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The growth of computer-assisted (robotic) surgery in urology 2000–2014: The role of Asian surgeons



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Abstract *Objective:* A major role in the establishment of computer-assisted robotic surgery (CARS) can be traced to the work of Mani Menon at Vattikuti Urology Institute (VUI), and of many surgeons of Asian origin. The success of robotic surgery in urology has spurred its acceptance in other surgical disciplines, improving patient comfort and disease outcomes and helping the industrial growth. The present paper gives an overview of the progress and development of robotic surgery, especially in the field of Urology; and to underscore some of the seminal work done by the VUI and Asian surgeons in the development of robotic surgery in urology in the US and around the world.

Methods: PubMed/Medline and Scopus databases were searched for publications from 2000 through June 2014, using algorithms based on keywords “robotic surgery”, “prostate”, “kidney”, “adrenal”, “bladder”, “reconstruction”, and “kidney transplant”. Inclusion criteria used were published full articles, book chapters, clinical trials, prospective and retrospective series, and systematic reviews/meta-analyses written in English language. Studies from Asian institutions or with the first/senior author of Asian origin were included for discussion, and focused on techniques of robotic surgery, relevant patient outcomes and associated demographic trends.

Results: A total of 58 articles selected for final review highlight the important strides made by robots in urology, from robotic radical prostatectomy in 2000 to robotic kidney transplant in 2014. In the hands of an experienced robotic surgeon, it has been demonstrated to improve functional patient outcomes and minimize perioperative complications compared to open surgery, especially in urologic oncology and reconstructive urology. With increasing surgeon proficiency, the benefits of robotic surgery were consistently seen across different surgical disciplines, patient populations, and strata.

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Conclusion: The addition of robot to the surgical armamentarium has allowed better patient care and improved disease outcomes. VUI and surgeons of Asian origin have played a pioneering role in dissemination of computer-assisted surgery.

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"If you always do what you always did, you will always get what you always got."-Albert Einstein

1. Introduction

When Dr Tom Lue asked us to chronicle the contribution of Vattikuti Urology Institute (VUI) in the field of robotic surgery, we knew we had two unique opportunities: one, to describe the development and progress of robotic surgery, and two, to convey the subliminal message of how VUI and urologists of Asian descent were instrumental in that process.

The foundation for robotic surgery was laid when Dr Mani Menon, then Chief of Department of Urology at Henry Ford Hospital (HFH), Detroit, USA set out to start an ambitious minimally invasive prostatectomy program at his center in 1999–2000. He set up a formal collaboration with the French group of Drs Vallancien and Guillonneau at Montsouris (the then leaders in laparoscopic prostatectomy), but was disillusioned with the inferior results and the cumbersome, counterintuitive approach of laparoscopy. It was somewhat serendipitous when the Food and Drug Administration (FDA), in the year 2000, approved the da Vinci robot for soft-tissue surgery. Even though its acceptance rate was rather slow in cardiac surgery (the initial *raison d'être* for the robot), it seemed to fill the voids in laparoscopy. There was minimal literature on its use in prostatectomy at the time when da Vinci was incorporated in HFH program. The first robot-assisted radical prostatectomy (RARP) was performed at HFH on November 29, 2000. Experience with laparoscopic and robotic prostatectomy accumulated quickly. A series of 50 RARPs performed at HFH was published in 2002 [1]. The rest is history.

While progression from radical prostatectomy to other pelvic surgeries was natural progression, robotic upper tract surgery evolved in parallel. Reconstructive techniques involved in these procedures were defined and refined. Robotic procedures in female and pediatric urology were planned and executed. Methods were adopted to safely transfer new surgical procedures from mere ideas to bench, and then to operating rooms.

In this review, we look back at the fascinating 15-year robotic journey from radical prostatectomy in 2000 to renal recipient surgery in 2014.

