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Review

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# Exploring the role of robotics in genital gender-affirming surgery: a review of techniques, innovations and outcomes

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## Abstract

Robotic surgery has expanded significantly across all surgical specialties due to the benefits of high-definition 3D visualization and 360-degree articulation of instruments. In the field of gender affirmation surgery (GAS), robotic surgery has numerous applications in both primary and revision surgery. We sought to review the current literature to discuss emerging robotic techniques for genital GAS in both the transmasculine and transfeminine population to determine feasibility, complication rates, and outcomes.

**Keywords:** Robotic surgery, gender affirmation surgery, transgender

## INTRODUCTION

Since its first applications in the fields of orthopedics and neurosurgery in the 1980s, the use of robotic surgical systems has gained popularity worldwide[1]. Robotic technology has evolved from basic single-arm systems to more sophisticated platforms featuring multiple jointed arms capable of 360-degree movement, all operated remotely via a surgical console from a single patient cart. Advanced surgical robots have numerous benefits, including high-definition 3D visualization, wristed articulation with markedly increased range of instrument motion compared to straight-stick laparoscopy and the ability to eliminate hand tremors. These features collectively enhance surgical precision, dexterity, and the ability to maneuver within deep, narrow spaces with less tissue trauma. Furthermore, surgeon control of a fourth arm improves efficiency by facilitating instantaneous instrument change without the need for manual exchange through ports.

As a result, robotic surgery is widely used across many surgical specialties, contributing to reduced operative time, postoperative pain, length of postoperative stay, and complications, as well as quicker recovery[2].

In the field of gender affirmation surgery (GAS), robotic surgery has numerous applications in both primary and revision surgery. While various robotic surgical systems exist, most published data on robotic-assisted surgery in GAS involve the use of the da Vinci Si, Xi, or single port (SP) Surgical Systems (Intuitive Surgical, Sunnyvale, CA). The standard Da Vinci Xi system has four robotic arms, which are used to access the peritoneal cavity through 4-5 separate ports, depending on patient positioning and instrument requirements. The more recent Da Vinci SP system enables the control of three multi-jointed surgical instruments and an articulating endoscope through a SP. Typically, two access ports are required with this system: one for the robotic trocar and another for a laparoscopic assistant port[3].

Here we will appraise the different robotic techniques applied to GAS and their published outcomes to date.

## ROBOTICS IN LOWER FEMINIZING SURGERY

### Robotic gender-affirming vaginoplasty

Penile inversion vaginoplasty (PIV) remains widely regarded as the gold-standard technique for full-depth vaginoplasty. However, it is not suitable for all patients - particularly those who have previously undergone circumcision, those with a micropenis, or those with peno-scrotal hypoplasia. In such patients, as well as those with neovaginal stenosis following ‘standard’ vaginoplasty techniques, robotic technology can become a valuable tool in the surgeon’s armamentarium.

*Primary robotic-assisted gender-affirming peritoneal vaginoplasty*

The most frequently reported robotic-assisted technique for gender-affirming vaginoplasty is the peritoneal flap vaginoplasty. This procedure has been adapted from Davydov’s original technique described in 1969, which was employed in cis female patients for dyspareunia[4,5]. Our literature search revealed nine studies reporting outcomes of primary robotic-assisted gender-affirming peritoneal vaginoplasty (pRA-GPV) [Table 1].

In 2019, Jacoby *et al.*[5] reported outcomes of pRA-GPV in 41 transfeminine patients. Their widely published technique involves simultaneous perineal and robotic approaches[3,5,6]. The perineal surgeon performs the perineal dissection, bilateral orchidectomy, and penectomy alongside neoclitoris, labia minora, and labia majora formation. Concurrently, the robotic pelvic surgeon raises 12 cm × 12 cm anterior and posterior peritoneal flaps from the posterior aspect of the bladder and the anterior border of the rectum, respectively. The ureters mark the lateral borders of the flaps. Externally, the scrotal skin graft is tubularized around a 38 mm dilator and inset with the inverted penile skin tube. This penoscrotal skin tube is then passed through the neovaginal canal to the robotic surgeon, who insets it with the peritoneal flaps using a barbed 3-0 absorbable suture. The anterior and posterior peritoneal flaps are sewn together at the apex of the neovagina and the flap donor sites are closed. In their study, the average operative time was 262 min and the average inpatient stay was 5 days. At the most recent follow-up (average 114 ± 79 days), neovaginal depth and width

