Current status of vasectomy reversal

J. Ullrich Schwarzer and Heiko Steinfatt

Abstract | Vasectomy reversal is the most common microsurgical intervention for the treatment of male infertility. Originally introduced in 1977, microsurgical vasectomy reversal has become highly sophisticated and is a minimally invasive, highly efficient and cost-effective treatment option for men with a desire to have children after vasectomy. It can be an effective physiological method of restoring fertility in more than 90% of vasectomized men. Although assisted reproductive technology (ART) is an alternative to vasectomy reversal, it is normally associated with higher costs without offering higher cumulative chances of a pregnancy. Recovery of physiological male fertility can take up to 2 years after vasectomy reversal, especially if reversal is performed >10 years after vasectomy, owing to impaired epididymal function. Under these circumstances, ART can be used to bridge the time until recovery of natural fertility. Although the basic principles of microsurgical vasovasostomy have been established since the late 1970s, there have since been numerous technical innovations to improve the delicate operation and promising new technical modifications, particularly for vasoepididymostomy, have been described. Robotic vasectomy reversal is an emerging field in specialized urologic centers, but whether the high quality of conventional microsurgical vasectomy reversal can be matched by robotic platforms is yet to be seen.

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Introduction

Vasectomy reversal is a surgical procedure that reconstructs the male reproductive tract after vasectomy. Although vasectomy reversal is usually performed to restore male fertility, it occasionally serves as a treatment for postvasectomy pain syndrome (PVPS). Depending on the obstructed location, vasectomy reversal can be performed as either vasovasostomy or vasoepididymostomy.

Vasectomy is a safe and effective method of voluntary contraception that is used by approximately 42–60 million men worldwide.[1,2] After vasectomy approximately 6% of men subsequently decide to undergo vasectomy reversal, despite preoperative counselling regarding the permanency of the procedure and the option of sperm banking.[3]

The surgical treatment of obstructive azoospermia was introduced by Edward Martin in 1902—Martin performed the first documented vasoepididymostomy using silver-wire sutures in a man with epididymal obstruction secondary to prior gonococcal infection. Martin, who was Chief Surgeon at the University of Pennsylvania, is considered by many to be the founding father of modern clinical andrology.[4] By the 1970s, many reports on macrosurgical vasectomy reversal were published. Hulka and Davis[4] reported a patency rate of 60% and a pregnancy rate of 44% in a cohort of 705 patients. In 1977, Owen[5] and Silber[6] independently described the microsurgical technique of vasectomy reversal, which is now well established in clinical practice. Although there have been numerous technical innovations for vasovasostomy—such as the microdot method, modified multilayer techniques and improved suture materials—the basic principles for modern microsurgical vasovasostomy are the same as those described in 1977. Vasoepididymostomy is still an evolving field and promising new technical modifications continue to be proposed. Large case series investigating microsurgical vasectomy reversal have been published, reporting excellent results compared with the initial macrosurgical approaches reported by Hulka and Davis. In our own series, which included 1,303 patients, overall patency and pregnancy rates were 89% and 59%, respectively.[7] Silber and Grotjan[8] report an overall patency rate of 89.5% ($n = 3{,}378$), but reported pregnancy rates for only a selected subgroup of patients, and Belker *et al.*[9] described a patency rate of 86% and a pregnancy rate of 52% ($n = 1{,}247$). In a series of 100 consecutive and concurrent vasoepididymostomies and 100 vasovasostomies, Matthews *et al.*[10] reported patency rates of 65% for vasoepididymostomy and 99% for vasovasostomy. Chan *et al.*[11] described a patency rate of 84% in 63 patients who underwent vasoepididymostomy performed bilaterally or unilaterally in a functionally solitary testis using a modern intussusception technique.

In the case of PVPS, vasectomy reversal can be an effective surgical treatment option after medical management has failed.[12–14] However, before proceeding with vasectomy reversal, patients should be offered comprehensive counselling and pain management as a first-line treatment.[12]

Competing interests
The authors declare no competing interests.

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Key points

- Vasectomy reversal is a very safe, minimally invasive and successful treatment option for managing male infertility after vasectomy
- Vasectomy reversal is more cost-effective than assisted reproduction techniques (ART) and cumulative pregnancy rates are at least as high as success rates of ART, even for couples in which the female partner is >35 years old
- The vasectomy reversal procedure demands the skills of an experienced microsurgeon who is capable of performing vasoepididymostomy—the most challenging microsurgical vasectomy reversal procedure—if indicated
- Intussusception vasoepididymostomy and the microdot method are technical innovations that can facilitate vasectomy reversal and might further improve outcomes
- In selected patients, vasectomy reversal and ART can be seamlessly combined; immediately starting ICSI after vasectomy reversal can bridge the interval between surgery and fertility when a longer recovery of fertility after vasectomy reversal is expected

In this Review, we will consider contemporary patient evaluation and care as well as microsurgical techniques and outcomes of vasectomy reversal. We will provide an insight into the physiology of postvasectomy changes and their consequences for optimal treatment of male infertility after vasectomy. Innovative surgical methods and important intraoperative considerations will be explained in detail. We will discuss the complex decision making process between vasectomy reversal and assisted reproduction technologies (ART) and recent advances and future developments in the field of vasectomy reversal will be presented.

