Robotic microsurgery 2011: male infertility, chronic testicular pain, postvasectomy pain, sports hernia pain and phantom pain
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Introduction
Since the use of the operating microscope for microsurgery in 1975 [1], there has been a steady increase in the use of such technology in the operative management of male infertility and chronic testicular or groin pain [1–11]. Added to the reports relating to greater patency rates and fertility rates of vasovasostomy performed with the operating microscope [12], the concepts of magnification have been successfully applied to vasoepididymostomy and varicocelectomy, microsurgical denervation of the spermatic cord for chronic testicular or groin pain, post-vasectomy pain, sports hernia pain, postnephrectomy, donor nephrectomy and phantom groin pain. Preliminary animal studies show an advantage in terms of improved operative efficiency and improved surgical outcomes. Preliminary human clinical studies appear to support these findings. The use of robotic assistance during robotic microsurgical vasovasostomy appears to decrease operative duration and improve early postoperative sperm counts compared to the pure microsurgical technique.

New robotic surgical platform
Intuitive Surgical (Sunnyvale, CA, USA) now offers an enhanced four-arm DaVinci type Si robotic system with High Definition digital visual magnification that allows for greater magnification than the standard robotic system (up to 10–15×). The enhanced magnification capability allows the surgeon to position the camera 6–7 cm away from the operative field to avoid any local tissue effects from the heat emitted from the camera lighting (this was a problem with the older system, in which the camera had

Purpose of review
The use of robotic assistance during microsurgical procedures has evolved from its early beginnings in the early 2000s. Currently, its use is expanding in the treatment of male infertility and patients with chronic testicular or groin pain. The addition of this technology may allow an improvement in outcomes as when the operating microscope was introduced in microsurgery. However, this is yet to be proven.

Recent findings
This review covers new robotic microsurgical tools and applications of the robotic platform in microsurgical procedures such as vasectomy reversal, varicocelectomy, microsurgical denervation of the spermatic cord for chronic testicular or groin pain, post-vasectomy pain, sports hernia pain, postnephrectomy, donor nephrectomy and phantom groin pain. Preliminary animal studies show an advantage in terms of improved operative efficiency and improved surgical outcomes. Preliminary human clinical studies appear to support these findings. The use of robotic assistance during robotic microsurgical vasovasostomy appears to decrease operative duration and improve early postoperative sperm counts compared to the pure microsurgical technique.

Summary
Long-term prospective controlled trials are necessary to assess the true cost–benefit ratio for robotic assisted microsurgery. The preliminary findings are promising and evidence is mounting, but further evaluation is warranted.

Keywords
denervation of spermatic cord, groin pain, neurolysis, phantom pain, postvasectomy pain, reversal, robotic, sports hernia pain, vascular anastomosis, vasectomy, vasoepididymostomy, vasovasostomy

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to be placed within 2–3 cm of the operative field for microsurgery). This new system allows a greater range of motion and better microsurgical instrument handling. The additional fourth arm has improved the range of motion and positioning capabilities to provide the microsurgeon with one additional tool during procedures. The robot is positioned from the right side of the patient for microsurgical cases.

**Refined robotic Doppler flow probe**

Cocuzza et al. [20**] have shown that the systematic use of intraoperative vascular Doppler ultrasound during microsurgical subinguinal varicocelectomy improves precise identification and preservation of testicular blood supply. During robotic microsurgical cases, the standard Doppler probe has to be held by a surgical assistant and cannot be manipulated readily with the robotic graspers. A new revised Micro-Doppler flow probe (MDP) has been developed by vascular Technology Inc. (Nashua, NH, USA) that is designed specifically for use with the robotic platform (Fig. 1). This new probe allows for easy manipulation of the probe with the fourth arm and allows the surgeon to perform real-time Doppler monitoring of the testicular artery during cases such as robotic assisted microscopic varicocelectomy (RAV\(x\)) and robotic assisted microscopic denervation of the spermatic cord (RMDSC). This allows the surgeon to hear the testicular artery flow while dissecting out the veins and nerves with the other two robotic arms.

A recent prospective randomized control trial of the MDP in 273 robotic microsurgical cases from July 2009 to September 2010 was performed: 67 robotic subinguinal varicocelectomies (RV\(x\)) and 206 robotic spermatic cord denervation procedures (RMDSC). The use of the MDP was randomized to five RV\(x\) and 20 RMDSC procedures. The primary endpoint was operative time and secondary endpoint was surgeon ease in testicular artery localization and robotic grasper maneuverability. Operative duration was not affected by utilization of the MDP (\(P = 0.5\)). The MDP was effective in identifying all testicular arteries within the spermatic cord in all cases. As a result of the compact size of the MDP, maneuverability using the robotic grasper was significantly improved over the standard handheld Doppler probe. MDP allowed for full range of motion of the robotic arms allowing the surgeon to easily scan vessels from a wide range of angles. No complications from use of the MDP occurred. The new Micro-Doppler probe for robotic microsurgical procedures appears to have performed effectively in this study.