**Table 1. Studies of gender-affirming robotic-assisted vaginoplasty**

| Author, year | Technique | Study design | No. of patients | Average follow-up (months) | Average operative time (mins) | Neovaginal dimensions (cm) | Complications (*n*, %) |
|---|---|---|---|---|---|---|---|
| Jacoby *et al.* 2019[5] | Primary (peritoneal flap + penile inversion with scrotal skin graft) | Case series | 41 | 3.7 ± 2.5 SD | 262 ± 35 | Depth: 14.2 ± 0.7 SD, Width: 3.6 ± 0.2 SD | Wound complications: granulation tissue and delayed wound healing in (20%) |
| Dy *et al.* 2021[12] | Primary (peritoneal flap + penile inversion with ± scrotal skin graft) | Case series | 100 (47 multi-port, 53 single-port) | 11.9 (range 6.0-25.4) | Multi-port: 254<br>Single port: 220 | Multi-port: Depth: 13.6 (range 9.7-14.5), Width: 3.7 (range 2.9-3.8)<br>Single port: Depth: 14.1 (range 9.7-14.5), Width: 3.7 (range 3.5-3.8) | Blood transfusion: 6 (6%), rectovaginal fistula: 1 (1%) Bowel obstruction: 2 (2%), pelvic abscess: 1 (1%) vaginal stenosis: 7 (7%), reoperation 13: (13%) |
| Robinson *et al.* 2022[7] | Primary (peritoneal flap + penile inversion with ± scrotal skin graft) | Retrospective chart review | 274 | 11.9 (range 0.6-37.9) | 180 (range 132-251) | - | Intra-abdominal complications: 6 (2.2%) - hematoma evacuation: 1 (0.4%), abscess drainage: 2 (0.7%), bowel obstruction: 1 (0.4%), incarcerated internal hernia: 2 (0.7%) |
| Morelli *et al.* 2022[9] | Primary (single peritoneal flap + penile inversion with scrotal skin graft | Case series | 8 | - | 360 ± 90 | - | None |
| Blasdel *et al.* 2023[13] | Primary (peritoneal flap + penile inversion with ± scrotal skin graft) | Retrospective case-control analysis (comparison of patients with peno-scrotal hypoplasia *vs.* controls without) | 92 (43 with peno-scrotal hypoplasia, 49 controls without) | 12 (IQR 6-5.6) | 206 (IQR 165-251), Hypoplasia group 204 (IQR 166-237) Control 212 (IQR 165-253) | Depth 14.5 (IQR 13.3 to 14.5), diameter 3.8 (IQR 3.8 to 3.8) - no significant difference between peno-scrotal hypoplasia *vs.* without | Bowel obstruction (secondary to intestinal herniation through peritoneal flap): 1 (1.1%), rectovaginal fistula: 1 (1.1%), neovaginal stenosis: 10 (11%) |
| Blasdel *et al.* 2025[8] | Primary (peritoneal flap + penile inversion with scrotal skin graft) | Retrospective cohort study | 500 | 14.8 (IQR 11.9-28) | - | Depth 14.5 (IQR 13.3 to 14.5), diameter 3.8 (IQR 3.8 to 3.8) | Rectal injury: 1 (0.2%), rectovaginal fistula: 1 (0.2%), blood transfusion: 18 (3.6%), reoperation for hemostasis: 5 (1%), abscess drainage: 4 (0.8%), peritoneal flap defect: 2 (0.4%), meatal stricture: 2 (0.4%), prostatic stricture with urethra-vaginal fistula: 1 (0.2%), bowel obstruction: 1 (0.2%), vaginal depth revision: 3 (0.6%), UTI: 39 (7.8%), LUTS: 25 (5%), UUI: 31 (6.2%) |
| Del Corral *et al.* 2024[19] | Primary (robotic-assisted jejunal free flap + penile inversion with scrotal skin graft) | Case series | 6 | 8 (range 1-14) | 263 (range 236-296) | Depth: 17.8 Width: 3.3 | Reoperation for: flap vascularity confirmation: 1 (16.7%), evacuation of groin hematoma: 1 (16.7%), repair of ventral hernia: 1 (16.7%), repair of dehiscence between jejunal flap and neovaginal introitus: 1 (16.7%), benign polyp removal: 1 (16.7%) |
| Acar *et al.* 2020[11] | Mixed (Primary - peritoneal flap + penile inversion with ± scrotal skin graft; | Case series | 11 | 2.6 ± 2.8 SD | 267.2 ± 85.9 | Depth: 13.9 ± 0.5 SD | Delayed wound healing: 2 (18%), VTE: 1 (9%), blood transfusion: 1 (9%), reoperation for urethra-neovaginal fistula: 1 (9%), 30-day re-admission: 2 (18%) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | revision - peritoneal flap) | | | | | | |
| Huang *et al.* 2022[16] | Mixed (Primary or revision peritoneal flap NOS) | Retrospective chart review | 19 | 6.5 ± 4.0 SD | 408.6 ± 111.9 | Depth: 13.1 ± 3.0 SD (intra-op), 11.0 cm ± 4.0 SD (at last follow-up) | Wound dehiscence: 7 (36.8%), urethral injury: 3 (15.8%), bladder injury: 2 (10.5%) neovaginal stenosis: 4 (21.1%), urethral fistula: 2 (8.7%), recto-neovaginal fistula: 1 (4.3%), perianal fistula: 1 (4.3%), clitoral prolapse: 1 (4.3%) |
| Johnston *et al.* 2025[10] | Mixed (Primary or revision tubularized single peritoneal flap ± penile inversion) | Retrospective cohort study | 33 | 16 (range 4.4-26.9) | 406 (IQR 154-220) | Depth: 17 (intra-op), 11 (at last follow-up) | Neovaginal stenosis: 12 (36%), Fever/UTI: 4 (12%), vaginitis: 2 (6%), blood transfusion: 2 (6%), VTE: 1 (3%), urinary retention: 3 (9%), labial hematoma: 1 (3%), flap dehiscence: 1 (3%) |
| Dy *et al.* 2021[17] | Revision (peritoneal flap) | Case series | 24 | 13.2 (range 5.7-22.2) | 279.5 (range 183-443) | Depth: 13.6 (range 10.9-14.5), Width: 3.6 (range 2.9-3.8) | Bleeding requiring reoperation for hemostasis: 1 (4.2%), curettage of granulation tissue: 2 (8.3%), de novo SUI 1 (4.2%) |
| Smith *et al.* 2022[18] | Revision (single-pedicled urachus peritoneal hinge flap) | Retrospective chart review | 10 | 18.3 ± 14 SD (range 1.2-39.4) | - | 15.1 (SD 2.2) immediately post-op, 12.5 (SD 2.1) at median follow-up | Anastomotic stricture: 1 (10%), temporary LUTS: 3 (30%) |

SD: Standard deviation; IQR: interquartile range; NOS: not otherwise specified; UTI: urinary tract infection; LUTS: lower urinary tract symptoms; UUI: urgency urinary incontinence; VTE: venous thromboembolism; SUI: stress urinary incontinence.

were 14.2 and 3.6 cm, respectively. All patients reported erogenous sensation postoperatively. There were no complications related to peritoneal flap harvest; the only reported issues were minor wound problems [Table 1]. Subsequently, they reported six complications among 274 transfeminine patients undergoing pRA-GPV[7] [Table 1].