Patient evaluation

Following a thorough history and evaluation of the patient and his female partner, feasibility and outcome of vasectomy reversal can be assessed quite accurately before the operation. Several preoperative and intraoperative factors influencing the success of vasectomy reversal—age at surgery, duration of obstruction, previous vasectomy reversal, presence of sperm granuloma and average testis volume—are well known and nomograms based on these factors can be used to predict patency rates preoperatively.[15]

Feasibility of the procedure

Vasectomy reversal can be considered a minimally invasive procedure with extremely low complication rates. In our cohort of 1,303 patients,[7] we reported a complication rate of just 0.3% ($n=4$) for postoperative haematoma, only one of whom had to undergo repeat surgery for evacuation. We observed a rate of 0.8% ($n=10$) for superficial wound infection, and no cases of epididymitis were seen. Apart from two patients who developed allergic reactions to antibiotics, no other adverse effects or complications were seen after vasectomy reversal. These results are comparable to those of Silber and Grotjan[8] and Belker and colleagues,[9] who reported no significant complications after vasectomy reversal in their large studies. Operative time in our institution ranges from 90 to 150 min (mean 110 min), and the operation is carried out under general anaesthesia. Although vasectomy reversal with local anaesthesia is possible, in our series[7] general anaesthesia was used in all patients, as it can be a challenge for the patients to stay calm for up to 2.5 h and the microsurgery could be hindered by excessive movement of the patient.

Given the minimally invasive nature of the procedure and the low rate of associated complications, vasectomy reversal is feasible for almost every man who has previously undergone vasectomy. Only patients who are not fit for a minor genital operation that can last over 2 h have to be excluded.

Before vasectomy, testicular cancer should be ruled out by preoperative physical examination and, in the rare case of an incidental testicular tumour, the oncological treatment would have priority. Depending on the specific oncological treatment required, sperm retrieval, cryopreservation and ART could be a more appropriate treatment for infertility than vasectomy reversal, especially when adjuvant radiotherapy or chemotherapy is indicated.

If there is a clear indication for ART because of a female infertility factor such as bilateral tubal occlusion, then vasectomy reversal should be ruled out as a treatment option and work-up for ART initiated instead.[16]

Preoperative prognostic factors

Several factors have been shown to influence the success of a vasectomy reversal and can be assessed preoperatively in order to predict the success of the procedure. Such factors include obstructive time (the time that has elapsed since vasectomy), past surgical history, and male infertility factors such as prevasectomy fertility and testicular volume. For the female partner, age and other female infertility factors (especially suspicion of tubular occlusion) should be taken into account.[16,17]

Postvasectomy changes and obstructive time

During vasectomy, the vas deferens is usually cut about 2 cm distal to the tail of the epididymis. The epididymis has an important role in male reproductive function—it is the organ in which the maturation of sperm is completed and the recycling and clearance of degenerating sperm takes place. Secretory products are added and excess fluid is absorbed.[17,18] Sealing of the dissected vasal stumps during vasectomy results in a build up of intraluminal pressure, which impairs and alters the function and integrity of the epididymis.[18,19] However, spermatogenesis itself can remain unaffected, even with obstructive intervals of over 25 years.[20,21] Following vasectomy, the continuous flow of millions of sperm per day to the epididymis leads to substantial changes in the epididymal tissue architecture. Epithelial cell apoptosis and necrosis are followed by sperm extravasation and phagocytosis. Inflammation and often formation of sperm granuloma are initiated in the epididymis.[22] In a series reported by Boorjian *et al.*[23] sperm granuloma was found in 28% of 213 men on preoperative examination before vasectomy reversal. Granuloma formation is a reaction to the leakage of sperm from the epididymal tubule or the vas. This leakage occurs owing to blowouts after pressure build up or insufficient occlusion or intended nonocclusion of the vas during vasectomy. Granuloma formation is a gross finding during physical examination or ultrasonography and depends on the amount of leakage and the consecutive immune response. Leakage provokes an immune response and a certain amount of inflammation occurs in any case within a few days after vasectomy.

Immunoregulatory processes that constrain the immune response to self antigens might influence the formation of sperm antibodies, which varies greatly between patients in terms of time to onset. The onset of postvasectomy sperm antibody response is often late (6–9 months after the procedure), which might be explained by an adaptive immune response to sperm antigens due to specific immunoregulatory processes.[20–22]

Shapiro and Silber have reported a reduction in damage to the epididymis when using open-ended vasectomy. In open-ended vasectomy, the epididymal stump of the vas deferens is left open during vasectomy and the vasal leakage of sperm results in the formation of a primary sperm granuloma that decreases epididymal pressure. Excessive leakage of sperm through the delicate epididymal tubules, epididymal blowouts and the formation of secondary sperm granuloma can often be prevented by using open-ended vasectomy. Nevertheless, only a small minority of urologists practice open ended vasectomy, as it might be less reliable.[18,19]

These postvasectomy changes in the epididymis (Figure 1) indicate the importance of obstructive time in influencing the outcome of vasectomy reversal. Most researchers have reported that patency and pregnancy rates decrease with increasing length of time after vasectomy, but a specific threshold after which patency rates decline sharply could not be unambiguously demonstrated. Our own data show a gradual downtrend in patency over time, with pregnancy rates following this trend and an increase in necessity of vasoepididymostomy over time (Figure 2).

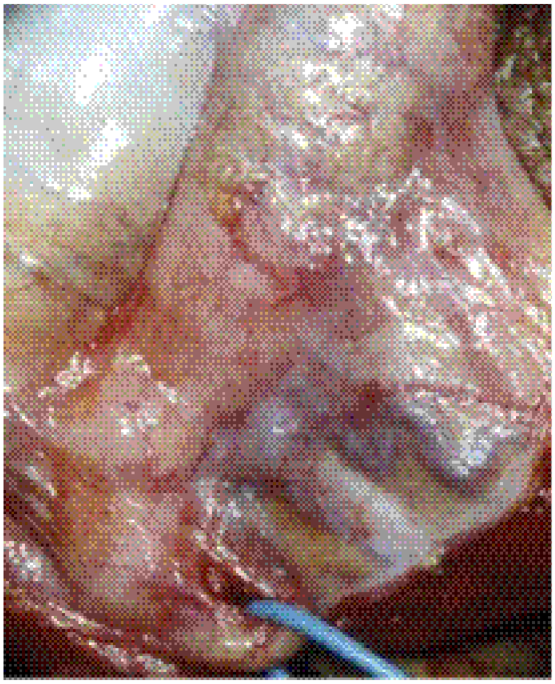

Figure 1 | Postobstructive changes in the epididymis. The preocclusive dilatation of the epididymal tubule can be clearly identified.