2. Evidence acquisition

2.1. Search strategy

A literature search was performed using PubMed/Medline and Scopus databases to identify the important publications

pertaining to robotic surgery (predominantly in urology) from January 1, 2000 through June 1, 2014. Two search algorithms were used. In the first search strategy, we sequentially combined the keyword "robotic surgery" with "prostate", "kidney", "adrenal", "bladder", "reconstruction", using the AND operator for each pair of keywords, to identify publications relating to the application of robotics in prostate, kidney, bladder, adrenal, and reconstructive urology, respectively. The second search was performed using the same combination of keywords but with the NOT operator, to identify the important non-urological publications of robotic surgery. Inclusion criteria used were published full articles, book chapters, clinical trials, prospective and retrospective series, and systematic reviews/meta-analyses written in English language. Next, results were screened according to the originating institution and the nationality of the first and/or senior author. Studies from Asian institutions or with the first/senior author of Asian origin were included for discussion (Fig. 1). The same search criterion was used for both the databases. Additional publications have been used to substantiate statement origins and help description as necessary.

2.2. Study selection

Included studies focused on one or more of the following areas: development/description of novel robotic surgical techniques, standardization/validation of a robotic surgical technique, important modifications in pre-existing surgical technique resulting in demonstrable benefit in patient outcomes, comparison of perioperative, short- or long-term outcomes of robotic vs. laparoscopic or open surgical approaches, and demographic and population trends associated with acceptance of robotic surgery. Although there was a preponderance of urological literature, a few important studies from other surgical specialties were also studied and discussed to highlight the position of robotic surgery in the said specialty.

2.3. Review methods

A total of 58 studies were included in the review, after preliminary screening of abstracts and exclusion of duplicate results. The searches were performed jointly by two co-authors (RA and DD), and a consensus on the relevance of the publication was arrived on by mutual discussion.

3. Evidence synthesis

3.1. Robotic prostatectomy

Dr Menon started the robotic prostatectomy program at the VUI at HFH in March 2001. Over the next few months, the

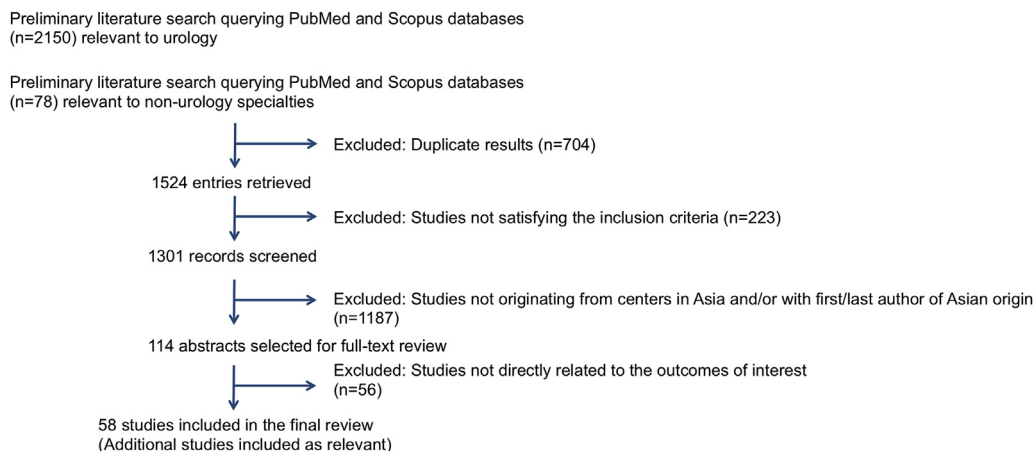


Figure 1 The selection of articles for review.

evolved robotic radical prostatectomy technique came to be known as the Vattikuti Institute Prostatectomy (VIP) [2]. Initial observations demonstrated the benefit of VIP over open or laparoscopic counterparts for all perioperative parameters, operating room time, estimated blood loss (EBL), complications, catheterization time and hospital length of stay (LOS) >24 h [1,3]. Median time to continence and postoperative PSA levels were lowest for VIP. Better vision and robotic dexterity improved functional outcomes of continence and potency too.