More recently, this group reported their further experience in a large retrospective cohort study of 500 consecutive cases of pRA-GPV[8]. Median patient-reported neovaginal dimensions at 1 year postoperatively were 14.5 cm (depth) and 3.8 cm (width). Intraoperative complications included 1 case of rectal injury (0.2%), which was repaired intraoperatively without subsequent recto-neovaginal fistula. Major complications (Clavien-Dindo grade ≥ 3a) occurred in 20 patients (4%) [Table 1]. Surgical revisions were performed in 61 patients (12%), including labiaplasty, clitoroplasty, and urethroplasty. Only 3 patients (0.6%) required revision to increase neovaginal depth, which was performed via a robotic intra-peritoneal approach whereby an additional peritoneal flap was raised and anastomosed to the deep edge of the segment from the primary surgery. An acellular dermal matrix was used to bridge the gap from the introitus to the superficial edge of the peritoneal flap.

Morelli *et al*. adapted this group's approach to utilize a single vascularized peritoneal flap in a small cohort of 8 patients[9]. The peritoneal flap was raised from the posterior bladder and anterior abdominal wall, resulting in a larger, wide-based flap to improve vascular integrity compared to a typically thinner pre-rectal peritoneal flap. They reported no intraoperative or postoperative complications.

In 2025, Johnston *et al*. reported outcomes of robotic-assisted tubularized peritoneal vaginoplasty in a mixed cohort of 33 patients undergoing primary or revision surgery[10]. By tubularizing a single anterior peritoneal flap instead of two flaps, the authors theorized that this may reduce the risk of internal herniation along suture lines. Furthermore, they postulated that by leaving the peritoneum overlying the rectum intact, the risk of rectal injury and recto-neovaginal fistula may be reduced. The anterior peritoneal flap was raised off the bladder wall, tubularized and anastomosed either directly to the introital skin (original technique) or to inverted penile skin (newer technique). Neovaginal stenosis occurred in one-third of patients and was thought to be related to difficulty dilating in patients who had had the original anastomotic technique, with stenosis occurring in only 1 out of 10 undergoing the newer technique. Revision vaginoplasty was performed for stenosis in 3 cases, with buccal vaginoplasty offered for introital stenosis and sigmoid vaginoplasty for canal stenosis. Acute postoperative complications occurred in one-third of patients, which were all Clavien-Dindo grade ≤ 2 [Table 1].

Single-port robotic systems have become increasingly popular in recent years. In 2020, a small study by Acar *et al.* used the Xi system in 2 patients and the SP system in 9 patients[11]. The study included a mixed population, including primary lower feminizing surgery (LFS), revision for neovaginal stenosis after prior LFS, and vaginal hypoplasia secondary to disorders of sexual development in cisgender women. The mean procedure length was 267 min and the initial postoperative mean neovaginal depth was 13.9 ± 0.5 cm. Major complications included 1 case of urethral injury in a patient with extensive scar tissue and distorted anatomy from prior PIV, which was repaired intraoperatively, but resulted in a subsequent urethra-neovaginal fistula managed with a robotic intestinal vaginoplasty.

In 2021, Dy *et al*. compared the da Vinci Xi and SP systems in 145 transgender patients undergoing pRA-GPV[12]. Average procedure times were longer using the Xi versus the SP system at 252 min *vs*. 222 min, respectively ($P < 0.001$). At mean follow-up of 11.9 months, the average neovaginal depth was greater with the SP system at 14.1 cm (range 9.7-14.5) *vs*. the Xi system at 13.6 cm (range 9.7-14.5 cm) ($P = 0.07$). However, the average neovaginal width was comparable [Table 1]. There were no reported differences in complication rates between the two approaches.

A major advantage of pRA-GPV is that it offers an alternative tissue to line the neovaginal canal in patients with insufficient penoscrotal skin for PIV. In 2023, Blasdel *et al.* published a retrospective case-control analysis comparing 43 patients with genital hypoplasia undergoing pRA-GPV *vs*. 49 controls without[13]. At a median follow-up of 12 months, there was no difference in neovaginal dimensions between the two groups (median depth 14.5 cm, diameter 3.8 cm), with 89% of all patients obtaining a neovaginal depth ≥ 12.1 cm. Neovaginal stenosis was reported in 10 patients (11%), but no revisions were required. There was no statistically significant rate of external revision between the two groups (7% in the hypoplasia group *vs*. 14% in the control group).

Comparison of pRA-GPV with PIV and other vaginoplasty techniques is limited by a lack of randomized control trials and the fact that most published studies have small sample sizes. Larger studies in our review of pRA-GPV with over 100 patients report a neovaginal stenosis rate of up to 7% and a recto-neovaginal fistula rate of up to 1.1%[8,12]. These rates are comparable with that of primary PIV published in a systematic review by Dunford *et al*., which found rates of 7.2% and 1.5%, respectively[14]. In this review, the average neovaginal depth with pRA-GPV was 13.1-15.7 cm, which is greater than in PIV and comparable to intestinal vaginoplasty in a meta-analysis of vaginoplasty outcomes by Bustos *et al.*[15]. In 2022, Huang *et al*. reported a small retrospective case review of 19 patients undergoing pRA-GPV, including 14 primary and 5 revision cases with neovaginal stenosis post-PIV[16]. Outcomes were compared with 28 patients who underwent primary PIV at their institution. Average intraoperative neovaginal depth with pRA-GPV was comparable to PIV, at 13.1 ± 3.0 cm *vs*. 12.7 ± 1.5 cm, respectively.