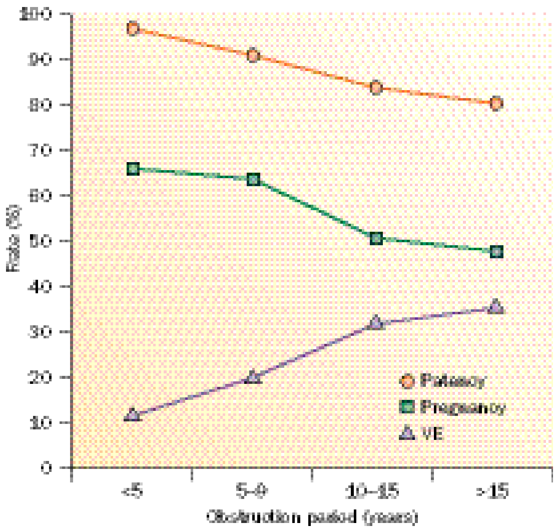

Figure 2 | The relationship between obstructive intervals and patency rates, pregnancy rates and vasoepididymostomy rates in a study of 1,303 consecutive vasectomy reversals by a single surgeon (data from Schwarzer[7]).

It has been postulated that pregnancy rates following vasectomy reversal are not significantly less than in a population of couples in which the male partner has not undergone vasectomy, as long as patency can be accurately re-established without epididymal damage, and that autoimmune changes or changes to spermatogenesis do not interfere with fertility after vasectomy reversal.[24,25] Thus, decreasing success of vasectomy reversal over time could be attributable to increasing epididymal damage, which is reflected in the increasing need for epididymovasostomy with longer obstructive intervals. Boorjian *et al.*[23] showed that patency, epididymovasostomy rate and pregnancy rates remain almost constant when reversal is carried out up to 15 years after vasectomy, but report a significant decline in pregnancy rates when the time elapsed since vasectomy is longer than 15 years. As accurately re-establishing patency and enabling pregnancy is the most important goal of vasectomy reversal, repeat procedures are a valid option in case of suspected failure of reversal.[26–28]

Surgical history

Technical aspects of the original vasectomy procedure can affect the success of vasectomy reversal. Prior vasectomy by an inguinal approach or iatrogenic injury to the vas deferens during inguinal surgery reduce the chances of successful vasectomy reversal.[29–31] Iatrogenic injuries are associated with more extensive vasal defects (such as formation of scar tissue or erosion after mesh implantation), impaired blood supply and longer obstructive intervals. In a series of 34 patients with mostly herniorrhaphy-associated iatrogenic injury to the vas deferens, Sheynkin *et al.*[32] report a patency rate of 65% and a pregnancy rate of 39% after vasectomy reversal. Shin *et al.*[33] reported that, in 14 patients with azoospermia secondary to inguinal vasal obstruction related to previous polypropylene mesh herniorrhaphy, surgical reconstruction could be performed in 8 men (57%). As success rates of vasectomy reversal can be substantially impaired by prior inguinal surgery, alternative treatments such as ART should be carefully considered under these circumstances. The usual advantage of vasectomy reversal compared to ART (at least equal success rates together with lower cost and morbidity) might be lost for these patients.

The length of the testicular vasal remnant can easily be measured during the preoperative physical examination and seems to have a protective effect on epididymal function after vasectomy. A testicular vasal remnant length >2.7 cm has been shown to predict the presence of whole sperm in the vasal fluid during vasectomy reversal.[34]

Furthermore, open-ended vasectomy and the presence of sperm granuloma tend to increase the chances of successful vasectomy reversal by reducing epididymal pressure.[8] As some smaller studies[35,36] suggested that open-ended vasectomy might be associated with an increased rate of vasectomy failure, it is used by just 7.5% of physicians in the USA[37] and by a minority of urologists in Europe. However, this failure seems not be the case when the prostatic end of the vas is adequately closed by fascial interposition and cautery.[38] The current guidelines on vasectomy of the American Urological Association (AUA) consider open-ended vasectomy combined with fascial interposition and mucosal cautery of the proximal vasal stump an appropriate and safe technique for vas occlusion.[39] The European Guidelines offer no specific recommendations regarding open-ended vasectomy.

Whether there has been a previous vasectomy reversal attempt does not seem to be important in terms of success of the procedure; around 10% of procedures performed by an experienced microsurgeon do not effectively restore patency and are deemed 'failed'. Almost equivalent results can be reached with vasectomy reversal and repeat vasectomy reversal.[26,27] If patency is not effectively restored by a first attempt of vasectomy reversal, a redo operation can be done with almost equivalent high chances of success and low morbidity. If an excessive length of vas has been resected during the original vasectomy procedure, it can be difficult to complete a tension-free anastomosis especially when vasoepididymostomy is required. Any damage to the epididymis by other procedures (such as spermatocele repair or percutaneous epididymal sperm aspiration [PESA]) can also reduce the chances of restoring patency. In a small series of eight patients that underwent vasectomy reversal after failed PESA, Marmar *et al.*[40] identified sperm in the vasal fluid of 10 out of 16 vasal units. Although the epididymal damage caused by PESA seems to be limited, each puncture of the epididymis can potentially cause a complete blockage of the delicate epididymal tubule. In this situation, only epididymovasostomy can restore patency and the option to perform a much easier vasovasostomy procedure would have been prevented by the PESA attempt.

