REVIEW

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Robotic live donor hysterectomy

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Purpose of review
Donor hysterectomy for live donor uterus transplantation was from the start performed by laparotomy, but minimal invasive surgery has entered the scene. In particular robotic-assisted laparoscopy is used since robotics is advantageous in the complex donor hysterectomy surgery in narrow space. This review covers the development and benefits of robotics and the published robotic donor hysterectomy experiences.

Recent findings
Robotic donor hysterectomy publications are scarce with eight cases in Sweden, five in USA, and one each in China and Spain. Robotics have been performed for either the entire donor hysterectomy or with conversion to laparotomy for the last steps of the surgical procedure. The total operative times are in line with open surgery, although a decrease is expected in the future. The estimated blood loss and hospital stays are less than at open surgery. The complication panorama includes hydronephrosis, ureteric fistula and pressure alopecia. Live births with healthy babies have been reported.

Summary
In uterus transplantation, robotic live donor hysterectomy has proven to be feasible, safe and associated with successful live births. The robotic donor hysterectomy is a low-volume procedure and an international registry to gather collective information is crucial for further evaluation and development.

Keywords
donor, hysterectomy, infertility, robotic, transplantation, uterus

INTRODUCTION

Absolute uterine factor infertility, due to absence of a uterus or presence of a nonfunctional uterus, was regarded untreatable until the first live birth after uterus transplantation (UTx) was reported in 2014 [1]. This proof-of-concept birth occurred in Sweden and was followed by several births within the same trial [2,3] and later from other centres [4–6]. The surgical method for donor hysterectomy used in the first reported live donor hysterectomies for UTx were by open surgery [7–10].

Minimal invasive surgery (MIS) and especially robotic-assisted laparoscopy, hereafter referred to as robotics, has developed during the last decades and especially in complex gynaecological surgery performed in narrow spaces [11–14]. Furthermore, robotic organ retrieval in transplantation, as in live kidney donors has been performed [15]. Moreover, the kidney transplantation procedure per se has been performed solely by robotics [16]. The advantages of robotic surgery, as a MIS technique, are multiple; 3D-enhanced vision, articulated wristed instruments and tremor reducing properties are important for exact precision surgery in narrow spaces and when the anatomical tissue to dissect is delicate, which in donor hysterectomy applies particularly to dissection of the ureters and the deep uterine veins.

The general benefits associated with robotics should also apply to UTx and the live donor hysterectomy to minimize risk and trauma for the donor. Robotics could possibly increase the number of eligible future donors to include a larger pool of nondirected altruistic donors, who would be willing to donate the uterus after completed childbearing.

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KEY POINTS

- Robotic live donor hysterectomy is associated with less estimated blood loss and decreased hospital stay in comparison with open donor hysterectomy.
- The rate of surgical complications is comparable with open live donor hysterectomy.
- Live births have been reported after robotic donor hysterectomy.
- International registration of all surgical outcomes is essential in this low-volume transplantation to safely develop the procedure.

GENERAL DEVELOPMENT OF ROBOTIC SURGERY

The Programmable Universal Manipulation Arm was introduced in neurological surgery in 1978, to replace human movements with a robotic arm to guide a needle for brain biopsy [17]. Thereafter, the robotic PROBOT system was developed at the Imperial College in London to aid in transurethral prostatectomies [18]. In 1998, the ZEUS tele robotic system was introduced and made commercially available. The system was constructed with surgeon-console with possibility to perform distance surgery with three robotic arms. In 2003, the developer of ZEUS merged with Intuitive surgery and a modified robotic system was developed. Initially, it was a governmental-run project for improving surgical capabilities using telepresence surgery, and consequently keeping the surgeon at a distance from the patient when performing a procedure [18]. In 2000, the United States Food and Drug Administration approved the first robotic surgical system (da Vinci; Intuitive Surgical Inc., Sunnyvale, California, USA) for general laparoscopic procedures and in 2005 for gynaecological indications. Thereafter, the robotic technique has evolved successfully in multiple surgical areas including complex gynaecological surgery [13], multifaceted general surgery [19,20], and transplantation [16,21].

