Radical prostatectomy continues to be the definitive surgical treatment for patients with localized prostate cancer. Patients with high-grade disease, close tumor proximity, or direct tumor invasion may require segmental resection of one or both neurovascular bundles, which travel along the lateral borders of the prostate gland. These neurovascular bundles originate from the intricate prostatic plexus located posterior to the prostate and contain the prostatic plexus may occur during radical prostatectomy even with the use of minimally invasive techniques. Reconstruction of these nerves by interpositional nerve grafting can be performed to reduce morbidity. Although the feasibility of nerve reconstruction has been shown, long-term functional outcomes are mixed, and the role of nerve grafting in these patients remains unclear.

**Methods:** A retrospective study was performed on 38 consecutive patients who underwent immediate unilateral or bilateral nerve reconstruction after open prostatectomy. Additionally, 53 control patients who underwent unilateral, bilateral, or non–nerve-sparing open prostatectomy without nerve grafting were reviewed. Outcomes included rates of urinary continence, erections sufficient for sexual intercourse, and ability to have spontaneous erections. Analysis was performed by stratifying patients by D’Amico score and laterality of nerve involvement.

**Results:** Unilateral nerve grafting conferred no significant benefit compared with unilateral nerve-sparing prostatectomy. Bilateral nerve-sparing patients demonstrated superior functional outcomes compared with bilateral non–nerve-sparing patients, whereas bilateral nerve-grafting patients displayed a trend toward functional improvement. With increasing D’Amico score, there was a trend toward worsening urinary continence and erectile function regardless of nerve-grafting status.

**Conclusions:** In the era of robotic prostatectomy, interpositional nerve reconstruction is not a routine practice. However, the substantial morbidity experienced in patients with bilateral nerve resections remains unacceptable, and therefore, nerve grafting may still improve functional outcomes in these patients. Further investigation is needed to improve the potential of bilateral nerve grafting after non–nerve-sparing prostatectomy.

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cavernous nerves, which mediate erectile function, and nerve fibers traveling to the pelvic floor and the urethral sphincter, which are important for urinary continence.\(^2\) Injury or transection of these critical nerves commonly results in permanent erectile dysfunction and urinary incontinence. To reduce the incidence of these common sequelae after radical prostatectomy, nerve-sparing prostatectomy techniques have been described.\(^3\) Furthermore, the implementation of minimally invasive laparoscopic and robotic-assisted techniques has greatly transformed the surgical management of prostate cancer.\(^4\) These new methods offer superior visualization and facilitate surgical finesse during radical prostatectomy and have contributed to the widespread shift away from the open approach.

Despite the universal practice of nerve sparing, purposeful sacrifice of the neurovascular bundle is still occasionally required to achieve adequate cancer control.\(^5\) Furthermore, iatrogenic injury to the prostatic nerves may occur during radical prostatectomy regardless of the surgical technique.\(^6\) For example, although long-term erectile dysfunction may occur less frequently in laparoscopic or robotic-assisted prostatectomies (26.3%) compared with open radical prostatectomies (45.3%), a considerable absolute number of patients still experience impotence despite the use of minimally invasive techniques.\(^7\) Immediate interpositional nerve grafting of the prostatic plexus can performed for the purpose of improving postoperative urinary continence and erectile function after nerve resection or injury. Although a number of studies have demonstrated the feasibility of immediate nerve reconstruction after prostatectomy, clinical outcomes have been mixed, and few studies have examined patients with long-term follow-up or in comparison with control groups.\(^8\) Furthermore, results of a well-designed randomized controlled trial demonstrated no benefit of unilateral nerve grafting after prostatectomy.\(^9\) As a result, these developments greatly tempered the enthusiasm for cavernous nerve reconstruction, and interpositional nerve grafting of the prostatic plexus after radical prostatectomy has been largely abandoned.

However, the morbidity of radical prostatectomy remains a significant challenge for many patients, especially those with bilateral cavernous nerve defects. Furthermore, the concept of interpositional nerve grafting to restore function in other areas, such as the upper and lower extremities, is well established. For these reasons, some have suggested that further experimental work is necessary to optimize various aspects of nerve grafting in select prostatectomy patients, and that the true role of cavernous nerve reconstruction has yet to be determined.\(^8\) This study examines our experience with interpositional sural nerve grafting after radical prostatectomy and discusses the continued potential of nerve reconstruction particularly in bilateral cases.

