	95%	No recurrent vaginal vault prolapse	Vyprol (absorbable) mesh used early but abandoned due to early recurrence in 3 patients
Klauschie <i>et al.</i> [2009] (<i>n</i> =43)	60	183	1.5	7	100%	No apical prolapse	Bladder injury 7%; no other difference between open and LSC; 14% of LSC underwent 2nd POP repair
Marcikiewicz <i>et al.</i> [2007] (<i>n</i> =60)	58 [30–83]	129	4 [2–21]	34 [13–60]	78% subjective 75% objective	Reoperation for prolapse	Compared vaginal sacrospinous fixation with LSC; most reoperations for cystocele or SU1.
Rivoire <i>et al.</i> [2007] (<i>n</i> =138)	60 ± 9.5	191 ± 50	5	34	88%	No recurrence > grade 2	Vaginal mesh erosion in 5%; 46% with postop SU1; 2% required emergent reoperation
Ross and Preston [2005] (<i>n</i> =43)	67 [41–83]	96 ± 42	NR	NR* (all have 5-year follow up)	93%	No recurrent prolapse	Complication 8% (mesh erosion); posterior mesh tacked to perineum
Rozet <i>et al.</i> [2005] (<i>n</i> =363)	63 [35–78]	97	4 [2–7]	15	96%	Anatomic cure	Conversion to open in 2%; mesh erosion 0.9%; <i>de novo</i> UUI in 19 patients;
Sarlos <i>et al.</i> [2008] (<i>n</i> =101)	62 [36–81]	141	4.6 [2–8]	12	92% objective 98% subjective	Stage 0 in all compartments on POP-Q	No mesh erosion; 3 rectal injuries; 2 bladder injuries; 2 converted to open
Sundaram <i>et al.</i> [2004] (<i>n</i> =10)	61 [43–83]	196	2 [1.5–3]	16	90%	Not defined	Gore-Tex patch used and not polypropylene mesh; mostly describe technique
ROBOTIC SACROCOLPOPEXY							
Akl <i>et al.</i> [2009] (<i>n</i> =80)	67 ± 8.3	198	2.6	5	97%	No recurrent prolapse	Mech erosion in 6%; conversion to open in 5%;
Daneshgari <i>et al.</i> [2007] (<i>n</i> =12)	64 [50–79]	317	2.4 [1–7]	3	100%	POP-Q scores	Mean C point +2.1 (pre) and –8.3 (post-op); 3/15 open conversion (continued)

Table 1. Continued

Author (year)	Mean age (years)	Mean OT (min)	Mean LOS (days)	Mean follow up (months)	Success rate	Definition of success	Complications/notes
Elliott <i>et al.</i> [2006] (<i>n</i> = 30)	67 [47–83]	186	1 [1–2]	24	95%	Not defined	Open conversion in 1; mesh extrusion in 2; recurrent rectocele in 1, apical prolapse in 1
Geller <i>et al.</i> [2008] (<i>n</i> = 73)	60	328 ± 55	1.3	NR	NR	POP-Q scores	Mean C point –9 for RASC vs. –8 for open;
Kramer <i>et al.</i> [2009] (<i>n</i> = 21)	66 [52–86]	194	1.1	25	95%	No apical prolapse	Apical support only; 12/21 underwent secondary repair of cystocele or rectocele.

OT, operative time; LOS, length of stay; NR, not reported; LSC, laparoscopic sacrocolpopexy; SCH, supracervical hysterectomy; SUI, stress urinary incontinence; UUI, urge urinary incontinence.

One series compared LSC with vaginal sacrospinous colpopexy, in which the authors reported a shorter operative time for the vaginal repair and a higher rate of surgery for recurrent apical prolapse in the LSC group [Marcickiewicz *et al.* 2007].

Complications

As with an open approach, there are potential complications unique to LSC, including port site bleeding or epigastric vessel injury, port site hernia, and vascular or bowel injury at the time of trocar placement. Vaginal erosion is a concern in any procedure using mesh, but particularly with sacrocolpopexy due to the large surface area of material secured to the vaginal wall. The reported incidence is between 5% and 9%, and does not appear to be significantly different from the reported incidence in open sacrocolpopexy series. The presentation can vary from a small, asymptomatic vaginal opening to infection, abscess, or fistula formation [Hart and Weiser, 2004; Cosson, 2003]. Management depends on extent of erosion, and in mild cases observation, topical hormonal application, or local debridement and closure may be sufficient. Removal of all or part of the material may be necessary if there is evidence of infection.