POTENTIAL ADVANTAGES OF ROBOTICS IN UTERUS TRANSPLANTATION

The robotic system is an advanced form of MIS, in comparison with traditional laparoscopy robotics provides the surgeon with improved ergonomics, wristed articulated laparoscopic instruments, 3D-enhanced-vision and tremor reducing capacities. These properties enable precise and exact surgical dissections in narrow spaces such as the dissections in the deep narrow pelvis of the uterine vessels and their connections to the internal iliacs. Moreover, robotics may make the learning curve from open to MIS surgery considerably steeper as has been shown for several surgical procedures [21,22], including hysterectomy with lymphadenectomy, a procedure with similarities to donor hysterectomy. To gain optimal surgical access, the robotic technique requires the patient in deep Trendelenburg position (defined as 25–30°) allowing a somewhat lower pressure of the pneumoperitoneum compared with conventional laparoscopy due to an elevation of the abdominal wall by the robotic arms. Furthermore, multiple studies have shown that robotic surgery is associated with less blood loss and shorter length of hospital stay compared with open surgery and laparoscopy [13,14,23]. Concerning operative time in robotic surgery, defined as from skin incision to skin closure, there are diverse results from longer to shorter operative times compared with open surgery and laparoscopy [20,24,25]. The unclear results may indicate surgeon- or procedure-dependent discrepancies, which may be assumed also in robotic donor hysterectomy in UTx.

In general transplantation surgery, robotics has gradually been introduced [26] initially for both the live donor and recipient in kidney transplantation [21]. Due to the possible benefits from robotics, this type of surgery has been shown to be feasible even in morbidly obese patients undergoing kidney transplantation [27]. In summary, robotics is considered to be part of the development in transplantation.

As in many new innovative complex surgical procedures, the initial donor hysterectomy by open surgery in UTx has been shown to be associated with prolonged operative times although to be expected to decrease over time as for other robotic complex procedures [7,10,28]. The rationale to develop robotics in UTx is to allow precise dissection procedures deep in the narrow pelvis and thereby secondary gains such as decreased blood loss and hospital stay as well as shortened recovery, as shown in prior studies in gynaecologic surgery [14,24,29].

ROBOTIC TECHNIQUE IN DONOR HYSTERECTOMY

A robotic system, preferable the da Vinci Xi dual-console system (Intuitive Surgical Inc) with a 4-arm setup through 8-mm robotic trocars may be used or corresponding systems from other manufacturers with dual-consoles. A proposed port placement setting is shown in Fig. 1. Two laparoscopic ports of which one port may be a 12 mm access port such as the AirSeal (CONMED, AirSeal system, Utica, NY, USA), could be used to enable the use of larger instruments, such as laparoscopic clip instruments (AirSeal no. 5 in Fig. 1). The second laparoscopic port may be a conventional port (5 mm) for