Anatomic studies further showed that the neurovascular tissue is not confined to the “bundle”, but is wider and spread over, intimately related to the anterolateral surface of the prostatic fascia [4,5]. We hypothesized that developing a high anterior plane between the prostatic capsule and the inner periprostatic fascial layer could potentially allow for greater nerve preservation [6]. The preserved neurovascular tissue, a remnant of interfascial dissection between 1 o’ clock and 5 o’ clock position and between 7 o’ clock and 11 o’ clock position, was eponymously termed “veil of Aphrodite”. Prospective comparison of bilateral “veil” technique with bilateral standard nerve sparing in men with localized prostate cancer and normal baseline erectile function showed significantly better recovery of erections (Sexual Health Inventory for Men [SHIM] >21 in 86% vs. 26%, $p < 0.0001$) and higher percentage of erections firm enough for intercourse (97% vs. 74%, $p = 0.002$) at 12 months after surgery [7]. Further preserving the fibers lying between 11 o’ clock and 1 o’ clock position of the prostate (along with the puboprostatic ligaments and the dorsal venous complex) formed the basis for the “super veil” procedure, which could be offered to men with low risk disease. A comparison of consecutive cases with the “veil” and the “super veil” procedure showed a faster return to erectile function with the latter [8].

We started performing double-layered urethrovesical anastomosis (UVA) to combine the claimed beneficial roles of posterior rhabdosphincter reconstruction [9], and lateral and anterior reconstruction [10], expecting a faster return of continence. However, randomized trials at our center

failed to show any advantage of double layered UVA on early (<30 d) continence recovery [11] or long-term (2 year) continence rates [12]. We, however, adopted this technique as a standard of care owing to the decreased incidence of cystographic leaks compared to the single layer UVA (3.4% vs. 8.8%, $p < 0.05$).

A running UVA with monofilament suture has a tendency to slip, leading to increased anastomotic time and the annoying need to tighten the suture after every couple of throws. FDA approved the polyglyconate self-anchoring barbed suture for soft-tissue approximation in 2010. We fashioned it into a double-armed stitch for UVA [13] with barbs directed in different directions from the center. It minimized slippage and revision of throws by the console surgeon, while overcoming the need to “follow” and retract the suture by the assistant. Comparison of patients undergoing VIP with the barbed vs. the standard monofilament suture showed a 26% reduction in total anastomotic time without compromising outcome [14].

Urethral catheter is disliked by most patients, and is a cause of discomfort and bladder spasms postoperatively, requiring anticholinergics. We explored the option of replacing the urethral catheter with percutaneous suprapubic tube and observed significantly less catheter-related discomfort, and need for anticholinergic medications [15]. Absence of postoperative urethral catheter did not increase bladder neck contractures, and reduced risk of urethral stricture or meatal stenosis [16]. That said, a watertight anastomosis and excellent mucosal apposition is a sine qua non for safely circumventing the need for a urethral catheter.

The need and optimal extent of pelvic lymphadenectomy to be performed in patients with low-risk prostate cancer (Gleason 3 + 3/3 + 4, T1c, PSA < 10 ng/mL) has generated significant debate. We modified our template to include internal iliac group of nodes (zone 2), shown to be the commonest site of metastases [17], to standard external iliac and obturator node dissection (zone 1). Patients that had zone 2 dissection had a 13.7 times higher incidence of positive nodal yield than patients with zone 1 dissection only [18].

A prospectively maintained database for 2766 patients with a minimum 5-year follow-up (the largest number ever reported with the longest follow-up) demonstrated an overall actuarial biochemical recurrence free survival (BCRFS) of 84% [19]. The quality of VIP improved with time, with significant reduction in mean console time (97 vs. 121 min, $p < 0.05$) and positive surgical margin (PSM) rate for organ-confined disease (4% vs. 7%, $p < 0.05$), although more patients with aggressive disease and prior abdominal surgery underwent VIP. A recent analysis of the oncological outcomes in 4803 patients after a mean follow-up of 34.6 months continues to demonstrate encouraging results, with actuarial 8-year BCRFS, metastases-free survival and cancer specific survival being 81%, 98.5% and 99.1%, respectively [20]. Multi-institutional collaboration between different surgeons from USA and Europe (like Dr Mani Menon, Dr Ashutosh Tewari, Dr Vipul Patel, and Dr Prasanna Sooriakumaran, to name a few) helped to formulate guidelines to achieve the ideal “trifecta” of outcomes (cancer control, potency and continence) [21–24]. Comparison of outcomes of open radical prostatectomy vs. RARP in the post-dissemination era found RARP to have lower 90-d overall rates of wound, respiratory, miscellaneous surgical and medical complications (all $p < 0.04$), lower postoperative transfusion rates and LOS (both $p < 0.001$) [25]. RARP resulted in significantly lesser PSM (even in intermediate and high-risk cases) and need for secondary cancer treatment at 6, 12 and 24 months after surgery [26].