**Enhanced 100\(x\) digital visual magnification**

The miniaturization and development of advanced digital microscopic cameras (100–250\(x\)) allows even greater magnification than the standard robotic (10–15\(x\)) and microscopic (10–20\(x\)) magnification in use at this time. Our group is currently involved in clinical trials of a 100\(x\) digital camera (Digital Inc., China) that can be utilized via the TileProDaVinci Si robotic system (Intuitive Surgical, Sunnyvale, CA, USA) to allow the surgeon to toggle or use simultaneous 100\(x\) and 10–15\(x\) visualization. This provides the surgeon with unparalleled visual acuity for complex microsurgical procedures.

**New saline-enhanced electrosurgical resection**

Saline-enhanced electrosurgical resection (SEER) has been utilized for cauterization of vessels in a number of liver and renal applications. It is a form of electrosurgical cauterization and resection that leads to minimal smoke and scar formation. The SEER (Fig. 2) is being adapted (Bovie Medical Corporation, Clearwater, FL,
USA) to possibly provide an option for ablation of veins during robotic assisted subinguinal varicocelectomy.

Robotic assisted microscopic vasectomy reversal

A number of groups have developed robotic assisted techniques to perform RAVV in animal and ex-vivo human models [21–25]. Some studies suggest that robotic assisted reversal may have advantages over microsurgical reversal in terms of ease of performing the procedure and improved patency rates [23,24]. A few groups have actually performed human robotic assisted vasovasostomies using the initial DaVinci robotic system [26] (Intuitive Surgical, Sunnyvale, CA, USA).

These efforts have been recently confirmed in human RAVV cases performed using the new DaVinci Si system [27*]. A recent prospective control study of robotic versus pure microsurgical vasovasostomy in 90 vasectomy reversal cases performed from August 2007 to September 2010 by a single fellowship trained microsurgeon was performed (this was an extension to a previously published study) [29**]. The primary endpoint was operative duration. The secondary endpoint was total motile sperm count at 2, 5, 9 and 12 months postoperatively. Case breakdown was as such: 45 robotic assisted cases and 45 pure microsurgical cases. Selection of approach (robotic versus pure microscopic) was based on patient choice (robotic was more expensive than microscopic). Pre-operative patient characteristics were similar in both groups. The same suture material and suturing technique (two-layer 10–0 and 9–0 nylon anastomosis) was used in both approaches.

Median clinical follow-up was 14 months (range 1–37 months). Median duration from vasectomy in the robotic group was 8 years (1–19) and in the microscopic group 6.5 years (1–19). Ninety-four percent overall patency was achieved in the RAVV cases and 79% in MVV (>1 million sperm/high power field). Median operative duration was significantly decreased in RAVV at 90 min (60–180) compared to MVV at 120 min (60–180), $P = 0.004$. Mean postoperative total motile sperm counts were not significantly higher in RAVV versus MVV but the rate of postoperative sperm count recovery was significantly greater in RAVV.

The use of robotic assistance in microsurgical vasovasostomy may have potential benefit over MVV with regards to decreasing operative duration and improving the rate of recovery of postoperative total motile sperm counts. Further evaluation and longer follow-up are needed to assess its clinical potential and the true cost–benefit ratio.

Robotic assisted microscopic varicocelectomy

Although reports of robotic assisted laparoscopic infra-abdominal varicocelectomy have been published [30], there are a number of publications that suggest that microscopic subinguinal varicocelectomy (MV$\times$) may provide superior outcomes compared to intra-abdominal varicocelectomy [31*,$32^*,33,34$]. Shu et al. [35] were the first to publish on robotic assisted microsurgical subinguinal varicocelectomy (RAV$\times$). They compared standard microsurgical to robotic assisted varicocelectomy and found that the robotic approach provided advantages in terms of slightly decreasing operative duration and complete elimination of surgeon tremor.

To further explore these findings, we performed a prospective randomized control trial of MV$\times$ to RAV$\times$ in a canine varicocele model by a fellowship-trained microsurgeon. The surgeon performed cord dissection and ligation of three veins with 3–0 silk ties. Twelve canine varicocelectomies were randomized into two arms of six: MVV versus RAV$\times$. Procedure duration, vessel injury
and knot failures were recorded. The RAV × mean duration (9.5 min) was significantly faster than MVV (12 min), \( P = 0.04 \). The duration for robot setup and microscope setup was not significantly different. There were no vessel injuries or knot failures in either group.