**METHODS**

An institutional review board-approved retrospective cohort study was performed on patients from a single center (University of Michigan) who underwent open radical prostatectomy with immediate prostatic plexus reconstruction from 1996 to 2004. Additionally, a group of control patients who underwent open radical prostatectomy without nerve reconstruction was randomly selected from a prospectively generated urologic database. These control patients underwent either unilateral nerve-sparing prostatectomy (transsection of 1 neurovascular bundle without reconstruction), bilateral nerve-sparing prostatectomy (no neurovascular bundle resection), or non–nerve-sparing prostatectomy (transsection of both neurovascular bundles). A minimum follow-up interval of 12 months was selected to allow adequate time for nerve regeneration after resection and interpositional grafting. For both nerve grafting and control groups, patients were excluded if there was documentation of complete urinary incontinence or no erectile capability before prostatectomy. However, patients with mild erectile dysfunction preoperatively, defined as still having some residual potency for intercourse prior to prostatectomy, were included in both nerve-grafting and control groups. Additionally, patients were included regardless of adjuvant chemotheraphy or radiation relating to prostate cancer treatment.

All patients in the study underwent a standard extirpation operation, which consisted of an open radical retropubic prostatectomy with pelvic lymphadenectomy. In the reconstruction group, unilateral or bilateral neurovascular bundle resection was anticipated preoperatively based on clinical examination and tumor characteristics. At the conclusion of prostatectomy and neurovascular bundle resection, these patients underwent immediate unilateral or bilateral interpositional sural nerve grafting. The sural nerve graft was harvested via an open fashion from a single lower extremity and was divided for bilateral cases. Sural grafts ranged from 2 to 8 cm in length and were coapted in a reversed fashion to recipient

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ends using an epineurial technique with interrupted 6-0 polypropylene sutures under loupe magnification. Because the prostatic plexus is composed of a network of nerves, neurovascular bundle resection commonly resulted in multiple nerve gaps per side; in these instances, the sural graft was coapted proximally and distally to all visualized nerve stumps (Fig. 1).

Urinary continence and erectile function were the primary outcomes of interest. Satisfactory urinary continence was defined as requiring no daily pad usage, no expressed difficulty with incontinence by the patient, and no surgical intervention for urinary incontinence. Satisfactory erectile function was defined as the reported achievement of erections sufficient for sexual intercourse with or without the assistance of medication. The ability to experience spontaneous erections as testified by the patient was also noted as a demonstration of recovered erectile function. Finally, the use of erectogenic medications was documented for each patient. Demographic data for both study and control groups were collected as well as information relating to prostate cancer diagnosis and treatment. Each patient’s D’Amico score was determined by taking into account a patient’s preoperative prostate-specific antigen level, Gleason score, and tumor stage. The D’Amico risk stratification system is widely used by urologists to determine the risk (low, intermediate, or high) of prostate cancer recurrence after localized treatment.10

Descriptive statistics were used to describe differences between the study patients and control patients. Bivariate analysis consisting of Fisher’s exact test was used to compare categorical outcomes between study and control groups after stratification by laterality of nerve involvement as well as D’Amico score. A value of $P$ less than 0.05 was considered statistically significant and Stata 11.2 (StataCorp LP, College Station, Tex.) was used for all analyses.

RESULTS

A total of 44 patients received immediate unilateral or bilateral cavernous nerve grafting after open prostatectomy for localized prostate cancer. Of these patients, 38 met the inclusion criteria and had a minimum follow-up period of 12 months. Fifty-three control patients met the inclusion criteria of undergoing open prostatectomy without nerve reconstruction (33 bilateral nerve-sparing, 10 unilateral nerve-sparing, and 10 non–nerve-sparing). The mean follow-up was 59 months for nerve-grafting patients and 57 months for the control patients ($P = 0.78$). Two patients in the nerve-grafting group and 9 patients in the control group developed biochemical recur-

Fig. 1. Bilateral cavernous nerve reconstruction after radical prostatectomy. The sural nerve graft is reversed and divided into 2 segments. The interpositional grafts are coapted to the ends of the transected cavernous nerve bundles within the prostatic plexus using several epineurial sutures. *When necessary, major distal branches of the sural nerve are coapted in a manner similar to cable grafting.
rence after prostatectomy, as determined by a rising surveillance prostate-specific antigen level, and required subsequent radiation therapy. The sural graft was most frequently 6 cm in length per side with a mean length of 5.4 cm. Permanent donor site anesthesia was documented in 45% of nerve reconstruction patients. Demographic information was collected and compared between groups (Table 1). There were no significant differences between the grafted and control groups except for age, where the grafted group was younger by 5 years ($P < 0.001$).