Male fertility

When pregnancy rates following vasectomy reversal are compared with patency rates, it becomes clear that the "success" (in terms of resulting pregnancies) of vasectomy reversal is influenced by fertility factors in both partners. In our cohort, the disparity between the two was a patency rate of 89% and pregnancy rate of 59%,[7] and in Belker and colleagues series, patency rate 86% and pregnancy rate 52%.[9] Men presenting for vasectomy reversal usually report normal fertility prior to vasectomy, so male fertility factors often require no special consideration. If there are signs that suggest impaired male fertility—such as decreased testicular volume, previous history of infertility treatments or an elevated serum FSH level— a fertility investigation that includes at least a thorough andrological history and an evaluation of sex hormone levels is mandatory.[41]

Causes of reduced pregnancy rates after vasectomy reversal are the source of debate. In the series of Silber and Grotjan,[8] pregnancy rates after successful vasectomy reversal are almost equal compared to a normal fertile population and the authors conclude that reduced male fertility after vasectomy reversal is either caused by partial blockage at the vasovasostomy site or at the epididymis or by impaired epididymal function and not by anti-sperm antibodies and other nonmechanical factors such as failure of spermatogenesis.[8] Accordingly, Carbone *et al.*[42] have shown that, in cases when vasectomy reversal failure is attributed to anti-sperm antibodies, partial obstruction can often be identified as the problem and can be resolved by a surgical revision. Likewise, Matsuda *et al.*[43] showed no significant influence of anti-sperm antibodies after epididymovasostomy on pregnancy rates.

Nevertheless, autoimmune changes could contribute to the failure of vasectomy reversal in individual patients.[44,45] It is well established that vasectomy and postvasectomy changes typically trigger the formation of anti-sperm antibodies.[19–21,44–46] However, preoperative identification of anti-sperm antibodies in the blood is not sufficient for diagnosis of immunologic infertility—only seminal, and not serum, anti-sperm antibodies have the potential to affect fertility[47] and evaluation of the ejaculate is possible only after vasectomy reversal is complete. Significant findings of anti-sperm antibodies in the ejaculate could trigger a need for further fertility therapies such as insemination of processed sperm or even intracytoplasmic sperm injection (ICSI), but such measures are confined to specific patients and are not widely applicable to the majority of men.[48,49]

Partner age and female fertility

Fertility factors in the female partner are, of course, equally important for the success of vasectomy reversal and contribute to the discrepancy between patency and pregnancy rates. Particular disorders in the female partner, such as bilateral tubal occlusion, can render vasectomy reversal futile and necessitate the use of ICSI to initiate further pregnancies.

The most important female factor for successful pregnancy after vasectomy reversal is the age of the female partner.[50] Regardless of whether natural conception, ART or vasectomy reversal is considered, pregnancy rates significantly decrease with age, particularly over the age of 35 years.[51,52] Thus, if age of the female partner is a concern, the probability of a successful vasectomy reversal should be discussed with the patient and their partner when they are counselled on the potential success of the procedure. In our own cohort, the mean age of the female partner was 35 years,[7] in the series of Silber and Grotjan[8] mean female age was 31 years and in the Vasovasostomy Study Group report, mean age of the female partner was 34 years.[9] Thus, couples with female partner age >30 years do seem to be the major group that seeks to restore fertility by vasectomy reversal.

Technique and intraoperative considerations

The excellent results of large vasectomy reversal series concerning postprocedure patency and pregnancy rates demonstrate the superiority of the microsurgical compared with the conventional technique.[7–9] Although there are small series showing comparable outcomes of microsurgical and nonmicrosurgical techniques,[53] independent review of the published data suggests that superior results are obtained with microsurgery.[17,54–56] This superiority is particularly noticeable in published results of vasoepididymostomy, which clearly indicate that microsurgery yields better results than the conventional technique.[55,57] Thus, the use of an operating microscope should be recommended for vasectomy reversal.[7–9]

The surgical technique

Vasectomy reversal is carried out through an incision high in the scrotum. The vasal stumps are exposed and the obstructed parts of the vas are excised. The patency of the distal portion of the vas is checked by a flush of normal saline to rule out a central obstruction of the lumen. By inserting and advancing a prolene suture through the prostatic vasal stump an inguinal obstruction can be distinguished from an obstruction in the area of the prostate and seminal vesicles. Vasography has never been necessary in our own experience, and is associated with serious adverse effects, such as extravasation and subsequent vasal fibrosis. Thus, we consider vasography almost obsolete for vasectomy reversal. It can be valuable only in rare circumstances, in order to provide anatomical detail of the vas, seminal vesicles and ejaculatory ducts, and to determine the site of obstruction in an azoospermic man with confirmed normal spermatogenesis on testis biopsy. Vasography can occasionally be useful in severely oligospermic men where there is a high clinical suspicion of unilateral vasal obstruction from iatrogenic injury during a previous procedure such as inguinal hernia repair.[29]

In the case of inguinal obstruction, serious consideration must be given as to whether it is reasonable to perform a technically challenging inguinal reconstruction that might involve laparoscopic or open retrieval of the pelvic vas.[29,30] When contralateral testicular atrophy is present, crossover reconstruction is a particularly useful alternative. In this procedure, the contralateral prostatic vasal stump can usually be brought easily to the other side and connected to the epididymal stump or epididymal tubule of the healthy testicle. Thus, the inguinal obstruction can be easily bypassed.[32] It is not unusual to find an inguinal obstruction accompanied by another obstruction at the epididymal level, owing to a long obstructive interval. To prevent impairment of the blood supply to the vas, reconstruction on both levels of obstruction at the same time generally cannot be recommended.[32]

In the case of a central obstruction, we usually proceed with the vasectomy reversal procedure and try to solve the central obstruction in a further surgery by transurethral resection of the ejaculatory duct (TURED). In our series,[7] an unexpected central obstruction was found in 2% of patients and an unexpected inguinal obstruction in 2% during surgery. These obstructions were unilateral in most cases, but, as the success of vasectomy reversal could be influenced, we inform our patients preoperatively about the rare likelihood of a central or inguinal obstruction.

