学 位 論 文

Morphological study of the neurovascular bundle to elucidate nerve damage in pelvic surgery

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ORIGINAL ARTICLE

Morphological study of the neurovascular bundle to elucidate nerve damage in pelvic surgery

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Abstract

Purpose Postoperative sexual and urinary dysfunction may occur after rectal cancer surgery involving the pelvis, but this problem cannot be solved. The aim of this study was to examine the nerve morphology of the neurovascular bundle in cadavers to determine possible causes of nerve damage during surgery.

Methods Twenty-two formalin-fixed cadavers were used in the study. The cadavers were donated to the Tokyo Medical University. The study comprised histological evaluation of paraffin-embedded bilateral neurovascular bundle specimens from the cadavers. Four slides of 3-cm thick were made every 1 cm in a plane perpendicular to the rectum towards the pelvic floor from the peritoneal reflection in bilateral neurovascular bundles in 22 cadavers. The number of nerves, the mean nerve area, and the mean nerve diameter were measured in each slide.

Results The results were categorized into cases with high (group H) and low (group L) positions of the pelvis 1 cm above and 2 cm below the peritoneal reflection, respectively. There was no significant difference in the number of nerves between these groups. The nerve area and nerve diameter were significantly smaller in group L, and these characteristics were more marked in males.

Conclusions Our results show that the nerves of the neurovascular bundle became smaller in the deep pelvis. This may cause these nerves to be more susceptible to injury, resulting in nerve damage in the deep pelvis that leads to postoperative dysfunction. Particularly, this type of nerve damage may be a cause of postoperative sexual dysfunction in males.

Keywords Rectal surgery · Postoperative dysfunction · Neurovascular bundle · Sexual dysfunction · Anatomy

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Introduction

D3 surgery with bilateral lymph node dissection was the standard treatment in pursuit of radical cure of rectal cancer in the 1980s in Japan, but the postoperative rate of sexual dysfunction or urinary disorder was 70–80 % [1]. To address this problem, nerve-sparing D3 surgery aimed at functional preservation and radical cure was developed [2]. This surgery has decreased the postoperative rates of urinary, erectile, and ejaculation dysfunction to 0–26, 4–27, and 5–67 %, respectively [3–6]. Heald et al. [7] proposed the concept of total mesorectal excision (TME) in Europe in 1982, and the low postoperative rates of local relapse and functional problems were similar to D3 surgery in Japan. TME or partial mesorectal excision (PME) has now become the standard treatment for rectal cancer worldwide and offers radical cure and functional preservation. However, Nishizawa et al. [8] reported that the rates of erectile and ejaculation dysfunction are 50 and 43 %, respectively, at 12 months after TME without lateral lymph node dissection for rectal cancer.

Laparoscopic colectomy was first described by Jacobs et al. in 1991 [9]. Subsequent control studies (COST [10], CLASICC [11], COLOR [12]) of the radical cure of advanced colorectal cancer in Europe and the USA showed no difference in the overall survival rate and the rate of no recurrence in comparison with laparotomy, and the use of laparoscopic colorectal surgery has spread rapidly. The advantages of laparoscopic surgery include improved quality of life based on reduced postoperative pain and an early return to normal life. Nerve preservation is enabled by more correct TME to PME and identifying the exact layer using the magnifying effect of laparoscopy, which reduces the risk of postoperative sexual and urinary dysfunction. However, sexual and urinary dysfunction still develop at rates of 5.5–63.6 % [11, 13–17] and 3–14 % [13, 14, 18], respectively, after laparoscopic surgery, and many patients still have functional problems, and especially sexual dysfunction, after rectal surgery.

In laparoscopic surgery for the treatment of rectal cancer, performance of minute maneuvers using the laparoscopic close-up view has been assisted by increased understanding of the dissection of the pelvis. These maneuvers allow better preservation of the pelvic plexus and neurovascular bundle (NVB), and this may reduce the rates of urinary and sexual dysfunction after intrapelvic surgery. However, many cases still have dysfunction, and this may be due to nerve damage during the operation, even in macroscopic nerve-sparing surgery. Therefore, we examined the nerves in the NVB in cadavers anatomically and morphologically, with the goal of establishing the cause of nerve damage during surgery.