*Revision robotic-assisted gender-affirming peritoneal vaginoplasty*

A robotic-assisted approach may be applied to revision vaginoplasty for neovaginal stenosis, prolapse, or canal malposition. Traditional perineal approaches in revision vaginoplasty can be technically difficult due to limited visibility from the perineum into the pelvis ('a deep dark hole'), with extensive scar tissue and the adherence of the stenosed neovagina to the bladder and rectum. The robotic approach offers better access to the narrow, deep pelvis and phenomenal visibility. An additional advantage is access to a concealed donor site, the peritoneum, for lining the revised neovaginal canal[17]. Neovaginal canal revisions can be successfully performed using peritoneal flaps, harvested in a similar fashion to the primary vaginoplasty technique and sutured to the remnant existing canal once the stenosis has been incised and released[17]. Our literature search revealed two studies reporting outcomes of revision robotic-assisted gender-affirming peritoneal vaginoplasty (rRA-GPV).

In addition to their large case series on primary RA-GPV, Dy *et al*. have reported on salvage neovaginal reconstruction with robotic peritoneal flap vaginoplasty in 24 patients. In most cases, the indication was neovaginal stenosis or a short neovagina[17]. While the technique is similar to that described for primary cases, the canal dissection between the bladder and rectum is toward the stenosed neovaginal cavity, which is subsequently incised and widened. The proximal peritoneal flap edges are approximated to form the neovaginal apex. The average procedure length was 300 min. The average neovaginal depth and width were 13.6 cm and 3.6 cm, respectively, at a median follow-up of 13.2 months. Despite the more scarred plane between the bladder and rectum, no patients experienced rectal injury. Complications included 1 case of postoperative canal bleeding requiring surgical re-intervention and 1 case of hypocontractile bladder secondary to inferior hypogastric plexus injury.

Smith *et al*. have described an alternate robotic technique for management of neovaginal stenosis post-PIV in 10 patients using a single-pedicled urachus-peritoneal hinge flap[18]. The mean preoperative neovaginal depth was 9.2 cm (SD 1.5 cm), which was increased to 15.1 cm (SD 2.2 cm) immediately post-revision surgery, with a subsequent reduction to 12.5 cm (SD 2.1 cm) at mean follow-up (13.1 months). Anastomotic narrowing occurred in 1 patient at 6 weeks postoperatively, managed with dilation under anesthesia. Satisfactory neovaginal receptive intercourse with male partners was reported by 5 patients (50%). Orgasmic function was maintained in the 8 patients able to achieve orgasm after primary PIV, with orgasm quality improved in 75% of patients following rRA-GPV. While the majority of patients (70%) reported being bothered by the appearance of their abdominal port scars, 80% reported that if given the opportunity to go back in time, they would still choose to undergo rRA-GPV for neovaginal stenosis.

*Robotic intestinal segment vaginoplasty*

Intestinal segment vaginoplasty can provide a self-lubricating neovagina secondary to intestinal mucus production. It is less commonly performed than PIV due to associated complications of using bowel segments, such as anastomotic leak, diversion colitis and mucus hyperproduction. While this is mostly performed via a laparoscopic approach, some surgeons are now exploring robotic-assisted approaches. Our literature search revealed two papers reporting a robotic-assisted intestinal segment vaginoplasty.

In 2024, Del Corral *et al*. described their technique and outcomes using a robotic-assisted jejunal free flap harvest in combination with PIV in 6 transfeminine patients[19]. Jejunum was selected over other bowel segments due to reduced mucus secretion and lower risk of functional bowel problems arising from short-segment harvest. The first part of the procedure involved performing a standard PIV augmented with a scrotal graft. Peritoneal flaps were then elevated from the posterior bladder wall via a robotic trans-abdominal approach and reflected down into the neovaginal canal. A 15-20 cm segment of jejunum was harvested as a free flap along with its vascular supply from mesenteric branches of the superior mesenteric artery. The great saphenous vein was harvested to create an arteriovenous loop between the flap vessels and the recipient femoral artery in an end-to-side fashion and a branch of the femoral vein. The jejunal free flap was then passed intra-abdominally through the groin incision and then transperitoneally into the neovaginal canal, where it was inset to the proximal peritoneal flaps and the inverted penoscrotal skin of the neovaginal introitus. The mean operating duration was 263 min (range 236-296 min). At mean follow-up of 8 months (range 1-14 months), mean neovaginal dimensions were 1.78 cm depth and 3.3 cm diameter. Major complications (Clavien-Dindo ≥ 3) occurred in 4 of the 6 patients [Table 1].

Robotic intestinal segment vaginoplasty may be utilized in the management of recto-neovaginal fistula post-gender-affirming vaginoplasty. Fouche *et al*. published a video vignette demonstrating their technique for robotic sigmoid colon vaginoplasty in a case of recto-neovaginal fistula after previous PIV[20]. A left colostomy had previously been performed as an initial step along with a rectal advancement flap via trans-anal approach. During the robotic sigmoid colon vaginoplasty, meticulous dissection between the anterior surface of the rectum and the neovaginal canal was performed until the fistula site was identified. A metal dilator was then introduced via the neovagina to widen its orifice to accommodate the sigmoid segment. The old colostomy site was resected, bowel continuity restored, and sigmoid vaginoplasty performed. Successful treatment of the fistula was confirmed on MRI and digital examination at 2 months postoperatively.

## ROBOTICS IN LOWER MASCULINISING SURGERY

### Robotic gender-affirming vaginectomy

Transmasculine patients may wish to undergo removal of the vagina for several reasons, including gender dysphoria related to the vagina, vaginal secretions, or the need for screening for gynaecological malignancy[21,22]. Vaginectomy in this population comes with its own specific challenges. Gender-affirming hormone therapy with testosterone can result in a narrow, atrophied vagina with friable mucosa prone to bleeding[23]. This may be compounded by the majority of this population being nulliparous and not engaging in receptive vaginal intercourse[24]. The resulting narrow vagina impacts surgical access, exposure, and visualization, making a purely perineal approach particularly challenging. This may increase the risk of injury to surrounding structures, including the bladder, ureters, and rectum, along with potential for incomplete removal of the vaginal epithelium[23].