Complications from the sacral component of the procedure include hemorrhage from the presacral vessels, which can be particularly troublesome. Intractable bleeding can be managed by coagulation, suture ligation, or thumbtacks [Fox and Stanton, 2000]. The vascular anatomy of the sacral promontory is highly variable, and the pneumoperitoneum during LSC may conceal low-pressure venous bleeding, which could go unrecognized following release of the intra-abdominal gas. Spondylodiscitis, an infective and/or inflammatory process resulting from direct extension of mesh violating the lumbosacral disc space, is rare, but has been reported in at least one case [Wattiez *et al.* 2003].

Robotic-assisted mesh sacrocolpopexy

With the introduction of the da Vinci (Intuitive Surgical; Sunnyvale, CA) robotic surgical platform system in 1999, the only US Food and Drug Administration-approved device for surgical robotics, there was a dramatic increase in the complexity of the laparoscopic procedures that could be performed. Within a brief time period, robotic surgery has become increasingly popular for pelvic surgery, most notably for radical

Table 2. Potential advantages and disadvantages of robotic-assisted laparoscopic surgery compared with laparoscopic surgery.

ADVANTAGES	DISADVANTAGES
Three-dimensional vision system Ergonomic positioning for the surgeon Wristed instrumentation Complete control of the camera Use of a fourth 'arm' for retraction Tremor filtering	Cost Purchase and maintenance Disposable instruments Patient positioning Steep Trendelenburg Limited vaginal access with docking of robot at foot of bed

prostatectomy in urology and hysterectomy and/or myomectomy in gynecology. The potential advantages and disadvantages of using robotics for laparoscopic surgery are outlined in Table 2.

Basic setup

Robotic surgery consists of a vision cart, a robotic master console, and a patient-side robot [Visco and Advincula, 2008]. The original da Vinci system employed the use of three arms, two operative arms and one camera arm, but the addition of a fourth arm to the current system allows for retraction and improved exposure while still allowing the surgeon the freedom to control all aspects of the procedure. At the console, the surgeon is able to control the robot using hand controls and foot pedals. The operative arms can be manipulated using finger-grip handles that can move up and down, left and right, and in and out. These movements are mimicked by the robotic arms and allow the surgeon to maneuver instruments in order to cut, dissect, suture, or otherwise manipulate anatomic structures. A clutch foot pedal allows the surgeon to easily switch control from the operative arms to the camera, or the third instrument arm. The camera can be maneuvered in a similar fashion, as can the focus. A separate foot pedal controls instruments connected to a monopolar or bipolar electrical source for tissue cauterization.

The camera uses a unique binocular vision to provide a three-dimensional image on the master console, while also being transmitted to multiple accessory two-dimensional monitors. Although the surgeon at the master console has autonomous control over the robot, a bedside assistant is required to exchange instruments, provide suction, or additional retraction.

Patient positioning

Deployment of the da Vinci robot during surgery mandates unique modifications to

patient positioning. While both robotic and open mesh sacrocolpopexy use a low lithotomy position to allow access to the lower abdomen and vagina simultaneously, the patient must be placed in steep ($>45^\circ$) Trendelenburg during RASC to allow for adequate access for the robotic arms to the pelvis without external interference (Figure 1(b)). Such steep positioning requires complete stabilization of the upper body to prevent the patient from sliding upward on the table and away from the robot. This is accomplished through a combination of techniques including foam padding, beanbags, and wide tape (Figure 1(a)).

The da Vinci robot is most often positioned at the foot of the bed between the patient legs, aligning the center arm of the robot with the patient midline. An alternative approach is 'side-docking', in which the robot is positioned outside the leg and the arms are brought in at an oblique angle (Figure 2(a)), the primary advantage being easier access to the vagina for manipulation by the bedside assistant (Figure 2(b)).

Port placement

As of now, there is no standardized port placement template for RASC, however many published series that describe port placement use a 'pyramid' or 'triangle' configuration, similar to what is currently in use for robotic radical prostatectomy. The 12-mm camera port is placed at or near the umbilicus, with at least two robotic arms and one assistant port. Initial port placement can be done percutaneously using a Veress needle, or via the open (Hasson) approach. The peritoneal cavity is then insufflated with carbon dioxide.