Materials and methods

Twenty-two formalin-fixed cadavers (mean age 83 ± 8 years old, 11 males, 11 females) were used in the study. The cadavers were donated to the Tokyo Medical University. Before death, the donors had signed documents agreeing to body donation and use in clinical studies. The format of the consent document met the Japanese law, as stated in the "Act on Body Donation for Medical and Dental Education." Cadavers used

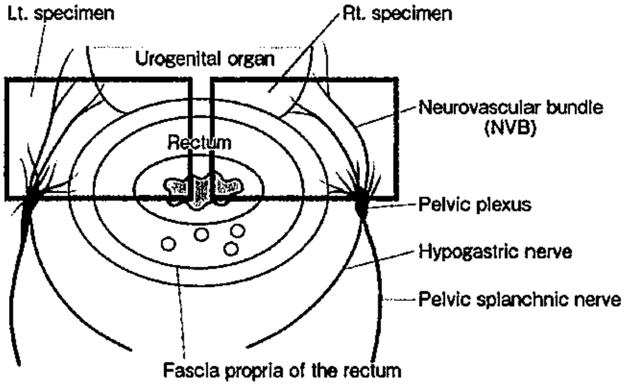

Fig. 1 Axial image of specimen manufacture. Specimens were made from the right and left NVBs included the rectal wall

in the study did not have colorectal or neurologic disease as the direct cause of death. Left and right NVB specimens were obtained from the 22 cadavers (Table 1). The block was cut down from the pelvic plexus or the NVB in the directions around 0–3 o'clock and 9–12 o'clock relative to the rectum, including the rectal wall, and embedded in paraffin (Fig 1). Four slides of border length 3 cm were made every 1 cm on the plane perpendicular to the rectum in the left and right NVB towards the pelvic floor from the peritoneal reflection on each cadaver (Fig 2). Thus, four slides were made for each of the left and right NVBs from one cadaver. However, the rectal wall was not included in the left NVB slides from four cadavers, and these slides were excluded from the evaluation. Therefore, 72 slides of the left NVB specimen from 18 cadavers and 88 slides of the right NVB specimen from 22 cadavers were evaluated. These slides were stained with

Table 1 Background characteristics of cadavers

Item	Value
Number of cadavers	22
Sex	
Male	11
Female	11
Age (mean ± SD, years)	83 ± 8
Number of evaluated specimens	
Right NVB	88 (22 × 4)
Left NVB	72 (18 × 4)

NVB neurovascular bundle

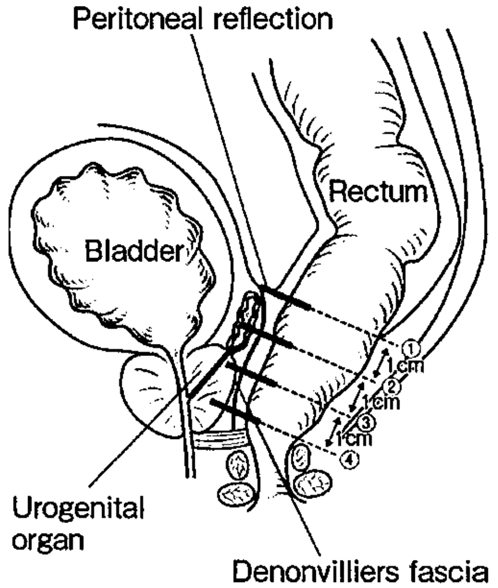

Fig. 2 Sagittal image of specimen manufacture. From the peritoneal reflection, the specimen was cut down to a depth of 3 cm every 1 cm in the plane perpendicular to the rectum towards the pelvic floor. The specimen was cut down to the solid line