While terminology regarding vaginectomy varies across the literature, there are two broad techniques: total vaginectomy and ablative colpocleisis[12]. Total vaginectomy (also referred to as colpectomy) involves full-thickness resection of the vagina whereas colpocleisis involves destruction of the vaginal epithelium with high power electro-ablation. In both techniques, the vaginal canal and perineum are closed. Part of the anterior vaginal wall may be preserved in patients wishing to undergo phalloplasty or metoidioplasty with urethral lengthening and hook-up to the phallic urethra. At present, there are no studies directly comparing the two techniques, nor evidence to determine the superiority of one technique over the other. Traditionally, vaginectomy has been performed via a completely perineal approach. However, many surgeons now favor a laparoscopic or robotic transabdominal approach, leaving distal vaginal closure to be performed via a perineal approach[22].

*Robotic gender-affirming total vaginectomy*

Our literature search found three papers regarding total vaginectomy via a transabdominal robotic approach [Table 2]. The perceived benefits of this approach were reducing the risk of leaving remnant vaginal mucosa, which can lead to mucocele and urethral complications. However, this appears to be at the cost of greater blood loss and the need for blood transfusion. Potential risk to adjacent organs from sharp dissection is also a concern, although no cases were reported in these studies.

Robinson *et al.* reported their two-surgeon technique for total vaginectomy with urethral lengthening using a split gracilis flap[3,25]. The perineal surgeon performs the distal vaginal excision from the introitus and the preservation of the anterior vaginal epithelium for urethral lengthening, while the robotic surgeon simultaneously establishes pneumoperitoneum and robotic access to the pelvis. The robotic surgeon completes the proximal vaginal dissection and then receives the inferior portion of the split gracilis flap created by the perineal surgeon, which is inset to the de-epithelialized vaginal wall to eradicate the dead space following vaginectomy. Using this approach, the authors reported no cases of persistent vaginal remnant. In their 24-patient retrospective review, they also had a significantly lower rate of urethral stricture and fistula of the pars fixa of 8% each compared to 50%-80% in the literature[3,25]. This group published outcomes using this technique in 16 patients with no complications related to vaginectomy[26].

In a separate paper from the same group, Jun *et al.* reported outcomes of robotic-assisted laparoscopic total vaginectomy in 42 patients undergoing lower masculinising surgery (LMS): 37 phalloplasty [19 radial forearm free flap (RFFF), 15 anterolateral thigh (ALT) flap, 1 abdominal phalloplasty], and 5 metoidioplasty[27]. A gracilis flap technique, as described by Robinson *et al.*, was used in 36 patients (86%)[3,25]. At median follow-up (15.8 months), the authors reported 4 patients (9.5%) had complications related to the vaginectomy. These were Clavien-Dindo grade 1-2 complications. There was also 1 case (2.4%) of a rectovaginal fistula, which was concluded to be a result of previous hysterectomy and was repaired intraoperatively. The authors reported that using a robotic approach to vaginectomy improved efficiency as it can be performed concurrently with scrotoplasty and gracilis flap harvest.

In a prospective cohort study by Groenman *et al.*, 36 transmasculine patients underwent robotic-assisted total laparoscopic hysterectomy and bilateral salpingo-oophorectomy (TLH-BSO) followed by robotic-assisted laparoscopic total vaginectomy[21]. Median blood loss was 75 mL (range 30-200 mL). Only 1 patient (2.8%) experienced a major complication related to the vaginectomy (vaginal bleeding). This occurred 8 days postoperatively and required re-admission for a 2-unit blood transfusion for a Hemoglobin drop from 7.7 mmol/L to 4.7 mmol/L. There was a statistically significant reduction in median operative time (278 to 197 min, $P = 0.00$) and blood loss (175 to 30 mL, $P = 0.01$) after the first 18 cases, signifying a relatively short learning curve. However, all cases were completed by a single gynecologist experienced in robotic surgery, so a longer learning curve may be seen in surgeons with less robotic experience.

Approaches to reduce the risks of blood loss and local organ injury associated with robotic vaginal dissection have been suggested by Coulter *et al.*[22]. These include using a combined dissection and ablative approach, limiting the amount of sharp dissection of the anterior vaginal wall. Alternatively, a combined robotic and perineal approach may be utilized, as performed by Robinson and Jun[3,25,27].

*Robotic gender-affirming colpocleisis*

There are currently no studies specific to colpocleisis using a robotic-assisted approach in the literature. Colpocleisis via a perineal approach has been associated with a higher risk of vaginal remnant compared to total vaginectomy[28,29]. This is likely secondary to incomplete electrocautery destruction, which may lead to

**Table 2. Studies of primary gender-affirming robotic-assisted vaginectomy**

| Author, year | Technique | Study design | No. of patients | Average follow-up (months) | Vaginectomy-related complications (*n*, %) |
|---|---|---|---|---|---|
| Groenman *et al*. 2017[21] | Primary<br>Total vaginectomy with robotic-assisted TLH-BSO | Prospective cohort study | 36 | - | Bleeding from vaginectomy site requiring re-admission for blood transfusion: 1 (2.8%), UTI: 2 (5.6%), acute urinary retention: 6 (16.7%) with subsequent successful catheter removal |
| Jun *et al*. 2021[27] | Primary<br>Total vaginectomy ± urethral lengthening using a split gracilis flap + vaginal mucosa (during staged phalloplasty or metoidioplasty) | Retrospective review | 42 | 15.8<br>(range 1.1-40.5) | Persistent vaginal remnant: 0<br>Perineal drainage: 3 (7.1%) (1 case managed with incision & drainage in the clinic)<br>SUI: 1<br>Rectovaginal fistula: 1 (2.4%) |
| Robinson *et al*. 2023[25] | Primary<br>Total vaginectomy with urethral lengthening using a split gracilis flap (during the 2nd stage of ALT phalloplasty) | Retrospective review | 24 | 21<br>(range 13.3-27.0) | Persistent vaginal remnant: 0, pars fixa fistula: 2 (8.3%), pars fixa stricture: 2 (8.3%) |

TLH-BSO: Total laparoscopic hysterectomy with bilateral salpingo-oophorectomy; UTI: urinary tract infection; SUI: stress urinary incontinence; ALT: anterolateral thigh.

mucocele, perineal cysts or sinuses, and abscesses. Furthermore, fistulae may form between the urethra and vaginal remnant, leading to pooling of urine, post-micturition dribble, and infection[3,22,23,27]. Surgical resection of vaginal remnant may be challenging due to scar tissue formation and loss of tissue planes, with potential for increased risk of injury to local structures[22].