A review of our initial 230 RMDSC cases from October 2008 to September 2010 (median follow-up 11 months; range 1–27) is as follows. The median duration per side was 30 min (10–80). Indications for the procedure were the presence of a grade two or three varicocele and the following conditions: 10 with azoospermia, 42 with oligospermia and 49 with testicular pain (with or without oligospermia, and failed all other conservative treatment options). Three-month follow-up was available for 81 patients: 75% with oligospermia had a significant improvement in sperm count or motility, one with azoospermia was converted to oligospermia. For testicular pain: 92% had complete resolution of pain (targeted neurolysis of the spermatic cord had been performed in addition to varicocelectomy). One recurrence or persistence of a varicocele occurred (by physical and ultrasound exam), one patient developed a small postoperative hydrocele and two patients had small postoperative scrotal hematomas (treated conservatively). The fourth robotic arm allowed the surgeon to control one additional instrument during the cases decreasing reliance on the microsurgical assistant. The fourth arm also enabled the surgeon to perform real-time intraoperative Doppler mapping of the testicular arteries while dissecting the veins with the other arms if needed.

Robotic assisted microsurgical subinguinal varicocelectomy appears to be safe, feasible and efficient. The preliminary human results appear promising. Further evaluation and comparative effectiveness studies are warranted.

**Robotic assisted microscopic denervation of the spermatic cord**

Recent studies by Levine [13] and Oliveira et al. [14] have shown that microscopic denervation of the spermatic cord is an effective treatment option for men with chronic testicular pain. Our group has been developing a robotic assisted microsurgical approach for the denervation of the spermatic cord (RMDSC) to assess if there may be any potential benefit over the standard microscopic technique.

A review of our initial 230 RMDSC cases from October 2008 to September 2010 was performed (median follow-up of 8 months). Selection criteria for patients were as such: chronic testicular pain (>6 months), failed standard pain management treatments and negative urologic workup. A robotic assisted subinguinal, inguinal or intra-abdominal approach was utilized based on the location of pain. Pain was assessed utilizing a standardized validated tool (PIQ-6). The median operative duration was 20 min (7–150). The fourth robotic arm allowed the surgeon to control one additional instrument leading to less reliance on the microsurgical assistant.

Postoperatively, 77% (176) patients had complete resolution of pain and 8% (19) had a 50% decrease in pain. RMDSC was successful in eliminating testicular and groin pain for a number of possible etiologies: postvasectomy pain syndrome, postinguinal hernia pain, sports hernia or groin trauma pain, chronic epididymitis or idiopathic pain, varicocele pain, postrobotic prostatectomy pain or testicular pain, postnephrectomy or donor nephrectomy groin or testicular pain, postpelvic radiation or brachytherapy groin or testicular pain and fibromyalgia groin pain. Figure 3 illustrates the outcomes in these various pain categories.

**Single port and abdominal robotic microsurgical neurolysis for phantom groin pain after orchiectomy or persistent orchialgia after denervation of the spermatic cord**

Chronic groin pain can be debilitating for patients. Microsurgical subinguinal denervation of the spermatic cord (MDSC) is a treatment option for this pain. However, there are limited further options for patients who fail this treatment or who have phantom pain after orchiectomy. Our goal was to develop a single port and abdominal robotic microsurgical neurolysis technique to ligate the genitofemoral and inferior hypogastric nerve fibers within the abdomen above the internal inguinal ring.

We performed a prospective study of patients with chronic groin pain who had either failed previous MDSC or had phantom pain after orchiectomy. Primary endpoint was impact of pain on quality of life (PIQ-6 pain impact questionnaire from RAND) and secondary endpoint was operative robotic duration. PIQ-6 scores were collected preop and at 1, 3, 6 and 12 months postop.

We completed 30 cases (five single port) from June 2009 to September 2010. Elimination of pain occurred in 60% (18 cases) and a greater than 50% reduction in pain occurred in an additional 13% (four cases) within 1 month postop. Two of the failures were patients who had pain elimination for 6 months but then pain returned thereafter. Median odds ratio duration was 10 min (5–30). There were three complications: one postop scrotal hematoma that resolved with conservative measures, one patient had pain at one of the port sites and one patient had pain that shifted from the groin to the leg.
Single port and abdominal robotic microsurgical neurolysis appears to be an option for treatment in this difficult patient population. Further follow-up and evaluation is warranted.

**Conclusion**

The use of robotic assistance during microsurgical procedures is expanding. The application of this technology in other microsurgery fields apart from urology is also expanding, such as ophthalmology, hand surgery, plastics and reconstructive microsurgery. The advantages of a stable microsurgical platform, ergonomic surgeon instrument controls, elimination of tremor and magnified immersive 3D vision are all intuitively apparent. Further comparative effectiveness studies are ongoing and will be forthcoming on the true applicability of this new surgical platform. However, the preliminary results so far are quite impressive.

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**References and recommended reading**

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 168).

Update on laparoscopic and robot-assisted laparoscopic surgery in urology

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