The decision whether to use vasovasostomy or vasoepididymostomy is dependent on the quality of the fluid obtained from the proximal vasal stump. The fluid is immediately examined by laboratory microscope while the patient is in theatre, and is graded according to the Silber classification[58] or the classification of Goldstein.[59] If intact spermatozoa or clear liquid are found, the surgery proceeds with vasovasostomy. If only sperm fragments are found or in the case of creamy liquid, there is suspicion of irreversible epididymal damage and we proceed with vasoepididymostomy. The decision between the two techniques is often the most important decision to be made during vasectomy reversal. Different decision-making strategies exist based on, for example, time of obstruction, quality of the collected liquid and experience of the surgeon. Kolettis *et al.*[60] report that although patency rates for vasovasostomy are reduced if just fragments are found in the vasal fluid compared with men in whom normal sperm is found in the vasal fluid, patency rates are still at least as high as with vasoepididymostomy in most surgeons' experience.[60]

Concise surgical recommendations based on the gross appearance of vasal fluid and microscopic findings have been suggested by Goldstein, which describe in detail when the surgeon should proceed to vasoepididymostomy as opposed to vasovasostomy. Besides the content of the vasal fluid the classification of Goldstein also takes the appearance of the vasal fluid into consideration, which provides additional information, especially in situations when no sperm can be found in the initial sample. In our opinion, the Goldstein classification offers a sound and pragmatic algorithm to determine which surgical strategy to use for the optimal patency outcomes.[59]

Single-layer versus multilayer vasovasostomy

Classic macroscopic vasovasostomy was originally usually performed with a single-layer technique. The introduction of microscopic surgery in the late 1970s

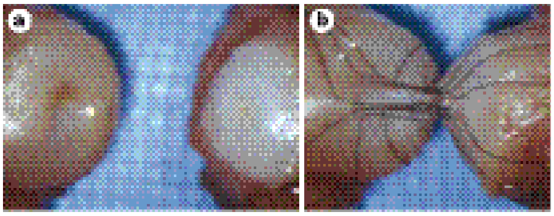

Figure 3 | Microsurgical site of a 3-layer vasovasostomy: approximation of vasal stumps and suturing of the first (mucosal) layer **a** | Different diameters of the dilated epididymal abdominal and the collapsed vasal stump. **b** | First layer of vasovasostomy (adaptation of delicate mucosa to mucosa with 8–12 single interrupted 10-0 Dafilon® sutures with a round needle).

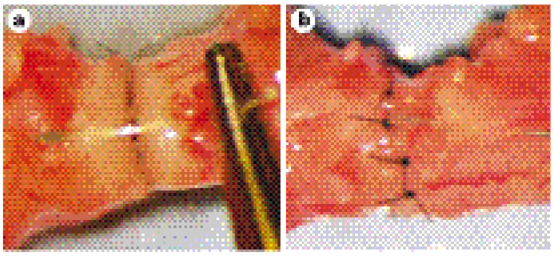

Figure 4 | Microsurgical site of a 3-layer vasovasostomy: second and third layers of vasovasostomy. **a** | The second layer involves approximation of thick muscularis to muscularis with 8–10 single interrupted 9-0 Dafilon® sutures with a spatula needle. **b** | In the third layer of vasovasostomy, adventitia is sutured to adventitia with single interrupted 8-0 Dafilon® sutures with a round needle.

offered the possibility to perform a two-layered anastomosis, in which mucosa and muscularis were adapted separately. Thus, the anatomy of the vas, which is characterized by a delicate mucosa, a small lumen compared to a large outer diameter and a relatively thick wall, could be handled much more accurately. Although with a single-layer technique, high patency rates might also be achievable, we consistently use a three-layer technique, as we believe that a multilayer approach is needed to adapt the different diameters of the dilated proximal and the collapsed distal vasal stumps (Figure 3). By selectively grasping first the tunica mucosa with 8–12 single interrupted 10-0 Dafilon® sutures (Aesculap AG, Tuttlingen, Germany), then the tunica muscularis with 8–10 single interrupted 9-0 Dafilon® sutures, a watertight anastomosis with matched layers is constructed (Figure 4). Although we choose to use a round needle for the delicate mucosa, a spatula needle is used for the much stronger muscularis, and the ability to select appropriate needles for each layer is another important advantage of a multilayer technique. Grasping the tunica adventitia with single interrupted 8-0 Dafilon® sutures adds further tensile strength to the anastomosis.

In 1998, Goldstein *et al.*[61] introduced the microdot technique for suture position planning, which enables the surgeon to separate the planning of sutures placement from the actual application by marking the planned suture exit points with microdots placed on the cut ends of the vas deferens. The microdot technique facilitates accurate suture placement and watertight anastomosis, and is especially helpful for the anastomosis of proximal and distal vas lumens of different diameters.[61]

Vasovasostomy of the convoluted section of the vas deferens is technically more challenging than vasovasostomy of the straight sections, but postoperative results are comparable. The indications for vasovasostomy in both the convoluted vas deferens and the straight portion of the vas should, therefore, be the same.[62,63] Men who have a varicocele and wish to undergo vasectomy reversal do not generally seem to profit from additional varicocelectomy as far as pregnancy rates are concerned; nevertheless vasectomy reversal can safely be performed with simultaneous microsurgical varicocelectomy,[25,64] and under special circumstances (such as testicular hypotrophy or scrotal pain attributed to varicocele) the surgeon might decide on an individual basis to combine vasectomy reversal and microsurgical varicocelectomy.

Vasoepididymostomy

If vasoepipididymostomy is required, the first step is to locate the obstructed area, which usually lies in the cauda of the epididymis. The preocclusive epididymal tubule is then identified under the microscope and tangentially incised with a subtle operating technique, which prevents damage to the back wall of the tubule. The occlusion and preocclusive location is confirmed by the identification of sperm in the outpouring fluid with the laboratory microscope. Our team carries out vasoepididymostomy as an end-to-side anastomosis in a three-layer technique. The most internal of the three layers is formed by joining the laterally opened epididymal tubule and the mucosa of the vas deferens using 8–10 nonabsorbable single-armed 10-0 Dafilon® stitches with a round needle. Then the muscularis of the vas and the epididymal serosa are sutured with 10 9-0 Dafilon® stitches using a spatula needle. Further tension relief is added by a third layer consisting of epididymal serosa and adventitia of the vas (Figure 5).