To avoid the robotic arms from colliding with each other during maneuvering, the ports should be placed approximately 9 cm apart; this often translates to one handbreadth distance [Elliott *et al.* 2006]. We do not place any further

Figure 1. Patient positioning for robotic docking. Once secured on the bed with beanbag, egg crate foam and wide tape (a), the patient goes from a flat angle (b) to 'steep' Trendelenburg (c).

ports until after full insufflation, as the between-port distance can be altered by abdominal distension (Figure 3). The 8-mm robotic ports can alternatively be placed at the lateral edge of the rectus muscle to avoid injury to the epigastric vessels [DiMarco *et al.* 2004]. In later series using a four-arm da Vinci robot, the fourth arm is placed as far lateral as possible, usually just above the left anterior superior iliac spine. Location of the assistant ports varies between published series, but includes at least one 10- or 12-mm port, and occasionally an additional 5-mm port, for a total of 5–6 ports. All ports are placed under direct vision. Differences between techniques for RASC are summarized in Table 3.

Surgical technique

Once all ports are placed, standard laparoscopy is used initially to lyse any adhesions, as well as to

confirm access to the sacral promontory by palpation. Alternatively, a bedside assistant can facilitate identification of the bony promontory once the robot is docked. Small intestine in the pelvis overlying the vaginal apex or uterus can be brought into the abdominal cavity with a bowel grasper once the patient is in steep Trendelenburg. This usually leaves only the sigmoid colon to be mobilized and retracted, which can be accomplished using the fourth arm of the da Vinci. Care must be taken to avoid 'clamping' the colon with the robotic arm as this can result in a serosal tear or full perforation. The use of a percutaneous suture, passed through the colonic serosa and clamped at the skin for retraction, has been reported [Akl *et al.* 2009; Daneshgari *et al.* 2007; DiMarco *et al.* 2004].

A 0° or 30° lens can be used exclusively or interchangeably, depending on surgeon preference [Daneshgari *et al.* 2007]. Patient anatomy will often dictate use of a 30° lens, particularly in the 'upward' configuration to allow visualization of the posterior vaginal compartment dissection and suturing.

Sacral promontory dissection. The promontory can be identified visually by following the pelvic brim to the base of the sigmoid mesentery medially and the pulsatile iliac artery laterally. The right ureter is a helpful landmark and is usually easily identified through the peritoneum with its characteristic peristalsis. The peritoneum is lifted off the bony promontory with a robotic grasper opposite an assistant grasper and opened via monopolar cautery. The dissection continues until the anterior longitudinal ligament is visualized (Figure 4(b)). Prominent vessels should be controlled with bipolar cautery, and one should take care to avoid the middle sacral artery if possible. Once the ligament is exposed, the peritoneum is incised caudally and medially to the vaginal apex, and blunt dissection is used to create a 'gutter' where the mesh is ultimately placed as an interposition between the vagina and sacral promontory.

Vaginal dissection. This portion of the procedure is executed in a very similar fashion to an open procedure. The presence of a pneumoperitoneum helps minimize venous bleeding from the pelvic structures. In posthysterectomy cases, the peritoneum is thinnest at the site of the cuff closure, and we avoid dissecting here first to minimize risk of an inadvertent vaginotomy.

Table 3. Variation in surgical technique between robotic-assisted sacrocolpopexy series.

Author (year)	Ports	Vaginal Manipulator	Graft	Suture	Additional
Akl <i>et al.</i> [2009]	12-mm camera 8-mm robotic (2) 10-mm accessory 5-mm accessory*	EEA sizer	Y-shaped polypropylene mesh	2-0 prolene (graft) 2-0 polyglactin (peritoneum)	Holding suture through sigmoid colon retracted at skin
Daneshgari <i>et al.</i> [2007]	12-mm camera 8-mm robotic (2) 12-mm accessory 5-mm accessory (1–2)	Vaginal sizer (sponge forceps)	Y-shaped polypropylene mesh	0 Ethibond (graft) 2-0 polyglactin (peritoneum)	Sigmoid colon retraction suture; Moschowitz culdoplasty in select cases
Elliott <i>et al.</i> [2006]	12-mm camera (Visiport) 8-mm robotic (2) 10-mm accessory 5-mm accessory	Right-angle EEA sizer	Y-shaped polypropylene mesh (IntePro)	1-0 PTFE (graft)	Halban culdoplasty with uterosacral plication in all cases; sigmoid colon retraction suture
Geller <i>et al.</i> [2008]	12-mm camera 8-mm robotic (3) 10-mm accessory	EEA sizer	Y-shaped polypropylene mesh (IntePro)	2-0 PTFE (graft)	3–4 sutures at anterior longitudinal ligament
Kramer <i>et al.</i> [2009]	12-mm camera 8-mm robotic (3) 12-mm accessory	Vaginal sizer	Y-shaped polypropylene mesh (IntePro)	2-0 polyglactin (graft-vagina) 2-0 Novafil (graft-sacrum) 3-0 polyglactin (peritoneum)	7–9 sutures between graft and vagina on each side (anterior/posterior)

PTFE, polytetrafluoroethylene (Gore-Tex); EEA, end-to-end anastomosis; mm, millimeter.
*Optional.