There were no significant differences in functional outcomes when unilateral nerve-grafting patients were compared with patients who underwent unilateral nerve-sparing prostatectomy (Table 2). High rates of urinary continence were seen in both unilateral nerve-grafting (79%) and unilateral nerve-sparing (90%) patients. The rates for both erections sufficient for sexual intercourse and for spontaneous erections were modest for both unilateral nerve-grafting (59% and 40%, respectively) and unilateral nerve-sparing (45% and 30%, respectively) groups. No difference was found between the 2 groups in regards to the use of erectogenic medications.

When comparisons were performed between the bilateral nerve-sparing, bilateral nerve-grafting, and bilateral non-nerve-sparing groups, the bilateral nerve-sparing group demonstrated superior urinary continence (73%) and erections sufficient for sexual intercourse (42%; Table 3). Although not statistically significant, the bilateral nerve-sparing group also had the highest rate of spontaneous erections (18%). In contrast, the bilateral nerve-grafting group displayed a trend toward more modest rates of urinary continence (56%), erections sufficient for sexual intercourse (11%), and spontaneous erections (11%). The bilateral non-nerve-sparing group experienced the most dismal functional outcomes, with only 20% of patients reporting urinary continence and no patients exhibiting any functional erectile recovery. There were no statistically significant differences between the bilateral nerve-grafting group and the bilateral non-nerve-sparing group. The rate of use of erectogenic medication was equivalent among the 3 groups.

When stratified by D’Amico score, there were few statistical differences between the functional outcomes of the nerve-grafting group and the control group (Table 4). There was a significantly higher rate of patients reporting spontaneous erections in the nerve-grafting group compared with the control group in both the low risk (100% vs 29%, $P < 0.05$) and the intermediate risk (56% vs 18%, $P < 0.02$) categories. As the D’Amico score increased from low risk to high risk, there was a trend that indicated worsening urinary incontinence and erectile dysfunction regardless of nerve-grafting status. However, this trend was not present in relation to the use of erectogenic medications.

| Table 1. Comparison of Nerve Grafting Patients versus Control Patients |
|---------------------------------------------------------------|
|                | Nerve Grafting ($n = 38$) | Control ($n = 53$) | $P$  |
| Mean age      | 55 y                       | 60 y               | <0.001* |
| Mean follow-up| 59 mo                      | 57 mo              | 0.78  |
| Diabetes      | 2 (5%)                     | 3 (6%)             | 1.0   |
| Active smoking| 5 (13%)                    | 3 (6%)             | 0.27  |
| PVD           | 11 (29%)                   | 12 (23%)           | 0.63  |
| CAD           | 0 (0%)                     | 2 (4%)             | 0.51  |
| Postoperative XRT | 2 (5%)          | 9 (17%)           | 0.11  |
| Prior ED      | 4 (11%)                    | 9 (17%)            | 0.55  |
| Prior incontinence | 0 (0%)         | 0 (0%)           | 1.0   |

Grafted patients were found to be slightly younger in age ($P = 0.001$), although this may not be a clinically significant finding. PVD, peripheral vascular disease; CAD, coronary artery disease; XRT, radiotherapy; ED, erectile dysfunction.

| Table 2. Outcomes between Unilateral Nerve Grafting and Unilateral Nerve-Sparing Prostatectomy |
|------------------------------------------------------------------------------------------|
|                                                                                         |
| Unilateral nerve grafting ($n = 29$)                                                     |
| Unilateral nerve sparing ($n = 10$)                                                      |
| $P$                                                                                      |
| Urinary Continence                                                                       |
| 23 (79%)                                                                                 |
| 9 (90%)                                                                                  |
| 0.65                                                                                    |
| Erections Sufficient for Sex                                                             |
| 17 (59%)                                                                                 |
| 4 (40%)                                                                                  |
| 0.47                                                                                    |
| Spontaneous Erections                                                                    |
| 13 (45%)                                                                                 |
| 3 (30%)                                                                                  |
| 0.48                                                                                    |
| Use of Medication                                                                        |
| 21 (72%)                                                                                 |
| 6 (60%)                                                                                  |
| 0.69                                                                                    |