A combined robotic-assisted abdominal and perineal approach to colpocleisis may address some of these potential risks. In our center, patients undergoing robotic-assisted TLH-BSO undergo ablative colpocleisis as a single procedure, with closure of the vaginal canal using a barbed 3-0 Filboc® 90 PDO purse string suture (Assut Europe, Rome, Italy). The majority of colpocleisis is performed via a robotic transabdominal approach, with the very distal aspect performed from a perineal approach. In our experience, this improves efficiency due to the improved ability to work in a narrow surgical field deep in the pelvis using a robotic approach. Similarly, concomitant robotic-assisted TLH-BSO and total vaginectomy has been reported as safe, feasible, and associated with a reduction in overall complications[23,27]. This combined approach may also be advantageous in terms of reducing patient recovery time and cost savings compared with performing these as separate surgeries[28].

*Robotic surgery in the management of gender-affirming vaginectomy complications*

A robotic-assisted approach also has applications in the management of post-vaginectomy complications. Cohen *et al.* reported their experience in surgical management of vaginal remnant and urethral diverticulum using a robotic approach in transmasculine patients who had previously undergone gender-affirming vaginectomy as part of phalloplasty surgery[30]. This approach avoids reopening the perineorrhaphy, which risks injury to the surrounding structures, including the reconstructed urethra. After robotic access to the abdomen is gained, dissection is performed between the bladder and rectum to access the vaginal remnant. To assist in dissection, an end-to-end anastomosis (EEA) sizer is placed in the rectum and flexible cystoscopy is performed to examine the urethra and vaginal remnant, with the use of Firefly™ to visualize the cystoscope light within the vaginal remnant transabdominally. The remnant vagina mucosa is then mobilized off the rectum or bladder and excised, then the edges closed using a running 3-0 V-loc suture. Finally, a leak test is performed cystoscopically and the incised perineum closed. There were no complications, including no cases of vaginal remnant or urethral diverticulum on cystoscopy, at a mean follow-up of 9.4 months.

### Robotic gender-affirming hysterectomy ± BSO

Gender-affirming hysterectomy ± BSO may be performed via open abdominal incision or via a minimally-invasive approach: transvaginal, laparoscopic, robotic, or v-NOTES (Vaginal Natural Orifice Transluminal Endoscopic Surgery).

Transvaginal hysterectomy was traditionally preferred due to the absence of abdominal scars compared to open surgery and maintaining continuity of the inferior epigastric vessels and rectus abdominis, which may be required for future phalloplasty[24]. As with vaginectomy, transvaginal hysterectomy may be challenging in this cohort due to the narrowed vagina under the influence of testosterone and in context of most transmasculine patients being nulliparous with minimal uterine descent and having not engaged in vaginal intercourse. The majority (95%) of transmasculine patients decide to have concomitant bilateral salpingectomy with unilateral or bilateral oophorectomy[31]. Unilateral oophorectomy may be performed in patients wishing to retain ovarian function for future fertility or hormone reserve where there is concern of potential inability to access gender-affirming testosterone therapy in the future.

It is suggested that transmasculine patients are more likely to undergo the minimally invasive route for hysterectomy ± BSO[31,32], although there are only a few studies specifically assessing outcomes of using a robotic approach in the transgender population. Our literature search revealed four original studies [Table 3] and one systematic review regarding outcomes of robotic-assisted TLH ± BSO.

Giampaolino *et al.* reported retrospective outcomes in a single-surgeon, single-center study of 20 transmasculine patients undergoing robotic hysterectomy using the multi-port Da Vinci Xi system between 2016 and 2018[33]. All patients were nulliparous and established on testosterone for a minimum of 6 months. Median operative time was 90 min, with low median blood loss (90 mL) and average length of stay of 2.5 days. Pain was well controlled using the visual analogue scale (VAS). Thus, they concluded that a robotic transabdominal approach to gender-affirming hysterectomy is feasible, safe, and effective.

In the previously mentioned study by Groenman *et al.*, 36 patients underwent multi-port robotic-assisted TLH ± BSO alongside robotic-assisted laparoscopic total vaginectomy as a single-stage procedure[21]. Median operative time was longer than in the Giampaolino study at 230 min[33], which may be related to the addition of vaginectomy to the procedure. Median length of stay was 3 days.

Bogliolo *et al.* reported preliminary outcomes with single-port robotic-assisted TLH ± BSO in 5 patients[34]. Median operative time was 166 min, with a low median blood loss of 33 mL. Postoperative pain was low, with a median VAS score of 1. Length of stay was relatively long in this group at 5 days, although the reasons for this are unclear. The authors reported benefits of a single-port robotic approach in reducing scarring and postoperative pain, as well as enabling a quicker return to usual activity. However, potential downsides included challenges with instrument crossover, although encountered fewer using a robotic approach compared with traditional laparoscopy.