Recently, we described the “ICE” technique (Intra-Corporeal cooling and Extraction) for VIP, which allows bimanual examination of the prostate, frozen section biopsies, and introduction of ice-slush for pelvic hypothermia, using the GelPoint[®] access platform [27]. We expected bimanual palpation and appropriate biopsies to reduce PSM, while pelvic cooling would limit the inflammatory damage to the pelvic neurovasculature during surgical trauma and help preserve potency and continence post-operatively. Compared to patients undergoing conventional prostatectomy, bimanual examination reduced the absolute risk of PSM by 26.6% in pT3a patients ($p = 0.04$). Impact of regional pelvic hypothermia on return of continence is currently being prospectively evaluated.

3.2. Robotic cystoprostatectomy

Menon et al. [28] published their pioneering robot-assisted radical cystoprostatectomy (RARC) series of 17 cases in 2003. Robotic interface provides a safer cystectomy by reducing blood loss and fluid shifts, and avoiding bowel exposure and handling. A less edematous bowel may, thus, be available for post cystectomy diversion, resulting in earlier return of bowel function and decreased length of hospital stay. The described technique by Menon et al. [28] involved nerve-sparing RARC using the principles learnt from the prostatectomy experience, with minimal blood loss. The 5–6 cm suprapubic incision, made for cystoprostatectomy specimen removal, was used to create a neobladder extracorporeally. The created pouch was internalized, and the neo-vesicourethral anastomosis completed with robotic assistance after closure of incision.

Overall margin positive rates of under 7%, 1.6% for T2 disease, are equivalent to published PSM rates of 4%–6% with ORC [29,30].

ORC has a 90-day complication rate of 64% using a standardized reporting methodology, although only 13% of these were Clavien grade 3 to 5. Reoperation was required in 3%, and 11% needed radiologic intervention. Mortality rate was 1.5% [31]. Median blood loss during ORC was 1 L, and two thirds of patients required a blood product transfusion. Using similar reporting format, Guru and coworkers [32] reported comparable postoperative complication and reoperation rates for RARC, with significantly lesser blood loss (400 mL) and need for transfusion (16%). For a matched cohort, there is quicker recovery of bowel function and convalescence following RARC compared to ORC, with equivalent oncological outcome and reduced complications at short and intermediate follow-up [33,34].

With the limited diagnostic capability of CT and MRI for LN staging [35] and evidence to show that extended lymphadenectomy may improve long-term survival and prognosticate the outcome in patients with muscle invasive bladder cancer [36], the role of surgical lymphadenectomy became increasingly more important. There were doubts about robotic lymphadenectomy techniques to raise lymph node yields similar to open methods, as well as capability to replicate the technique at other centers. A multi-institutional cystectomy database, International Robotic Cystectomy Consortium (IRCC), was created for the purpose. Using this large multi-institutional cohort database with approximately 450 lymphadenectomies, yield of lymphadenectomy at robotic cystectomy was shown to be similar to those of open cystectomy series, obtaining a mean of 18 lymph nodes [37]. Further, MD Anderson Cancer Center series had a robotic lymph node yield of 43, with an efficiency of 93%. There was no residual lymphatic tissue in 80% cases on open “second look” lymphadenectomy [38]. The finding is not surprising considering the degree of vessel mobilization and the views available with the robot.