| Table 3. Comparison of Outcomes between Bilateral Nerve Sparing (Reference Group) and Bilateral Nerve Grafting and Bilateral Non-nerve-sparing Prostatectomy |
|---------------------------------------------------------------------------------------------|
|                                                                                             |
| Bilateral nerve sparing ($n = 33$), reference group*                                         |
| Bilateral nerve grafting ($n = 9$)                                                          |
| Bilateral non-nerve sparing ($n = 10$)                                                      |
|                                                                                             |
| Urinary Continence                                                                         |
| 24 (73%)                                                                                 |
| 5 (56%)                                                                                  |
| 2 (20%)                                                                                  |
| $P$                                                                                      |
| 0.42                                                                                    |
| 0.01*                                                                                     |
| Erections Sufficient for Sex                                                              |
| 14 (42%)                                                                                 |
| 1 (11%)                                                                                  |
| 0 (0%)                                                                                     |
| $P$                                                                                      |
| 0.12                                                                                    |
| 0.02*                                                                                     |
| Spontaneous Erections                                                                     |
| 6 (18%)                                                                                  |
| 1 (11%)                                                                                  |
| 0 (0%)                                                                                    |
| $P$                                                                                      |
| 1.0                                                                                       |
| 0.31                                                                                    |
| Use of Medication                                                                         |
| 26 (79%)                                                                                 |
| 8 (89%)                                                                                  |
| 8 (80%)                                                                                  |
| $P$                                                                                      |
| 0.66                                                                                    |
| 1.0                                                                                       |

*Statistically significant comparisons ($P < 0.05$).
DISCUSSION

Radical prostatectomy is frequently the treatment of choice for relatively healthy patients with localized prostate cancer in any stratified risk level. Although the reported rates of functional deficits after radical prostatectomy varies greatly in the literature, surgical intervention for prostate cancer is associated with up to a 15% rate of permanent urinary incontinence and up to 80% of patients do not have sufficient erectile function for intercourse.11 Nerve-sparing techniques have been shown to improve functional outcomes after prostatectomy, and potency rates may be as high as 60–80%.3,12 However, from an oncologic standpoint, a proportion of prostate cancer patients with substantial disease burden or increased risk of extracapsular extension are not nerve-sparing candidates and will require wide extirpation involving resection of 1 or both of the neurovascular bundles.13 When nerve sparing is not possible and nerve fibers of the prostatic plexus are transected, cavernous nerve reconstruction may offer the potential for improved recovery of urinary continence and erectile function by facilitating axonal regeneration and end organ reinnervation.14 Although the practice of cavernous nerve reconstruction has generally fallen out of favor, our study suggests that there may still be a role for interpositional sural nerve grafting of the prostatic plexus, especially for patients with bilateral segmental defects of the neurovascular bundles after radical prostatectomy.

The advent of laparoscopic or robotic-assisted prostatectomy has been hailed by some to improve continence and potency outcomes,7 but in fact the superiority of these new methods over open prostatectomy in regards to these issues has not been definitively proven in the literature.15,16 Despite this fact, robotic-assisted prostatectomy has become the predominant technique for prostate cancer extirpation in many hospitals across the United States. At our institution, the widespread adoption of robotic-assisted prostatectomy has been attributed to improved magnification and visibility that results in an ostensible decrease in the documented incidence of neurovascular bundle injury. However, because the purpose of this investigation was to focus specifically on the effects of nerve grafting for prostatic plexus defects after radical prostatectomy, this series only included patients who underwent open prostatectomy because during the study period, nerve grafting was commonly attempted in this population. Despite the fact that radical prostatectomy is now widely performed using minimally invasive techniques, our findings remain relevant to any patient facing necessary or iatrogenic injury to the prostatic plexus during prostatectomy regardless of surgical technique.

In our study, unilateral sural nerve grafting provided no significant functional benefit compared with unilateral nerve-sparing prostatectomy, and this is consistent with the findings of other authors, who have reported varying potency rates from 32% to 76% after unilateral nerve grafting.17–20 A recent randomized control trial comparing unilateral nerve-sparing prostatectomy with unilateral sural nerve grafting failed to reveal any difference at 2 year follow-up in rates of potency (67% vs 71%).9 Furthermore, it has not been shown that any apparent gains in function were directly attributable to the unilateral nerve graft. This study affirms the conclusion that unilateral nerve grafting offers no functional improvement, and in addition, our investigation demonstrates that no further recovery can be expected after a long-term follow-up period of almost 5 years. Although morbidity from the sural nerve-graft harvest is minimal, reconstruction of the prostatic plexus is technically demanding and significantly increases operative time. Given these practical considerations, routine unilateral reconstruction of nerve defects after radical prostatectomy cannot be recommended until substantial advances are made in the efficacy of unilateral nerve grafting.