**Table 3. Studies of gender-affirming robotic-assisted total laparoscopic hysterectomy + bilateral salpingo-oophorectomy (TLH-BSO)**

| Author, year | Technique (surgical system) | Study design | No. of patients | Follow-up (months) | Average operative time (mins) | Average blood loss (mL) | Complications (*n*, %) |
|---|---|---|---|---|---|---|---|
| Bogliolo *et al.* 2014[34] | TLH-BSO (Single-port: Da Vinci SP) | Case series | 5 | - | 166 (range 140-210) | 33 (range 20-50) | - |
| Groenman *et al.* 2017[21] | TLH-BSO + robotic-assisted total vaginectomy (Multi-port: Da Vinci system NOS) | Prospective cohort study | 36 | - | 230 (range 197-278) | 75 (range 30-200) | Bleeding from vaginectomy site requiring re-admission for blood transfusion: 1 (2.8%), UTI: 2 (5.6%), acute urinary retention: 6 (16.7%) with subsequent successful catheter removal |
| Giampaolino *et al.* 2019[33] | TLH-BSO (Multi-port: Da Vinci Xi) | Retrospective review | 20 | 1 | 90 (range 65-150) | 90 (range 30-150) | None |
| Gardella *et al.* 2021[35] | TLH-BSO (Single-port: Da Vinci Si) | Case-control analysis | 112 (60 transmasculine *vs.* 52 cisgender women) | 1.5 | 143.7 ± 40.4 | - | In transmasculine cohort - Fever: 2 (3.3%), Cystitis: 1 (1.7%) |

TLH-BSO: Total laparoscopic hysterectomy with bilateral salpingo-oophorectomy; SP: single port; NOS: not otherwise specified; UTI: urinary tract infection.

Gardella *et al.* compared outcomes of TLH ± BSO in transmasculine patients versus cisgender women for benign conditions using a single-port robotic approach[35]. This prospective database study with retrospective analysis included 112 patients (60 transmasculine, 52 cisgender women). A statistically significant difference was found in terms of shorter operative time (144 min *vs.* 165 min), uterine volume (70 $cm^3$ *vs.* 129 $cm^3$), and previous comorbidity in favor of the transmasculine patient cohort. There was no difference in length of stay, conversion to open surgery, blood loss, or complications.

In a systematic review of 8 studies, Dominoni *et al.* compared the outcomes of robotic-assisted TLH-BSO with non-robotic approaches in transmasculine patients, including open abdominal, transvaginal, laparoscopic, and v-NOTES approaches[36]. Outcomes from a total of 425 patients across all studies were assessed (20 robotic multi-port, 66 robotic single-port, 11 open abdominal, 142 transvaginal, 35 v-NOTES). A robotic approach was associated with a lower average blood loss than open abdominal, transvaginal, or v-NOTES (30 mL single-port, 90 mL multi-port versus 225 mL abdominal, 200 mL vaginal, and 200 mL v-NOTES). Robotic multi-port surgery had a slightly longer mean operative time of 90 min *vs.* 75 min for laparoscopic approaches, but was quicker than for transvaginal (100 min), robotic single-port (140 min), and v-NOTES (270 min) approaches. However, it should be taken into account that due to the small number of studies included, this may be heavily influenced by surgeon experience & position on the surgical learning curve. The average length of stay was best for robotic and laparoscopic approaches (robotic multi-port 2.5 days, robotic single-port 3.15 days, laparoscopic 2.65 days) compared to transvaginal (5.5 days) and v-NOTES (4.65 days). This translates to cost savings from a shorter inpatient stay and possibly a quicker recovery with robotic and laparoscopic approaches. However, it is not clear if this offsets the costs associated with the setup and maintenance of a robotic system. Post-op VAS pain scores were surprisingly poorer for robotic surgery compared to transvaginal and v-NOTES, which may be related to abdominal scars and gas insufflation. Complications were relatively similar across all studies.

In our center, we perform robotic-assisted TLH ± BSO, with concomitant robotic-assisted transabdominal vaginectomy if desired by the patient, as a day-case procedure. A combined approach to robotic TLH ± BSO and vaginectomy may improve surgical efficiency, promote shorter recovery, avoid the need for multiple general anesthetics, and reduce the associated costs.

### Robotics in gender-affirming phalloplasty

Phalloplasty, a complex, multi-stage surgical procedure for transmasculine patients, aims to create a functional and aesthetically pleasing phallus. Achieving these outcomes typically involves free or pedicled flaps harvested from donor sites such as the radial forearm or ALT, accompanied by intricate microsurgical vascular and neural reconstructions. Since Sir Harold Gilles performed the first successful phalloplasty for a transgender man in 1946[37], the surgical technique has been continuously evolving. In 1984, Chang and Hwang pioneered the 'tube-within-a-tube' design using a free radial forearm flap[38], which remains the most frequently described technique[39]. Currently, phalloplasty is most often performed using a RFFF, but not infrequently, ALT, pubic, latissimus dorsi (LD), and superficial circumflex iliac artery perforator (SCIP) flaps are employed.

Phalloplasty combines the reconstructive techniques of flap harvesting and microsurgery. Inherent within these techniques are several challenges: lengthy operative times, significant physical demands on surgeons, and learning curves requiring high volumes of cases. Risks such as flap failure are likely to result in suboptimal functional and aesthetic outcomes.

This section explores whether the application of robotics to phalloplasty (flap harvesting and microsurgery) offers any advantages to standard phalloplasty in the hands of an experienced reconstructive team.

#### *Robotic-assisted microsurgery*

Microsurgery has been a cornerstone of reconstructive surgery, particularly for intricate procedures requiring high precision, such as free tissue transfer and nerve coaptation. Robotic microsurgery is an emerging field that combines microsurgical techniques with the advanced capabilities of robotic systems. The proposed advantages include improving surgical outcomes by enhancing precision, reducing tremors, and minimizing surgeon fatigue.

In 2007, the first microsurgical anastomosis was performed between the deep inferior epigastric vein and the mammary vein during a breast reconstruction with a muscle-sparing free TRAM-flap (transverse rectus abdominis myocutaneous flap) using the da Vinci robot[40]. Since then, two specialized microsurgical robotic systems, MUSA MicroSure (MicroSure, The Netherlands) and Symani Surgical System (Medical Microinstruments Inc., USA), have been developed.

In 2024, a small study evaluating fifteen surgeons with varying levels of expertise found that robotic assistance enabled novice and intermediate surgeons to perform microsurgical anastomoses comparably to experts. This suggests that robotic systems may facilitate safer microsurgical performance at earlier stages of training[41].

