Robotic surgery in male infertility and chronic orchialgia
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Purpose of review
The use of robotic assistance during microsurgical procedures is currently being explored in the treatment of male infertility and patients with chronic testicular pain. Whether the addition of this technology would allow a corresponding improvement in outcomes as when the operating microscope was introduced in microsurgery is yet to be seen.

Recent findings
The present review covers new robotic microsurgical tools and applications of the robotic platform in microsurgical procedures such as vasectomy reversal, varicocelectomy, denervation of the spermatic cord for chronic testicular pain and microsurgical vascular anastomosis. Preliminary animal studies appear to 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 significantly improve early postoperative sperm counts compared with the pure microsurgical technique.

Summary
As with any new technology, long-term prospective controlled trials are necessary to assess the true cost–benefit ratio for robotic assisted microsurgery. The preliminary findings are promising, but further evaluation is warranted.

Keywords
denervation of spermatic cord, neurolysis, reversal, robotic, vascular anastomosis, vasectomy, vasopididymostomy, vasovasostomy

Introduction
Since the earliest published descriptions of the use of the operating microscope 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 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 vasopididymostomy and varicocele ligation. More recently, microscopic spermatic cord neurolysis has demonstrated applicability to the treatment of groin and testicular discomfort [13,14]. These techniques require varying degrees of microsurgical skills and an array of supporting technology, neither of which may be part of many urologists’ personal or technical armamentarium. The melding of improved visualization with magnification to an ergonomic platform that can be operated on remotely has a significant application to testicular and reproductive surgery. Robotic assistance during surgical procedures has been utilized in a wide array of surgical fields with the above mentioned benefits [15–19]. This review covers the latest developments in the robotic microsurgical platform, robotic microsurgical tools and current evaluations of various robotic microsurgical applications for male infertility and patients with chronic testicular pain.

New robotic surgical platform
Intuitive Surgical (Sunnyvale, California, USA) now offers an enhanced 4-arm DaVinci type S or Si robotic system with high definition digital visual magnification that allows for greater magnification than that with 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 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

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side of the patient for microsurgical cases as illustrated in Fig. 1.

**Enhanced 100× digital visual magnification**

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

**Robotic Doppler flow probe**

A recent study by Cucuzza et al. [20**] has 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 micro-Doppler flow probe (MDP) has been developed by vascular Technology Inc. (Nashua, New Hampshire, USA), which is designed specifically for use with the robotic platform (Fig. 2). 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 (RAVx) 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.

During initial evaluation in one patient who was undergoing bilateral RMDSC, the MDP was effective in identifying three testicular arteries within the spermatic cord on either side. Due to the compact size of the MDP and the presence of a small grasping handle for the robotic grasper, 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. The total operative duration for the case (bilateral) was 70 min, eight veins were ligated on the left and six on the right. No complications occurred. The new MDP for robotic microsurgical
Robotic assisted microscopic vasectomy reversal

A number of groups have developed robotic assisted techniques to perform robotic assisted vasovasostomy (RAVV) in animal and ex-vivo human models [21–25]. Some studies suggest 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 vasovasotomies using the initial DaVinci robotic system [26] (Intuitive Surgical).

These efforts have been recently confirmed in human RAVV cases performed using the new DaVinci S system [27]. A recent prospective control study compared initial results for RAVV in 20 human cases compared with seven cases of standard microscopic vasovasotomies (MVV) by a single fellowship-trained microsurgeon from July 2007 to June 2009 [28]. A three-layer 10–0 and 9–0 suture anastomosis (Fig. 2) was performed with up to 22 months of follow-up (mean – 3 months). Mean operative duration for the RAVV cases was 109 min and 128 min for MVV (P<0.09). At 2 months postoperation, all patients were patent (defined as greater than 2 million motile sperm in ejaculate). Mean sperm count was 54 million in RAVV and 11 million in MVV (P<0.04). The use of robotic assistance in microsurgical vasovasotomy may have potential benefit over MVV in decreasing operative duration and significantly improving early semen analysis measures. Further evaluation and longer follow-up is needed to assess its clinical potential and the cost–benefit ratio.

Robotic assisted microscopic varicocelectomy

Although reports of robotic assisted laparoscopic intraabdominal varicocelectomy have been published [29], there are a number of publications that suggest that microscopic subinguinal varicocelectomy (MVx) may provide superior outcomes compared with intraabdominal varicocelectomy [30–32,33]. Shu et al. [34] were the first to publish on robotic assisted microsurgical subinguinal varicocelectomy (RAVx). 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 controlled trial of MVx vs. RAVx in a canine varicocele model by a fellowship-trained micro-

Figure 2 Robotic micro-Doppler probe (Vascular Technology Inc., Nashua, New Hampshire, USA)

surgeon. 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 vs. RAVx. Procedure duration, vessel injury and knot failures were recorded. The RAVx mean duration (9.5 min) was significantly shorter than that of MVV (12 min; P<0.04). The duration for robot set-up and microscope set-up was not significantly different. There were no vessel injuries or knot failures in either group.