In addition to the traditional end-to-side anastomosis for vasoepididymostomy, intussusception techniques have been proposed that might improve watertight closure and enable simplified needle placement (Figure 6). Berger[65] used three double-armed sutures passed through a distended epididymal tubule in a triangular arrangement, whereas Marmar[66] introduced a technique of simultaneous double-needle placement, tubulotomy and tubular invagination. In a consecutive series of 153 bilateral vasoepididymostomies, patency rates were 80% ($n=15$) with two-suture longitudinal intussusception, 84% ($n=19$) with three-suture triangulation intussusception and 74% ($n=27$) with end-to-side technique.[67] In our cohort,[7] the patency rate for bilateral end-to-side vasoepididymostomy was, likewise, 74% ($n=84$). The intussusception technique is a promising innovation that can offer better or comparable outcomes compared with traditional end-to-side techniques with the use of fewer sutures. However, even with a traditional

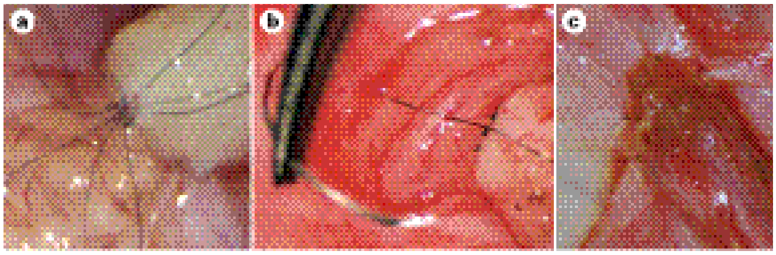

Figure 5 | Three-layered vasoepididymostomy. **a** | In the first layer, laterally opened epididymal tubule is joined to mucosa of the vas deferens. **b** | The second layer joins the muscularis of the vas and epididymal serosa. **c** | The third layer involves approximation of the epididymal serosa and adventitia of the vas.

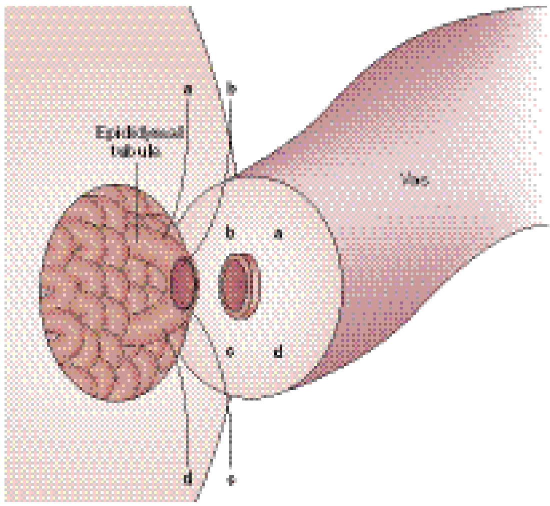

Figure 6 | Microsurgical two-suture longitudinal intussusception vasoepididymostomy. Two parallel sutures are placed longitudinally in the selected preocclusive epidymal tubule. Once the tubule has been incised between the two needles, the sutures are pulled through and the double-arm needles are placed in-to-out through the vasal lumen to achieve a four-point anastomosis. Permission obtained from Elsevier Ltd © Schiff, J. *J. Urol.* **174**, 651–655 (2005).

end-to-side technique and the use of more sutures an even more subtle adaption of the anastomosis might be possible. In our opinion, the choice of the optimal technique for vasoepididymostomy very much depends on the experience and preference of the individual surgeon. Whether single-armed or double-armed sutures are used seems not to make a substantial difference to outcomes, so single-armed sutures are a practical and effective alternative, especially since these sutures tend to be cheaper and more widely available.[68]

The aforementioned technical details represent our own group's approach to vasectomy reversal, but other sensible techniques have been described and have yielded excellent results regardless of different numbers of sutures or layers used.[8,56,57,59,61] Above all, the success of both vasovasostomy or vasoepididymostomy requires that the surgeon adheres to general principles applicable to creating anastomoses of all tubular structures—that they are leak-proof, tension-free, that mucosa–mucosa approximation is accurate, the blood supply is sufficient, the mucosa and muscularis are healthy, and that the procedure is carried out using good atraumatic anastomotic technique. The ability to level lumens of discrepant diameters is a key obstacle that an adequate technique for vasectomy reversal has to overcome.[57,61] The necessary skill to perform a vasoepididymostomy when indicated is, in our opinion, a minimum standard of care. In our series of 1,303 patients,[7] the secondary azoospermia rate was 1%, compared with 3% reported by Belker *et al.*[9] and 5% by Kolettis *et al.*[69] Although patient characteristics and follow-up differed in these studies, the low rates of secondary azoospermia reported after vasectomy reversal using the three-layer technique reflect the special attention this technique pays to the vascularisation of the anastomosis, which might contribute to a low restenosis rate.

Vasectomy reversal and ART

Couples seeking fertility treatment after vasectomy in general have two choices: sperm retrieval plus ICSI or vasectomy reversal. In certain situations the decision between these two modalities can be straightforward, for example, if vasectomy reversal is unfeasible owing to bilateral tubular occlusion in the female partner, or because the man is not fit for surgery; or correspondingly, if ART are rejected by the couple owing to religious reasons or concerns regarding the risks of ART. In most cases, however, the decision requires a complex consideration of advantages and disadvantages of both alternative techniques (Box 1). This consideration comprises success rates, risks and benefits as well as relative costs. No randomized controlled studies exist that could be used for guidance, so each decision has to be based on individual circumstances.[70]

The results of available studies seem to suggest that almost equal cumulative birth rates can be achieved with vasectomy reversal and ART.[50,71–73] A disadvantage of using vasectomy reversal can be the long period of time that sometimes is necessary for fertility to recover after the surgery. Sperm retrieval and ICSI can start as soon as a couple decides they wish to have a child, but additional risks are associated with ART, and these must be considered.