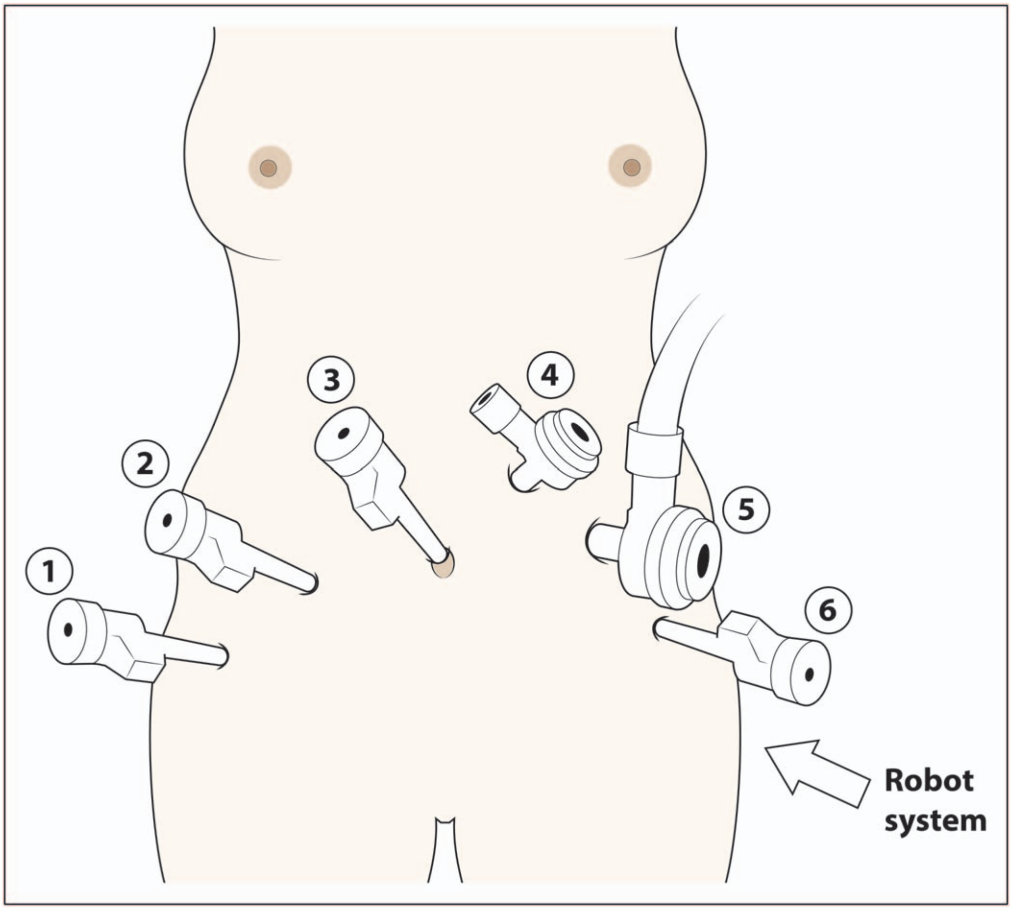

FIGURE 1. Schematic drawing of proposed robotic docking setting for robotic live donor hysterectomy showing; (1) robotic port using prograsp forceps/vessel sealer extend (2) robotic port using monopolar curved scissors/large needle driver/medium-large clip applier (3) robotic optic camera (4) conventional 5 mm laparoscopic port (5) AirSeal 12 mm access port and (6) robotic port using Maryland bipolar forceps.

laparoscopic instruments (port no. 4 in Fig. 1). The conventional laparoscopic ports may be used by the assisting surgeon, with a position just adjacent to the patient. Robotic instruments that may be used in the robotic ports are; a Maryland bipolar forceps (robotic port no. 6 in Fig. 1), monopolar curved scissors/large needle driver/medium-large clip applier (robotic port no. 2 in Fig. 1) and prograsp forceps/vessel sealer extend (robotic port no. 1 in Fig. 1). When the robotic system has been docked properly the robotic donor hysterectomy may start. An optic scope of both 0 and 30° as alternative for optimal vision in all spaces should be prepared. Before docking the robotic system, the donor should be placed in steep Trendelenburg position (preferable angle 28°) and a side-docking (45°) towards the patient's left hip. This docking enables access to a vaginal probe, such as for example a spherical vault silicon probe (30103; Karl Storz, Tüttlingen, Germany), or a none-invasive uterus manipulator not causing trauma to the uterus. Two robotic surgeons should be active in the dual console system and one experienced laparoscopic surgeon immediately adjacent to the donor.