A 2024 systematic review identified only eleven studies that evaluated the role of robotics in microvascular plastic and reconstructive surgery[42]. Most studies had a low evidence base. Ruccia *et al*. concluded that robotic-assisted microvascular anastomosis is feasible, effective, and safe, with comparable rates of anastomotic patency and leak incidence to conventional techniques, but with longer anastomotic times[42]. The review emphasized the need for robust comparative studies to validate the advantages of robotic-assisted microsurgery over traditional methods.

The first application of robotic-assisted microsurgery in a gender-affirming phalloplasty was only recently described in a case report by Wellenbrock *et al.* using the Symani Surgical System. This procedure utilized the robot for end-to-side nerve coaptation and arterial anastomosis of a RFFF, demonstrating its feasibility[43]. The time for nerve coaptation was 17 min and the arterial anastomosis time was 26 min, with a total surgical time of 401 min, comparable to conventional phalloplasty. No complications occurred within the 8-week follow-up period. The authors highlighted advantages such as tremor elimination, motion scaling, and enhanced precision for deep-plane procedures, including movements in the peri-clitoral space beneath the suspensory ligament. These features suggest that robotic assistance could enhance precision and flexibility during gender-affirming phalloplasty.

*Robotic-assisted flap harvesting*

In 2012, Patel and Pedersen reported the first robotic-assisted flap harvest[44]. Since then, robotic applications for flap harvesting have expanded. A systematic review pooling data from 262 patients across 25 studies found that robotic flap reconstruction is feasible and safe, with shorter hospital stays compared with conventional flap harvest[45]. However, as with robotic microsurgery, longer operative times were seen compared to conventional techniques. The advantages of robotic-assistance described in the same review were: lower complication rates and quicker recovery, particularly for commonly used flaps like the LD and RFFF.

In 2023, robotic-assisted RFFF harvesting was described by Shin *et al.*[46]. Although the cases were not performed as GAS procedures, their experience with eleven patients using the Da Vinci Si robot demonstrated statistically significant longer harvesting times compared to conventional methods. However, a decreasing trend in harvesting time was observed as surgeons gained experience, suggesting that robotic harvesting times could eventually match those of conventional techniques.

## LIMITATIONS

The main limitations of this review include the small number of studies published in this field, the small sample sizes in the majority of studies, and the lack of randomized control trials or direct comparisons to traditional surgical techniques in GAS. This reflects the relatively recent introduction of robotic surgery to the specialty, and as experience increases, we hope to see larger, controlled studies to strengthen the evidence base and guide practice. The evidence for robotic-assisted phalloplasty in our review was limited, with only 1 case review, reflecting limited experience in this area, which remains under research. This review is also limited to genital surgery within GAS, with robotic surgery in other areas of GAS in relative infancy.

## CONCLUSION

This paper outlines robotic-assisted techniques for genital gender-affirming surgery. It highlights the clear benefits of robotic techniques in pelvic surgery. These include improved visualization and working space in a narrow surgical field compared to traditional surgical approaches, improved postoperative recovery, and, in some cases, decreased complications. While costs and surgical learning curve are potential downsides, as the use of robotic surgery becomes more widespread across more surgical specialties, these factors may be offset.

Introducing robotic techniques into GAS may attract a different cadre of surgeons working in a multidisciplinary team setting, which is required in a field where surgical expertise is limited to a few surgeons in each country. In a survey among plastic surgeons and trainees, 89.7% of respondents expressed support for incorporating robotic surgery into future plastic surgery residency training; 43.6% identified microsurgery and 40.7% flap tissue harvest as the most beneficial areas for adoption[47]. More studies using standardized measures of satisfaction and functional outcomes are welcomed to strengthen the evidence base.

In the transfeminine population, the current literature suggests both primary and rRA-GPV are safe and can provide good outcomes in terms of neovaginal depth, with a comparable rate of complications to standard techniques. In addition, it provides an option for vaginoplasty in patients unsuitable for PIV or "standard" skin techniques. The visibility and manoeuvrability with robotic systems is a particular advantage in patients in the salvage setting, where dissecting between the stenosed rectum and bladder via an open or laparoscopic approach carries a significant risk of rectal injury. The current evidence for robotic intestinal segment vaginoplasty is limited, but it shows considerable potential.

In the transmasculine population, robotic-assisted approaches to vaginectomy overcome challenges commonly seen in this cohort, most notably improved access and working space in a narrow, atrophied vagina. While there are no studies reporting outcomes of ablative colpocleisis via a robotic transabdominal approach, the small number of studies regarding robotic-assisted total vaginectomy suggest this is feasible and safe, with a low risk of major complications. Based on the current literature, robotic transabdominal hysterectomy ± BSO in the transmasculine population appears safe and is associated with low blood loss, low complication rate, and reasonable operative times.

The published evidence for robotic surgery applications to phalloplasty is very limited, and thus, early conclusions can only really be extrapolated from evidence from non-GAS robotic microsurgery and robotic flap harvesting in other reconstructive surgeries. Current evidence suggests that operative time is longer for both flap harvesting and microsurgery using a robotic approach. Potential advantages could include shorter learning curves for the less experienced surgeon, tremor reduction, shortened recovery and hospital stay for patients, and lower complication rates.

Further large, prospective studies are needed to fully demonstrate the applications and assess outcomes of robotic-assisted surgery in genital GAS, including direct comparisons with traditional techniques.

## DECLARATIONS

### Authors' contributions

Literature search and analysis: Oliver R, Kanthabalan A, Tinajero JD
Writing-review: Oliver R, Kanthabalan A, Tinajero JD, Rashid T, Ahmed J, Flint R, Rose V, Di Taranto G

### Availability of data and materials

Not applicable.

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### Conflicts of interest

Ahmed J serves as a proctor for Intuitive. The other authors declared that there are no conflicts of interest.

### Ethical approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Copyright



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