An issue that has been addressed in several studies is cost. Costs tend to be substantially higher with ART than with vasectomy reversal (Figure 7), so vasectomy reversal is certainly the most cost-effective approach to treatment of postvasectomy infertility.[74] The morbidity of ICSI for the female partner, such as the risk of ovarian hyperstimulation syndrome, as well as the risk of multiple pregnancies and the slightly increased risk of birth defects also has to be taken into account.[75] Thus, we recommend vasectomy reversal as the first-line treatment in men who want to father a child after vasectomy, unless there are clear reasons to prefer ICSI such as the wish to start with the treatment immediately or circumstances that make natural conception unlikely, such as bilateral tubular occlusion.[76] However, the return of sperm to the ejaculate can sometimes take up to 2 years after vasectomy

Box 1 | Advantages and disadvantages of vasectomy reversal and ART

Vasectomy reversal

Advantages

- Morbidity is very low and only affects the male partner
- Cumulative pregnancy rates are at least as high as success rates with ART even for females >35 years old[50,51]

Disadvantages

- Contraception is required after vasectomy reversal if the couple do not wish to conceive
- Loss of time (recovery of fertility can take up to 2 years after vasectomy reversal)[77]

Sperm retrieval and intracytoplasmic sperm injection

Advantages

- It is possible to begin the treatment immediately without loss of time waiting for fertility to return
- Enables treatment of specific male and female factors for infertility (such as tubular occlusion or immunologic infertility)

Disadvantages

- Morbidity for the female partner, e.g. ovarian hyperstimulation syndrome
- Risk of multiple pregnancies
- Slightly increased risk of birth defects compared with spontaneous conceptions[75]

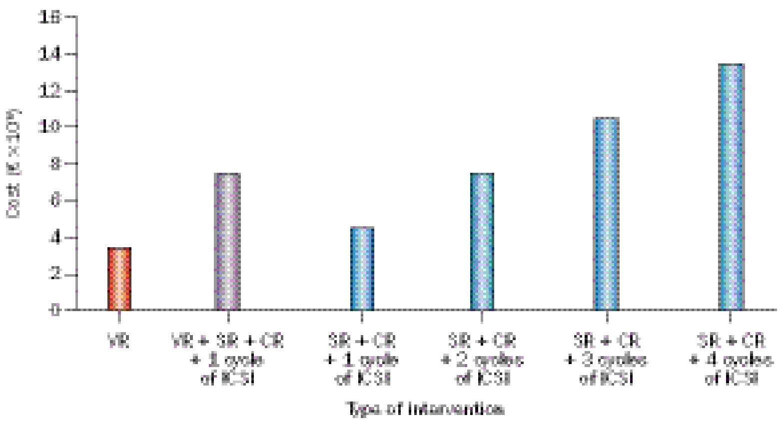

Figure 7 | Costs associated with the treatment of postvasectomy infertility in Munich, Germany. Vasectomy reversal is the least expensive option, but combining it with sperm retrieval and ICSI increases the cost to a similar level to that of sperm retrieval with two cycles of ICSI. Thus, if one cycle of ICSI is saved, the cost of vasectomy reversal is recouped. Vasectomy reversal and vasectomy reversal combined with ICSI offer ongoing chances to conceive with each recurrent ovulation, but with ICSI alone conception chance drops to zero if ICSI cycles are stopped. Abbreviations: CR, cryopreservation; ICSI, intracytoplasmic sperm injection; VR, vasectomy reversal.

reversal, especially when bilateral vasoepididymostomy was performed.[77] For couples with a strong desire for a child this period can be accompanied with a great emotional burden. In contrast, vasectomy reversal and ART can be combined seamlessly—sperm retrieval and vasectomy reversal are performed during the same surgery and ICSI can then start immediately. For sperm retrieval we cryopreserve motile sperm that are retrieved from vasal or epididymal fluid during vasectomy reversal, and also use open excisional testicular biopsy, which provides a 100% sperm retrieval rate in patients with normal spermatogenesis.[78] The testicular tissue can also be cryopreserved and ICSI performed at a later date if indicated. We believe that combining cryopreservation of sperm from vasal or epididymal fluid and testicular tissue offers the most reliable basis to plan the ICSI procedure completely independently from vasectomy reversal and sperm retrieval, thus preventing unnecessary ovarian stimulation in the female partner. In a series of 1,025 ICSI cycles, the highest birth rate per cycle was achieved with epididymal cryopreserved sperm (33%, $n = 163$), although this rate was not significantly different than that achieved with testicular sperm.[79] Thus, we prefer to use epididymal sperm for ICSI, but will alternatively resort to testicular spermatozoa if necessary, according on the assessment of the biologist who performs the ICSI.

As soon as fertility has recovered after vasectomy reversal, ICSI can be paused as there is a chance of a spontaneous pregnancy. By using this strategy, chances for conception might be increased, as an initial start with ART and cumulative chances after vasectomy reversal are combined. This strategy can be helpful in patients in whom a longer period before recovery of fertility after vasectomy reversal can be expected (such as when bilateral vasoepididymostomy has been carried out or after a long obstructive interval). It can also be helpful in couples where the female partner is over 40 years of age with decreasing reproductive potential and can relieve the emotional burden of a long waiting period.