A review of our initial 25 human cases from June 2008 to July 2009 is as follows. Mean operative duration per side was 41 min (25–80 min). Indications for the procedures were three for azoospermia, 17 for oligospermia and five for testicular pain (had failed all other conservative treatment options). A 3-month follow-up is available for 11 patients: seven with oligospermia had a significant improvement in sperm counts (two achieved pregnancy) and two with azoospermia remain unchanged. As regards to testicular pain patients, all had complete resolution of pain. The fourth robotic arm allowed the surgeon to control one additional instrument during the cases, decreasing reliance on the microsurgical assistant.

Robotic assisted microsurgical subinguinal varicocelectomy appears to be feasible. There are potential advantages of decreasing operative duration and improving surgeon efficiency. Further prospective randomized controlled trials are needed to define the benefit of robotic assistance in this procedure over standard microsurgery.

Robotic assisted microscopic denervation of the spermatic cord

Recent studies by Levine [13] and Oliveira et al. [14] have shown that MDSC 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 whether there may be any potential benefit over the standard microscopic technique (Fig. 3).

A review of our initial 24 RMDSC cases from October 2008 to June 2009 was performed (mean follow-up – 2 months). Selection criteria for patients were as follows: chronic testicular pain (>6 months), failed standard pain management treatments, negative neurologic and urologic workup and complete temporary resolution of pain with local anesthetic spermatic cord block. A robotic assisted subinguinal, inguinal or intraabdominal approach was utilized based on the location of pain. Pain was assessed utilizing a standardized validated tool (Pain Index Questionnaire, PIQ-6). The mean operative duration was 41 min (19–80 min). Postoperatively, 75% of patients (18) had complete resolution of pain and 17% (four) had a 50% decrease in pain. The two patients with continued pain had resolution of pain for only 1 month. The fourth robotic arm allowed the surgeon to control one additional instrument leading to less reliance on the microsurgical assistant.

Robotic assisted microscopic testicular artery reanastomosis
During a robotic assisted denervation of the spermatic cord in a patient with chronic testicular pain, an inadvertent injury to one of the three testicular arteries occurred. Real-time intraoperative Doppler mapping of the testicular arteries had been performed during this case and helped to identify the injury immediately. The two ends of the artery were tied and the denervation procedure was completed. Microvascular atraumatic clamps were placed on both ends of the artery, the injured segment of artery was excised and a robotic assisted microsurgical vascular anastomosis was performed with eight interrupted 8-0 prolene sutures (Fig. 4). The clamps were removed and arterial flow was confirmed distally with Doppler evaluation. The operative duration (skin to skin) for the entire procedure – denervation and artery repair – was 95 min. The patient was admitted overnight for observation and then discharged the next morning without any further complications. At 1-month follow-up, there does not appear to be any testicular atrophy or testicular pain. We will be following this patient to assess long-term outcomes. This case illustrates the capability of the robotic microsurgical platform to not only perform the desired procedure, but also to act as an additional tool in the microsurgeon’s arsenal in repairing injuries that occur during procedures.

Conclusion
In the last part of the 20th century, urology became one of a few surgical specialties to embrace robotic technology in the management of urologic disease. Right, wrong or even only transient, the use of the robot as a steady platform, for multiple instrument manipulation with seven degrees of freedom and a three-dimensional view with 10–15 times magnification should be intuitively attractive to microsurgeons looking to embrace this advance in technology and for robotic surgeons looking to increase their robotic surgical repertoire. There are distinct potential advantages for both groups. The studies to date are preliminary and further evaluation is warranted.
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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. 102).

• This article provides an extensive in-depth review of the MDSC procedure and its long-term outcomes.
• This article provides a good multi-institutional review of outcomes of the MDSC procedure and supports previous publications on the subject.
• This paper definitively proves previous speculations that the use of intraoperative Doppler may lead to a decrease in inadvertent testicular artery injury. It also shows that the use of Doppler allows the surgeon to detect more veins and arteries compared with non-Doppler cases.
• This article presents initial clinical human results for RAV and vasovasodinstomy using the new enhanced robotic platform.
• This article provides an in-depth discussion of the technique of RAV using the new enhanced robotic platform. It also provides the first human clinical outcomes that suggest a possible advantage of the robotic approach over the pure microsurgical technique.
• This article provides a thorough comparison of various varicocelectomy approaches and favors the subinguinal microsurgical approach.
• This article is a meta-analysis that provides evidence that favors the subinguinal microscopic approach to varicocelectomy.
• This article further provides evidence to support the subinguinal microscopic approach over laparoscopy for varicocelectomy.
• This article is the first comparative clinical human study to show advantages of the robotic assisted microsurgical approach to varicocelectomy over the pure microscopic technique. This article illustrates that robotic microsurgical procedures are reproducible at different institutions.