Figure 2. Side docking of the da Vinci robot, with illustration of robot positioning (a) and advantage of having assistant at foot of bed to manipulate the vagina (b). (Courtesy of Intuitive Surgical).

Figure 3. (a) Cephalad view of port placement for robotic-assisted sacrocolpopexy with skin markings and port sites lateral to each other (dotted line). (b) Optional placement of the robotic port lateral and caudal to the camera port, approximately 9 cm apart. (c) Ports in place after insufflation in image (a).

Almost equally important as the dissection by the robotic instruments is manipulation of the vagina by the bedside assistant, using a sponge stick [Daneshgari *et al.* 2007] or stainless steel end-to-end anastomosis (EEA) sizer. Elliott and colleagues described the use of a specialized sizer with a long handle at a right angle to allow easier maneuverability by the assistant with the robot docked at the foot of the bed [Elliott *et al.* 2006]. Identification of the plane between the bladder and vagina should be bloodless and one should be suspicious for dissecting into the

bladder wall if bleeding is encountered [DiMarco *et al.* 2004]. Gentle insufflation of the bladder may assist in finding this plane, which is continued down to above the trigone. The posterior plane is dissected using blunt and sharp dissection. The steep Trendelenburg position may make carrying this dissection as far distal as possible a challenge, but additional manipulation of the posterior vaginal wall with the EEA sizer, rectum, or both, can facilitate this step (Figure 4(a)). Graft sutures can be placed at this point, using absorbable (polyglycolic acid) [Kramer *et al.* 2009; Daneshgari *et al.* 2007] or nonabsorbable sutures (polypropylene or polytetrafluoroethylene [PTFE]) [Akl *et al.* 2009; Geller *et al.* 2008; DiMarco *et al.* 2004] (Figure 4(c) and (d)). Suturing of the distal posterior sutures first has been recommended to facilitate the procedure [Elliott *et al.* 2006].

Mesh placement. Wide-pore ($>75\ \mu\text{m}$) polypropylene mesh is most commonly used as the graft interposition. The mesh can be cut *ex vivo* to size from a larger piece of mesh, but many series describe use of a pre-packaged Y-shaped mesh (IntePro; American Medical Systems, Minnetonka, MN, USA), that is ready for deployment. It is not uncommon to have redundant mesh, particularly at the anterior limb (Figure 5). The mesh is secured to the outer vagina with full-thickness bites; we use PTFE (Gore-Tex) sutures, as we find this material is easier to tie and less likely to break than polypropylene suture. A recent study testing the *ex vivo* knot strength showed that polyglactin 910 suture was less likely to untie after a set force than polypropylene, although PTFE was not tested [Muffy *et al.* 2009]. Once in place on the vagina, the cephalad limb of the mesh is sutured at the promontory using 2–4 sutures, with the vaginal apex pushed in as far as possible to avoid any tension on the mesh. Redundant mesh at the promontory is also removed. The peritoneum is then closed over the mesh with running absorbable suture to minimize bowel adhesions in the pelvis (Figure 6).

Concomitant procedures

In many women with advanced POP, the mesh sacrocolpopexy does not provide any support to the bladder neck or urethra, and concerns for unmasking ‘occult’ stress urinary incontinence (SUI) will often mandate performing an additional anti-incontinence procedure. The CARE

Figure 4. (a), Identification of vaginal apex with end-to-end anastomosis sizer in place. Maryland bipolar forceps are in the left arm, monopolar scissors are in the right arm. (b), Identification of the anterior longitudinal ligament (ALL, arrow) with palpation by bedside assistant (suction tip). (c), and (d), Views of posterior vaginal apex after dissection of rectovaginal space with placement of 2-0 PTFE suture.

trial was a multicenter, randomized, controlled trial comparing open mesh sacrocolpopexy combined with Burch colposuspension with mesh sacrocolpopexy alone and the findings demonstrated that those who did not undergo a Burch procedure had nearly double the rate of postoperative secondary SUI [Brubaker *et al.* 2006]. No such data for robotic sacrocolpopexy exists at this time, but most pelvic floor reconstructive surgeons will apply the CARE trial findings to their robotic surgical practice. Although a Burch colposuspension can be performed robotically, placement of a polypropylene mid-urethral sling (either via a retropubic or transobturator route) in lieu of a Burch colposuspension has been described [Daneshgari *et al.* 2007].