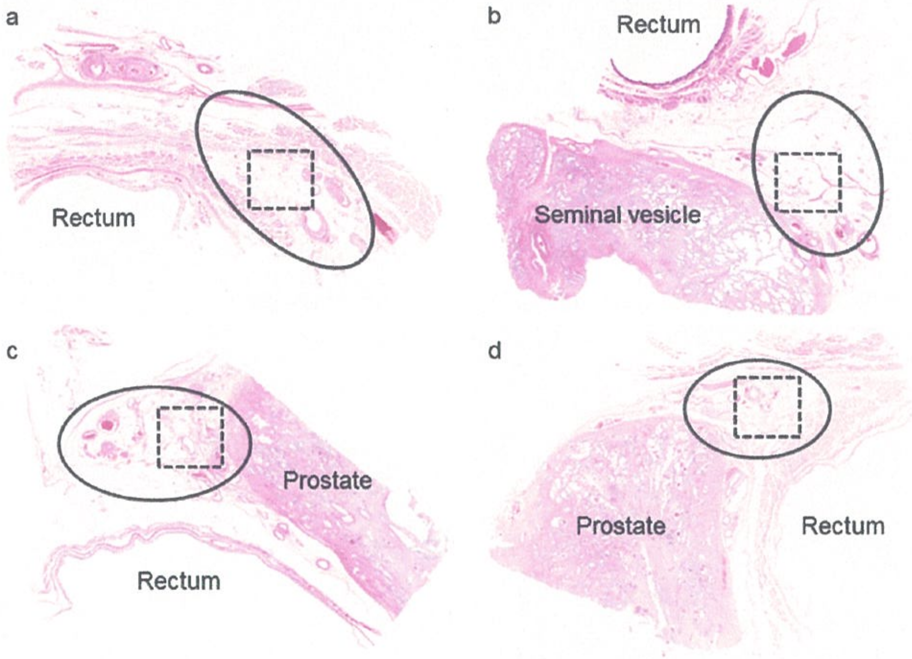

Fig. 3 **a** A sample of a right NVB specimen from a male taken at position 1 in Fig. 2. The specimen included the rectal wall. The *circle* indicates the NVB region in the specimen, and the *square* (*dotted line*) indicates the area in which the number, areas, and diameters of nerves were measured. **b** A sample of a right NVB specimen from a male taken at position 2 in Fig. 2. The specimen included the rectal wall and the seminal vesicle. The *circle* indicates the NVB region in the specimen, and the *square* (*dotted line*) indicates the area in which the number, areas, and diameters of nerves were measured. **c** A sample of a right NVB specimen from a male taken at position 3 in Fig. 2. The specimen included the rectal wall and the prostate. The *circle* indicates the NVB region in the specimen, and the *square* (*dotted line*) indicates the area in which the number, areas, and diameters of nerves were measured. **d** A sample of a right NVB specimen from a male taken at position 4 in Fig. 2. The specimen included the rectal wall and the prostate. The *circle* indicates the NVB region in the specimen, and the *square* (*dotted line*) indicates the area in which the number, areas, and diameters of nerves were measured

hematoxylin eosin (HE) (Fig. 3). The thickness of the paraffin sections was 5 μm.

Microscopic evaluation

Each specimen was evaluated using an optical microscope (BX-51, Olympus, Tokyo, Japan). In a pilot study, data were collected in areas of 3 × 3, 5 × 5, and 10 × 10 mm. Some 3 × 3-mm specimens did not include a nerve, whereas some 10 × 10-mm specimens included tissue outside the NVB region. Therefore, we decided to use measurements in an area of 5 × 5 mm for the collection of data. Thus, a random area of 5 × 5 mm in each HE-stained specimen was selected for the measurement of the number of nerves, the nerve area, and the nerve diameter (Fig. 3). In counting the number of nerves, a nerve fascicle covered with a perineurium was considered to be one nerve (Fig. 4). The nerve area (μm^2) was traced using a perineurium on an image and measured using image processing software (DP2-BSW ver.2.2, Olympus). The nerve diameter (μm) was evaluated based on the minor axis and measured using the same software (Fig. 5). The mean nerve area, mean nerve diameter, and the minimum and maximum nerve areas and diameters were evaluated on each slide.