Robotic donor hysterectomy: surgical steps

The donor hysterectomy surgery is challenging and should preferably be performed by experienced robotic surgeons, with long track records in gynaecology and transplantation. The surgery has some similarities to donor hysterectomy by laparotomy, as previously described [7] but with some minor modifications. We propose a structured robotic surgery, with separate surgical substeps in accordance with two recent publications on robotics in donor hysterectomy [30▪▪,31▪]. In general, the substeps involving dissection of the ureteric tunnel and the veins are the most demanding and time-consuming, regardless what surgical technique is used.

Our proposed defined surgical steps are:

(1) Dissection of bladder off of the anterior uterus and cervix, opening the pararectal and paravesical spaces, and division of round ligaments.

(2) Dissection of the uterine arteries, anterior portions of internal iliac arteries and umbilical arteries.
(3) Dissection of the ureters between the crossing over the iliac vessel and ureteric tunnel.
(4) Dissect the proximal portions of the ureteric tunnels.
(5) Dissect the internal iliac arteries with branches.
(6) Dissect the distal portions of the ureteric tunnels to the insert of the ureters into the bladder, with caution to preserve over-riding and under-riding veins.
(7) Dissect the internal iliac veins with branches, including distal parts of uterine veins.
(8) Perform bilateral salpingectomy and dissect proximal parts of the utero-ovarian vein.
(9) Dissect pouch of Douglas, with separation of the rectum from the posterior vagina and dived sacrouterine ligaments.
(10) Transect the vagina, the utero-ovarian veins, uterine arteries and uterine veins.
(11) Remove the uterine manipulator and introduce a specimen pouch for transvaginal uterine graft extraction.
(12) Vaginal cuff closure.

RESULTS OF ROBOTIC LIVE DONOR HYSTERECTOMY

Surgical outcomes

The first reported UTx live donor hysterectomy using MIS was a fully robotic procurement of a uterus taking place in China already in 2015 [32]. The case involved a recipient with Mayer–Rokitansky–Küster–Hauser (MRKH) syndrome and a 42-year-old, premenopausal donating mother. The uterine veins were not used for anastomosis but the utero-ovarian veins, which necessitated bilateral oophorectomy. The operative time was 6 h with an estimated blood loss of 100 ml and 5 days of hospital stay for the donor [32]. No immediate complications were reported in the donor although she had an indwelling catheter for 2 weeks postoperatively. Since this pioneering case, eight robotic UTx procedures has been performed in Sweden between 2017 and 2019 [30▪▪,33▪], five in USA in 2019 [31▪] and one case in Spain in 2020 [34].

In the Swedish study, the robotic donor hysterectomy was converted to a laparotomy according to the approved ethics protocol, allowing a time of 6–7 h in the robot [30▪▪]. This was to ensure safety of the donor, especially concerning previously reported long operative times in the demanding steep Trendelenburg position [30▪▪]. Full dissection of the bilateral deep uterine veins on segments of the internal iliac veins together with bilateral proximal portions of the utero-ovarian veins were possible to accomplish solely by robotics in the three last donor hysterectomies and in five donors by a combination of robotics and open surgery. The reported total operative time, including both robotic and open surgery, was still more than 10 h with a median blood loss of 125 ml and 5.5 days of hospital stay, which both were less compared with open donor hysterectomy [33▪]. Moderate and reversible complications were seen in two out of the eight donor hysterectomies; one reversible pressure alopecia on the back of the head, classified according to the Clavien–Dindo complication scale as grade 2 and one donor with unilateral pyelonephritis which was treated successfully by ureteric stent (Clavien–Dindo grade 3b) [35]. Importantly, there was a clear progression during the study of eight live donor hysterectomies, where all surgical steps were completed by robotics in the three last procedures indicating feasibility, but with a 25% complication rate, which is unacceptable high but in the range for a new procedure.