In women who have an intact uterus, a sacrohysteropexy can be performed in those women who are either still of childbearing age or wish to keep their uterus. A complete or supracervical hysterectomy can be performed, with the primary

reason for leaving the cervix being to provide an additional 'anchor' for the mesh and minimizing any risk of vaginal mesh extrusion. Women who undergo this procedure should have no history of abnormal Papanicolaou smears and be counseled on the continued need for routine cervical cancer surveillance in the future.

Outcomes

At the time of writing, no level 1 evidence exists comparing RASC with open sacrocolpopexy or vaginal repair, and the current literature is limited to a few cohort series with short-term outcome data. Outcome measures are summarized in Table 1 in comparison with LSC series. In the largest retrospective review, Akl and colleagues described a technique and learning curve for RASC, performed for stage III–IV prolapse in 80 patients, of whom 76 patients completed RASC [Akl *et al.* 2009]. Of note was that mean operative time decreased from 198 minutes in the

Figure 5. Laparoscopic view of Y-shaped polypropylene mesh (IntePro) after initial sutures placed in the posterior vaginal wall (a), and at placement on the anterior vaginal wall (b).

Figure 6. Laparoscopic view of peritoneal closure with absorbable suture (a), and at completion of closure (b).

first 30 cases to 167 minutes for the last 30 cases in the series.

Elliott and colleagues evaluated 30 patients with posthysterectomy grade 4 Baden–Walker vaginal vault prolapse, specifically focusing on 21 patients with minimum 12-month follow up [Elliott *et al.* 2006]. The success rate was 95% (19/20) based on physical exam with a mean follow up of 24 months. The single failure was in a patient whose sutures pulled through the vagina with the mesh was still adherent to sacrum. Patient satisfaction, based on asking whether they would recommend the procedure to a friend, was also 95%. In this series, the da Vinci robot was only utilized to facilitate suturing whereas all of the dissection was otherwise performed with conventional laparoscopy.

One study comparing RASC with open MSC reviewed a cohort of 73 RASC and 105 open counterparts [Geller *et al.* 2008]. Interestingly, preoperative prolapse stage based on POP-Q exam was more advanced in the RASC cohort. Comparing RASC with open MSC, estimated blood loss (EBL) and length of hospital stay were significantly less, but operative time was significantly longer for RASC. The overall complication rate was comparable between the two groups: 17.8% in the RASC arm *versus* 11.4% in the open arm. The primary outcome was vaginal vault support at 6 weeks as determined by POP-Q, with significant improvement in all preoperative POP-Q points for the RASC cohort. The C point was slightly better in the RASC arm compared with open surgery (−9 *versus* −8).

Complications

In addition to the potential complications already described for open and laparoscopic approaches, the use of the da Vinci robot is associated with its own set of unique potential complications. As noted in Figure 1, the need for 'steep' Trendelenburg to safely dock the robot can lead to difficult ventilation of the morbidly obese patient or those with underlying pulmonary disease. Furthermore, it has not been determined whether such positioning could affect prolapse repair and tensioning of the mesh. Technical failure of the robot has been reported, and in such an instance, one must convert either to straight laparoscopy or open surgery.

Disadvantages

One argument against the use of robotics in surgery is the cost, which is assumed up front for most medical centers and includes purchase of the surgical system, as well as the annual maintenance costs, and cost of robotic instruments, which can only be used for a finite number of cases before disposal. A recent study comparing robotic prostatectomy with laparoscopic and open surgery estimates an additional cost burden of US\$2698 per patient based on an average of 126 cases per year [Bolenz *et al.* 2010].

Conclusion

The advances in robotic-assisted laparoscopic surgery have made this approach to mesh sacrocolpopexy not only feasible, but also quite popular. The scant data currently available on RASC suggests similar outcome and complication rates to LSC and open MSC, but as with LSC, the primary advantages at this time are decreased blood loss, length of hospital stay, and convalescence. RASC is still in its infancy, as there are only 21 references on PubMed for 'robotic sacrocolpopexy'. While it is certainly possible that, with longer follow up and more studies comparing open to RASC, a minimally invasive approach could supplant the open sacrocolpopexy as the 'gold standard', the introduction of robotics at the very least facilitates a minimally invasive approach for the surgeon experienced in performing open sacrocolpopexy but with limited laparoscopic experience. The popularity of robotic surgery is reflected in the fact there was a State of the Art lecture at the American Urologic Association (AUA) Meeting in 2010. What remains to be determined is whether RASC can produce similar long-term durable outcomes compared with the gold standard open

sacrocolpopexy, while showing that it can be cost effective at centers with higher surgical volume.

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Conflict of interest statement

None declared.

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