Statistical analysis

Nerve measurements were analyzed by the comparison of two groups defined by high (group H) and low (group L) positions. That is, positions 1 and 2 (Fig. 2) were defined as group

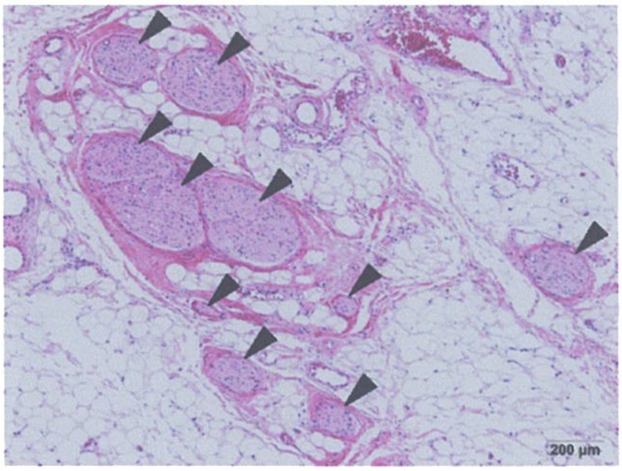

Fig. 4 Evaluation of the nerve number under a microscope. A nerve fascicle covered by a perineurium was counted as one nerve. Each *arrowhead* indicates one nerve

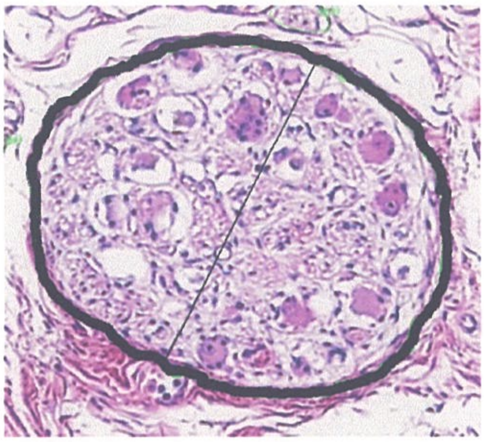

Fig. 5 Measurement of the nerve area and diameter. The nerve area (μm²) was traced using a perineurium on each image and measured using an image processing software (DP2-BSW ver.2.2, Olympus, Tokyo, Japan). The nerve diameter (μm) was evaluated based on a minor axis and measured using the same software

H, and positions 3 and 4 (Fig. 2) were defined as group L. Data were analyzed by *t* test using PASW Statistics 17.0 (SPSS Inc., Tokyo, Japan), with $p < 0.05$ considered significant.

Results

The results for all NVBs and for the right and left NVBs are shown in Table 2. The number of nerves did not differ significantly between groups H and L in all NVBs ($p = 0.35$) and in right ($p = 0.31$) and left ($p = 0.87$) NVBs.

The mean nerve area was significantly smaller in group L in all NVBs ($p < 0.01$) and in the right ($p = 0.02$) and left ($p = 0.01$) NVBs. The maximum nerve area was also significantly smaller in group L in all NVBs ($p < 0.01$) and in the right ($p < 0.01$) and left ($p = 0.02$) NVBs. In contrast, the minimum nerve area did not differ significantly between the two groups in all NVBs ($p = 0.4$) and in the right ($p = 0.48$) and left ($p = 0.59$) NVBs.

The mean nerve diameter was significantly smaller in group L in all NVBs and in the left NVBs (both $p < 0.01$) and showed a tendency to be smaller in group L in the right NVBs (78 ± 22 vs. 67 ± 15 μm, $p = 0.08$). The maximum nerve diameter was significantly smaller in group L in all NVBs and in the right and left NVBs (all $p < 0.01$). The minimum nerve diameter did not differ significantly between the groups in all NVBs ($p = 0.62$) and in the right ($p = 0.33$) and left ($p = 0.74$) NVBs.