Although initial technique of RARC described by Menon et al. [28] involved exteriorization of bowel through the specimen retrieval wound for extracorporeal suturing before dropping it back for robotic neo-vesicourethral anastomosis, it gradually turned intracorporeal with robotic suturing dexterity as well as developing stapling devices. Multi-centric IRCC data for 90 day postoperative follow-up has recently been published, comparing 167 intracorporeal (ileal conduit: 106; neobladder: 61) to 768 extracorporeal diversions (ileal conduit: 570; neobladder: 198). The operative time (414 min) and median hospital stay (9 days intracorporeal vs. 8 days extracorporeal) were comparable, as were reoperation rates (within 30 days) and complication rates (90 days). As expected with less bowel handling, gastrointestinal complications were significantly less in the intracorporeal group [39].

3.3. Robotic upper tract and renal surgery

The advent of the robotic platform transformed the realm of upper tract surgery too. Robotic kidney surgery program was developed at VUI simultaneous to the pelvic surgery. Robotic nephrectomies were started in January 2004. A

retrospective evaluation of the results for 42 patients (35 radical nephrectomy) showed a mean operative console time of 158 min, mean EBL 223 mL and a mean LOS of 2.4 days. There was no evidence of recurrence at a mean follow-up of 15.7 months [40]. We showed the feasibility of robotic extended pyelolithotomy in 13 patients with stag-horn calculi with a mean operative time of 158 min, mean console time 108 min, and EBL 100 mL, achieving stone free status in all but one patient [41]. Eun et al. [42] described a four-port "baseball diamond" strategy of port placement for patients undergoing nephroureterectomy to allow instrument access to the ipsilateral upper and lower urinary tract in the same operative session, without repositioning the patient and re-docking the robot. Utilizing the robotic magnification and precision in movement for microdissection of anatomical planes around the adrenal gland, a four-step technique of robotic right adrenalectomy [43] and synchronous bilateral adrenalectomy [44] were described.

Helped with some revealing data of laparoscopic partial nephrectomy from Cleveland Clinic, Gill et al. [45] and Ng et al. [46] had established the feasibility of minimally invasive partial nephrectomy using laparoscopy. The steep learning curve of laparoscopy combined with working under the pressure of a limit of warm ischemia time (WIT), unfortunately, limited the use of this minimally invasive platform to select centers only, much like laparoscopic prostatectomy. Efforts had started to develop and refine robot-assisted partial nephrectomy (RAPN) techniques. With minimally invasive partial nephrectomy (PN) becoming the standard of care for renal tumors <4 cm in size, we published our initial experience of RAPN in 10 patients with mean tumor size of 2 cm [47]. In order to improve minimally invasive surgical skills, we devised novel laboratory models for solid renal tumor ("pseudotumor") and renal vein tumor thrombus ("pseudothrombus") in pigs and cadavers [48]. The robotic technique allowed precise resection and helped perform pelviciceal system closure and renorrhaphy, without unduly increasing the warm ischemia time [49].

Techniques of RAPN were continuously refined. In 2009, we illustrated our four-arm technique of RAPN using a transperitoneal approach, highlighting the role of the fourth arm in renal hilar dissection, vascular control and during renorrhaphy [50]. The Tile-Pro feature of the da Vinci allowed visualization of intraoperative USG and pre-operative CT images as a picture-on-picture image on the console screen to aid tumor margin identification [51]. Development of robotic bulldog clamps and intraoperative ultrasound probes gave further functional autonomy to the console surgeon, reducing his dependence on the variably skilled patient-side assistant [52,53]. The first report on the single-surgeon, single-center experience of RAPN for renal tumors was published from VUI, comparing T1a with larger tumors, and found equivalent EBL, total operative time, LOS, complication rates and change in estimated glomerular filtration rate (eGFR) in the two groups [54]. Multi-institutional series later confirmed our results even for more complex tumors [55] and in obese patients [56].

Various techniques for minimally invasive PN, like sliding clip renorrhaphy and early unclamping, appeared in an effort to reduce warm ischemia. Encouraged with the success of UVA with barbed suture during VIP, we established its safety and feasibility of a two-layered, running closure

of the collecting system and renal capsule during renorrhaphy, and significantly lowering WIT compared to standard polyglactin suture (18.5 vs. 24.7 min, respectively, $p = 0.008$) [57]. As regional hypothermia would expand the window for duration of permissible ischemia, we successfully experimented with the GelPoint access platform to introduce ice-slush. With a mean cold ischemia time of 19.6 min and mean EBL of 296 mL, the technique of intracorporeal cooling was successfully used to achieve reproducible results [58].