Furthermore, an intelligent combination of vasectomy reversal and ART even produces synergistic cost effects. In our institution, the extra cost to add vasectomy reversal to sperm retrieval is about €3,000. Sperm retrieval and cryopreservation amount to about €1,500, one cycle of ICSI to €3,000. Thus, if just one cycle of ICSI can be saved, the combination of vasectomy reversal and sperm retrieval with ICSI is worthwhile in terms of cost savings. Even in older couples, for whom success and not cost is often the main priority, the combination of ART and vasectomy reversal should be seriously considered.

Robotics and future developments

Robotic-assisted surgery is an emerging field that has changed the face of urologic surgery.[80] In clinical practice, the da Vinci® surgical system (Intuitive Surgery, CA, USA) dominates the field and robotic surgery is offered in a great number of advanced urological centres.

To date, robotic-assisted vasectomy reversal is virtually synonymous with vasectomy reversal by the da Vinci® surgical system, which improves dexterity and reduces tremor, and has a 10–15× magnification function. The system is intuitive to use and the learning curve seems to be relatively low when compared to microsurgical training.[81] However, the da Vinci® robot is associated with substantial costs, and setting it up can be time consuming and often requires a specialized surgical team. Furthermore, the system is not designed with microsurgery in mind and, therefore, the availability of microsurgical instruments for use with the robot is low.[82] However the focus of the da Vinci® robot on laparoscopic surgery could be an advantage, for example in the rare case of an inguinal obstruction of the vas deferens after hernia repair, harvesting of the pelvic vas could be performed laparoscopically using the da Vinci® robot and open pelvic surgery could be avoided.

Robotic-assisted vasectomy reversal consists of the following steps: conventional dissection and transsection of the vasal stumps, examination of the vasal fluid, and approximation of vas to vas or vas to dilated epididymal tubule after the epididymal tunic has been opened. The robot is then positioned to perform the anastomosis. For example, Intuitive Black Diamond Micro Forceps (Intuitive Surgical, CA, USA), which serve as needle drivers and for tissue handling, are loaded on the right and left surgical robot arms, Micro Potts Scissors (Intuitive Surgical, CA, USA) are loaded onto the fourth arm and the camera onto the third arm. As vasectomy reversal is an open procedure, even when carried out using the robot, the trocars are loaded only to allow the instruments to function and to stabilize their movements outside of the patient's body. When the anastomosis of the first side has been completed, the robot is repositioned after standard preparation of the contralateral side for the second robot-assisted anastomosis. Finally the skin is closed and dressings are applied.[83]

The first prospective single-centre study to compare robotic-assisted vasectomy reversal with standard microsurgical vasectomy reversal suggests that almost equal outcome can be reached no matter which technique is used. Parekattil *et al.*[84] reported reports from 110 patients who were operated on with robotic assistance compared with 45 patients who underwent vasectomy reversal using the classical microsurgical technique. The selection of the technique was based on patient choice and preoperative patient characteristics were similar in both groups. The patency rates were significantly different between groups at 96% in the robotic group and 80% in the microsurgical group ($P=0.02$), and the authors suggested that this difference might be attributable to a learning curve bias towards the robotic technique. The learning curve associated with the robotic technique means it might be possible for surgeons without extensive microsurgical training to reach a sufficient standard of robotic-assisted vasectomy reversal in a relatively short time—in this study a surgeon who had just completed his fellowship was able to use the robotic technique to garner patency outcomes that matched the results of very experienced microsurgeons.[84] However, we doubt that the quality of an experienced microsurgeon can be improved upon by contemporary robotic vasectomy reversal using the da Vinci® robot. 20–30× magnification is often necessary, especially for the vasoepididymostomy procedure. As dexterity and tremor (which are considered improved in the da Vinci® procedure) can be controlled by an experienced microsurgeon, in our opinion the inferior magnification available using the robot is a disadvantage, especially when vasoepididymostomy is indicated. Unfortunately no multi-institutional or large studies comparing robotic-assisted with microsurgical vasectomy reversal are yet available, and, since the robotic technique is not widely used, it is not possible to determine when any such studies might be instituted.

Improvements to robotic systems will be available in the near future, and might include a da Vinci® system with a greater magnification and more specialized microsurgical instruments. New systems might be designed especially for microsurgery and might reduce the overheads of the da Vinci® system that comes with the focus on laparoscopy.[85] Vasectomy reversal by experienced microsurgeons has reached a high level of skill and efficiency, so future developments will have to show whether new robotic systems can actually improve surgical quality or whether the robot simply serves to facilitate vasectomy reversal for surgeons without extensive microsurgical expertise.

Conclusions

Vasectomy reversal is a safe and successful method for treating male infertility after vasectomy, but it is also technically demanding. Although a high level of excellence has been reached today, there are still promising surgical innovations such as modern intussusception techniques for vasoepididymostomy or the microdot technique for precision suture placement that might further improve the outcome. Microsurgical expertise currently has a central role in the success of the procedure, and whether robotic-assisted vasectomy reversal improves on the success of microsurgical techniques remains to be seen. ART is a good alternative, but microsurgical vasectomy reversal involves lower costs, lower morbidity and offers the most physiological treatment of male infertility after vasectomy. At present cumulative pregnancy rates for vasectomy reversal are usually at least equal to pregnancy rates for ART. The recurring chance to conceive naturally with each ovulation that is restored by vasectomy reversal can be seen as a significant advantage when compared with ART. In our opinion, microsurgical vasectomy reversal will continue to have a central role for the treatment of male infertility after vasectomy that can be supplemented, but not replaced, by ART.

Review criteria

The PubMed database was searched for articles with the terms "vasectomy reversal", "vasovasostomy", "vasoepididymostomy" and "epididymovasostomy". Wherever possible, original full-text articles published in English were retrieved. The reference lists of identified articles were searched for further relevant papers. Although no limits were set on the years of publication, this Review focuses on articles published within the past 20 years.

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Author contributions

Both authors researched data for article, wrote the manuscript and reviewed and edited the article before submission.