Five fully robotic live donor hysterectomies were reported from the USA [31▪]. The uteri were retrieved transvaginally inside surgical bags. The team aimed for procuring the deep uterine veins and the proximal portions of the utero-ovarian veins in all cases, but did not reach that in all cases. Three of the four venous outflow options could be obtained in all five hysterectomies although the large deep uterine veins were only used in the recipient in two patients [31▪]. The operative times ranged between 9.5 and 12 h with estimated blood loss of less than 200 ml in all hysterectomies. Complications occurred in three out of the five donors. A pressure alopecia (Clavien–Dindo grade 2) was seen in one donor and ureteric complications in two donors (Clavien–Dindo grade 3b), where one donor developed unilateral hydronephrosis and one donor acquired bilateral ureteric-vaginal fistulae [31▪]. The complication rate of 60% is high but often seen in the learning and development of new procedures.

In addition, there is one case recently reported from Spain with a robotic procurement of the donor hysterectomy showing successful organ transplantation although no specific surgical outcome details are available on the robotic live donor hysterectomy procedure [34].

Live births after robotic donor hysterectomy

In 2019, we reported on the first live birth after robotic donor hysterectomy in UTx in a 33-year-old woman with MRKH syndrome with her 62-year-old mother as donor [36▪]. After the recipient's first embryo transfer, she got pregnant and a healthy boy was delivered at 36 gestational weeks with an uneventful follow up during the first year for both the mother and child. Thereafter, the robotic donor hysterectomy from China reported in 2020 a delivery of a healthy boy at gestational week 33 + 6 after her fifth embryo transfer [37]. There are up until today no clear published reports on the live births after the five robotic live donor hysterectomies from the USA or the single case from Spain, but will probably presented in the future.

FUTURE PERSPECTIVES

UTx has evolved during the last decades from basic-science research into a clinical transplantation procedure although still considered at an experimental stage. During the same time, robotic surgery has developed considerably making it possible to implement MIS in complex surgical fields. Robotic live donor hysterectomy for UTx has been performed and shown to be feasible, and with a clear progression towards increased surgical outcomes though not yet decreased operative times. Significantly, in kidney transplantation it has been suggested that 35 robotic cases are needed before achieving reproducibility in terms of timing, complications and functional result [21]. This is probably comparable with live donor hysterectomy and larger volumes of procedures should be gathered before assessing its progression and efficacy correctly. One may speculate that the robotic operative times will decrease over time by acquiring more experience of the robotic procedure and this should minimize the rate of complications, as has been shown in many other robotic procedures [20–22].

By offering a safe MIS method to future uterus donors, it is likely that there will be a considerable increase in the number of eligible donors. Studies have shown that suitable donors are quite few after standard screening procedures for UTx [38]. It is quite likely that robotic donor hysterectomy will develop as a safe procedure, associated with acceptable hospital stay, low complication rate and fast recovery. Since UTx is still in an experimental and developmental phase, one may estimate that robotic live donor hysterectomies will be a low-volume procedure for the coming 5 years at least. The robotic live donor hysterectomies should only be performed by experienced teams with both advanced robotic gynaecologic and transplantation surgery. Nevertheless, the procedure will be a low-volume procedure and it is crucial to assemble collective information to receive larger cohorts to perform valid assessments. Therefore, an international registry to collect data, is of outmost importance for the future. The International Society of UTx has implemented a web-based register [39] which will publish annual reports. This will enable valid valuable assessments and possibilities to identify prognostic risk factors for negative outcomes such as prolonged operative times, complications, organ graft failures and other important outcome measures. Furthermore, the registry will be important to test different scientific research hypothesis concerning robotics in UTx.

CONCLUSION

In conclusion, robotic donor hysterectomy in UTx has proven to be feasible, safe and associated with less blood loss and shorter hospital stay for donor hysterectomy, as compared with open surgery. The complication rates for donor hysterectomy by robotics may still be considered unacceptable high. Importantly, live births have been reported as proofs of transplantation success. Nevertheless, the robotic live donor hysterectomy is a low-volume procedure and an international registry to gather collective information of performed robotics is essential for the future.

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Conflicts of interest

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