Retroperitoneal route to kidney obviates the need for bowel mobilization, and may reduce bowel related complications as well as hospital stay. The approach will also confine blood and urine leaks to retroperitoneum, and may maximize the effectiveness of hypothermia techniques in the limited retroperitoneal space. Our recent description of robotic retroperitoneal partial nephrectomy, which permits direct access to renal hilum for posterior renal and hilar tumors is an effort in this direction [59]. A multi-centric study by Hu et al. [60] showed retroperitoneal RAPN to have acceptable morbidity and cancer control outcomes over a median follow-up of 2.7 years, proving retroperitoneal RAPN to be a reasonable option for patients with posterior renal masses or with prior abdominal surgery.

The dissemination of partial nephrectomy has been rapid and safe throughout the world despite its short existence of 10 years, as evident from the published literature. In 2014, RAPN is most common minimally invasive approach for PN, supplanting laparoscopy. Looking at results from nationwide in-patients sample, patients undergoing RAPN had significantly lower odds of receiving a blood transfusion, intraoperative or postoperative complication, or a prolonged LOS, when compared to open PN, and less likely to have intraoperative complications than following laparoscopic PN [61].

3.4. Reconstructive procedures

The advanced laparoscopic procedures involving reconstruction and suturing have steep learning curve and have remained limited to select few laparoscopic wizards and centers around the world. Versatile instrument tip movements, tremor filtering, intuitive movements and 3D vision of robot are most suited for intracorporeal suturing and reconstructive work. It was no surprise that all laparoscopic reconstructive procedures were better accomplished with the robot, and gradually shifted to robotic platform.

Laparoscopic pyeloplasty (LP), dismembered or one of its variants, is a minimally invasive alternative for its open counterpart with equivalent results, and became a reference standard for managing pelvi-ureteric junction obstruction (PUJO) at turn of century. Large experiences with robotic pyeloplasty have appeared in ensuing years. Although long-term success rates could not be bettered, Hemal et al. [62] reported better quality of suturing and faster perioperative parameters of dissection time, intracorporeal suturing, and overall operating time using robotic interface when compared to conventional pyeloplasty. Sukumar and colleagues [63] found that use of minimally invasive pyeloplasty increased dramatically from 2.4% to 55.3%, a 23-fold increase, in the United States during the decade 1999 to 2009. Though it was not possible to

differentiate robotic and laparoscopic trends as robotic code had not been separated till 2008, robotic pyeloplasty was the clear winner in 2009, accounting for 45.1% of all cases, with LP accounting for just 10.2%.

Pelvic organ prolapse (POP) affects 30% of women aged above 50 years, and needs surgical repair in 11% by 80 years. Robotic sacrocolpopexy (RSC) became a natural successor to its laparoscopic counterpart, as the procedure was being performed in a limited pelvic space with need for intracorporeal suturing. The robotic technique of sacrocolpopexy was refined at VUI to modify the port placements and docking identical to RARP, using a uterine positioning system for vaginal vault adjustment instead of a sponge-vaginal pack, a softer mesh to reduce the risk of erosion, and a barbed continuous suture (V-Loc) for securing the mesh and closing the peritoneal incision. The modifications reduced operating times, LOS and intraoperative blood transfusions during RSC [64].

Congenital anomalies of the urinary tract make a large chunk of reconstructive urology, involving removal of whole kidney or its part, with or without ureteric or ureterovesical reconstruction. With its capability to work in small places and better identification of planes (especially following previous surgery), robot was expected to improve upon the laparoscopy outcomes and reduce conversions. Robotic pediatric urology program was simultaneously developed at VUI. Small distance of abdominal wall to the target organ was initially a challenge for pediatric robotic surgery in infants and younger children, since it is mandatory to keep a fixed cannula length inside the port. The problem was sorted out by keeping the skin incisions as far away from the operative site as possible [65]. It takes small excursions of the robotic arm to reach different parts of peritoneal cavity in such cases, thus avoiding collision despite crowding. Almost all urological surgical procedures in children have been performed with the assistance of the robotic interface, most common being pyeloplasty, nephrectomy or hemi-nephrectomy and surgery for vesico-ureteric reflux. Initial series of advanced reconstructive procedures like bladder augmentation and appendicovesicostomy are available. Although it may not yet be possible to demonstrate the superiority of robotic approach over conventional surgery, it is feasible, well tolerated, and advantageous in reconstructive pediatric urological procedures [66].