In contrast, bilateral non–nerve-sparing prostatectomy is well known to cause substantial functional deficits; in our study, none of these patients reported erections sufficient for sexual intercourse or spontaneous ejections, and this group also experienced the lowest rate of urinary continence. Bilateral nerve...
grafting did appear to bestow some improvement in urinary continence and potency, but the best functional outcomes were seen in bilateral nerve-sparing patients. Certainly, one would expect that the preservation of intact nerves maximizes long-term outcomes compared with bilateral interpositional nerve grafting, which requires axonal regeneration across multiple end-to-end nerve coaptations. Rates of erectile function after bilateral nerve grafting in this study are lower than the 20–70% potency rate reported in the literature.\(^{14,21-23}\) This can be because of a variety of factors, such as small sample size, lack of randomization, and the subjectivity of study outcomes. However, when one considers the certainty of poor functional outcomes after bilateral neurovascular bundle resection without reconstruction, we believe that it is still reasonable to consider sural nerve grafting when nerve sparing cannot be accomplished.

Conceptually, interpositional cavernous nerve grafting is logical. Lessons learned from nerve grafting in the upper and lower extremities suggest that optimal functional restoration may be achieved if axons are redirected to their intended end-organs. Accordingly, reliable intraoperative detection of the nerves that mediate urinary continence and erectile function is crucial to the success of nerve grafting. However, a major challenge of prostatic plexus reconstruction is the complexity of the segmental defect after neurovascular bundle resection and the inability to accurately repair a gap within a convoluted network of transected nerves. By gross examination of the residual neurovascular bundles, it is impossible to distinguish the precise fibers belonging to the cavernous nerves or to the nerves traveling to the external urethral sphincter. Therefore, out of practicality, all proximal nerve endings are crudely connected to all distal stumps via the sural nerve grafts. Regeneration and reinnervation is consequently rather nonspecific, and this undoubtedly diminishes postoperative function. For example, using this method, sympathetic nerves that serve to trigger detumescence may in fact be inadvertently routed to reinnervate the corpora cavernosa. Some investigators have attempted to use intraoperative nerve stimulation to identify the cavernous nerves, but several studies have indicated a lack of sensitivity for this technique, and therefore, the benefits of its use remains uncertain.\(^{24-26}\) In light of these known challenges, perhaps we have prematurely abandoned the concept of cavernous nerve reconstruction after radical prostatectomy. Conceivably, if transected nerve ends within the prostatic plexus could be reliably identified and repaired as in extremity surgery, the true benefits of sural nerve grafting in bilateral or even unilateral cases may be elucidated in future studies.

The preoperative D’Amico score was used to stratify each patient by oncologic risk level. Although the trends were nonsignificant, the rates of urinary continence, erections sufficient for sexual intercourse, and spontaneous erections generally worsened with increasing D’Amico score regardless of nerve-grafting status. This could be attributed to more aggressive margins taken during prostatectomy on account of an increased risk assessment that was known preoperatively. Given small sample sizes, the analysis was underpowered to elucidate statistically significant differences between risk-stratified nerve-grafting subgroups, but these trends suggest that future research on functional outcomes after prostatic nerve reconstruction should certainly account for tumor characteristics.

This study possesses several limitations in addition to those inherent to its retrospective design. First, although this study differs from the majority of existing reports by incorporation of a control group and a follow-up period of 5 years, one limitation was the sample size. Despite including 38 nerve-grafting patients, subgroup comparisons within either the unilateral or bilateral nerve-grafting cohorts were difficult after stratification by D’Amico score and by laterality of nerve involvement. Another limitation common with many other studies analyzing functional results after prostatectomy is the subjective nature of the postoperative outcomes. Urinary continence, erections sufficient for sexual intercourse, spontaneous erections, and use of erectogenic medications were chosen because these were readily elicited in the clinic setting and consistently documented in the medical records. Although urinary incontinence is frequently described as number of pads used per day, there has been no uniformly objective method to quantify the degree of erectile function. A possible solution in subsequent studies is to use validated survey instruments specifically designed to evaluate functional outcomes after prostatectomy, such as the Expanded Prostate Cancer Index Composite.\(^{27}\)

**CONCLUSIONS**

Immediate nerve grafting for reconstruction of the prostatic plexus after radical prostatectomy may be most valuable for improving postoperative morbidity in patients requiring bilateral neurovascular bundle resections. Currently, the benefit of nerve grafting is limited by the inability to accurately isolate the putative nerves, which mediate erectile function and urinary continence. Development of reliable intraoperative techniques to identify these critical nerves requiring repair after radical prosta-
tectomy will help determine appropriate indications for interpositional nerve grafting in bilateral or even unilateral cases.

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