3.5. Robotic kidney transplantation

Menon and colleagues at VUI conceived the idea of Robotic Kidney Transplantation (RKT) with hypothermia in 2012 in collaboration with Medanta Vattikuti Institute in India. Open Renal Transplantation technique has remained unchanged since last 60 years. Theoretically, a minimally invasive kidney transplantation would avoid wound infections, reduce complications and speed recovery, as has been proved in every other surgical sphere so far.

Other than an early description by Abbou and coworkers [67], where the authors performed a kidney transplantation using articulated robotic instruments through a left lower quadrant open incision, there were only two case reports of RKT in literature till 2013 [68,69]. There were small

experiences with attempts at laparoscopic recipient surgery too [70]. These attempts, apart from their non-uniform approaches, had been criticized for slow decline of renal functions postoperatively, ascribed mainly to lack of intracorporeal organ cooling during the anastomosis. The technique of pelvic cooling and regional hypothermia had been standardized at HFH using the prostatectomy model, achieved by ice slush delivered through a GelPoint[®] device. Following pre-clinical studies, successful phase 1 clinical trial of RKT with hypothermia, conducted at Medanta, India in January 2013, proved its feasibility, with results equivalent to the open surgery [71].

Seventy successful RKT have been performed till May 2014. A minimum of 6 months in 25 RKT recipients showed mean console, arterial, and venous anastomotic times to be 135, 12, and 13.4 min, respectively. All grafts could be maintained at 18–20 °C till clamp release, without change in core body temperature. All grafts functioned immediately post-transplant and the mean serum creatinine level at discharge was 1.3 mg/dL. No perioperative complications, such as anastomotic leaks, wound complications, or wound infections, were observed. At 6-month follow-up, no patient developed a lymphocele, detected on CT scan [72]. Usefulness of RKT in morbidly obese patients, who have traditionally not been candidates for open surgery, has also been proved [73]. RKT, thus, seems to have a potential of being another important robotic application in future.

3.6. Growth of robotic applications in other specialties and around the world

The da Vinci Robot got FDA approval for gynecologic procedures in 2005. The last decade has seen a rapid increase in use of the robot in the gynecologic world, and the related literature. Robotic hysterectomy, myomectomy, gynecologic fistula repair and transabdominal sacrocolpopexy have shown results equivalent to open surgery. In a systematic review of both randomized and observational studies, the Society of Gynecologic Surgeons Systematic Review Group found that robotic approach consistently provided shorter hospital stay, and robotic technique was more advantageous than open surgery while managing endometrial cancer [74].

Robotic assistance also helped video assisted thoracic surgery (VATS) reach organs in depth of chest wall with ease [75]. Robotic thymectomy using the thoracoscopic approach has been accepted as technically sound and safe with very low complication rates for the treatment of myasthenia gravis. It was performed most frequently using the unilateral three-trocar approach. Approximately 3500 robotic thymectomy have been already registered till 2013 [76]. In a recent review of national database, robotic assisted pulmonary resections were associated with significant reductions in mortality, hospital stay and overall complication rates when compared with open thoracotomy [77].

Application of robotic dexterity and technology also helped the approach to superficially placed organs where breach of skin was to be avoided, either due to cosmetic reasons (as for thyroidectomy and parathyroidectomy using the bilateral axillo-breast approach) or dreaded morbidity (as for inguinal lymphadenectomy). Trans-oral robotic

surgery (TORS) became another specialist area of use of robotic advantage in an open platform, to treat the lesions in the skull base [78] or the depths of oral cavity [79]. Oropharynx, base of the tongue or larynx is approached with robotic arms using one of advanced oral retractor systems and a temporary tracheostomy. Robot with its tremor filtration, magnified view and console ergonomics is a wonderful tool for fine suturing alone, even in an open platform, a fact that has found its use in the field of male infertility, for vaso-vasostomy [80] and vaso-epididymostomy [81], using as fine suture as 11/0.

It took nearly half a decade for the robot to travel to the opposite part of the world, but since then, South Korea has been quick to jump on the robotic bandwagon. Dr Rha's group in Korea demonstrated the safety and feasibility of robotic laparoendoscopic single-site (LESS) partial nephrectomy for renal tumors >4 cm [82]. The benefits of robotic surgery were borne out in India too, not only for RARP, but also for robotic pyeloplasty [83], robot-assisted inguinal lymph node dissection for penile cancer [84], and robotic high-intensity focused ultrasound [85].

3.7. IDEAL guidelines for pioneering surgical work

The introduction and adoption of a surgical innovation has to be evidence based, rather than trial and error. It is also important to derive learning curves so as to assess mentoring requirements while disseminating a new procedure. All robotic developments at HFH, from prostatectomy in 2000 till renal recipient surgery in 2013, have that hallmark, with similar design process. After conceiving a procedure, a talent pool was created for initial trials. Development and long-term studies followed, and objective assessment of the outcome variables was done at each step. Learning curves for surgeons with differing experiences were defined during the monitoring and proctoring of the procedure. McCullouch and colleagues [86] have described IDEAL (innovation, development, exploration, assessment, long-term follow-up) model for assessing and reporting a new surgical procedure in 2009, consisting of five-stage process. RKT has been recently innovated using IDEAL guidelines at HFH and reported [71].

Learning curve and surgical dexterity are two parameters that are used to compare surgical learning and training. It is difficult to define learning curves, with varying definitions from study to study. Studied parameters have varied from subjective (like confidence and comfort level of operating surgeon or self assessed study scores) to objective to reach a proficiency limit (like number of cases required to reach a threshold console time, OR time, or PSMs). While developing RKT, we have used new statistical tools of cumulative summation (CUSUM) and Shewhart control chart analytic techniques to monitor the patient safety and define learning curves, respectively. These methods allow objective determination of the duration of mentorship and identification of adverse events in a timely manner [87].

4. Conclusion

The growth of minimally invasive surgical techniques afforded definite advantages to the surgeon and the

patient: it decreased surgical trauma and blood loss during procedures, and hastened convalescence with better cosmesis. This was achieved with loss of wrist movements and ergonomics, non-intuitive movements, and downgrade of normal vision to 2D monitors. It is not surprising that advanced laparoscopic techniques had steep learning curve, and remained confined to few skilled masters only. Laparoscopy was a transition technology with tremendous benefits, but could not prosper with so many limitations. Robotic assistance gave laparoscopy everything back it lost, except haptic feedback, at an additional added cost. Mani Menon, and his team at the VUI, pioneered and helped establish the role of robot in the field of urology. It helped allied specialties to join in the robotic revolution.

These developments and innovations had both direct and indirect benefits, ushering in revolutionary changes in the specialties of urology, thoracic surgery and gynecology, amongst others. New fields like TORS have emerged. Innovative use of unidirectional barbed suture has benefitted outcome measures in a variety of reconstructive procedures, and transformed its use profile. Use of the GelPoint[®] device for uninhibited access to peritoneal cavity helped improve prostatectomy PSMs, and develop pelvic cooling technique, which in turn paved way for pioneering RKT with hypothermia. It also helped barbed suture and GelPoint[®] industry to widen indications and applications, and flourish.

Surgical robots are here to stay. With integration of computers, the field has become one of the front-runners in applied research. Computer interphase has already made it possible to integrate imaging with the current generation robots. New robots and applications are on horizon. The major downside of the technology is the cost. We expect the technology to prosper and proliferate, becoming better and cost effective in times to come. The market competition and device innovations should translate to cost effectiveness and improved quality, outcome parameters and experience for the patients.

Conflicts of interest

The authors declare no conflict of interest.

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