We also examined the results in male and female subgroups (Table 3). The mean nerve area and mean nerve diameter were significantly smaller in males in group L compared to males in group H, while these parameters did not differ between females in the two groups. In the deep pelvis, the nerves became significantly smaller in males (Table 3). Regarding sex differences (Table 4), there was no significant difference in the number of nerves between males and females in group H, but there were significantly more nerves in males in group L. We also evaluated laterality in the same individual, but no particular trend was observed.

Discussion

In this study, we examined the organization of nerves in NVBs anatomically and morphologically in cadavers to determine possible causes of nerve damage in rectal surgery. We hypothesized that nerves of the NVB may become smaller and increase in number with repeated splitting deep in the pelvis, and that these nerves may therefore be susceptible to damage in the deep pelvis. However, we found no significant correlation of the number of nerves with the pelvic depth, thus disproving this hypothesis. We did find that there were more nerves in males than in females in the deep pelvis. We also found that the nerves of the NVB tended to be thicker in males based on the nerve area and diameter, and especially the maximum nerve area and diameter, and that the minimum nerve area and diameter tended to be smaller in males than in

Table 2 Results for specimens from neurovascular bundles (NVBs)

	All NVB ($n = 40$)			Right NVB ($n = 22$)			Left NVB ($n = 18$)		
	Group H	Group L	*p*	Group H	Group L	*p*	Group H	Group L	*p*
Number of nerves	82 ± 37	75 ± 29	0.35	92 ± 41	80 ± 35	0.31	70 ± 28	69 ± 20	0.87
Mean nerve area (×10³ μm²)	16.5 ± 11.3	9.7 ± 4.6	*<0.01*	16.7 ± 11.5	9.4 ± 4.6	*0.02*	15.9 ± 8.6	9.7 ± 4.6	*0.01*
Minimum nerve area (μm²)	560 ± 230	520 ± 250	0.4	470 ± 230	420 ± 210	0.48	670 ± 200	630 ± 260	0.59
Maximum nerve area (×10³ μm²)	245 ± 241	83.2 ± 60.5	*<0.01*	267 ± 264	83.7 ± 55.9	*<0.01*	212 ± 208	84.6 ± 65.9	*0.02*
Mean nerve diameter (μm)	80 ± 19	67 ± 14	*<0.01*	78 ± 22	67 ± 15	0.08	83 ± 15	67 ± 14	*<0.01*
Minimum nerve diameter (μm)	20 ± 4	20 ± 4	0.62	19 ± 4	18 ± 4	0.33	21 ± 3	22 ± 4	0.74
Maximum nerve diameter (μm)	350 ± 190	200 ± 70	*<0.01*	360 ± 210	210 ± 70	*<0.01*	340 ± 140	180 ± 70	*<0.01*

The significance of the items set in italic

NVB neurovascular bundle

Table 3 Results for groups H and L in males and females

	Male ($n = 11$)			Female ($n = 11$)		
	Group H	Group L	p	Group H	Group L	p
Number of nerves	90±37	86±32	0.72	74±36	64±23	0.3
Mean nerve area (×10^3 μm^2)	19.1±10.4	9.7±5.0	*<0.01*	13.6±11.6	9.4±4.3	0.14
Minimum nerve area (μm^2)	520±210	450±180	0.25	600±260	570±300	0.81
Maximum nerve area (×10^3 μm^2)	327±268	96.6±69.5	*<0.01*	157±172	71.5±46.7	*0.04*
Mean nerve diameter (μm)	85±13	68±15	*<0.01*	74±23	66±14	0.15
Minimum nerve diameter (μm)	20±4	19±4	0.31	20±3	20±5	0.79
Maximum nerve diameter (μm)	400±210	210±70	*<0.01*	300±140	190±60	*<0.01*

The significance of the items set in italic

females in groups H and L. The nerve network may be more complicated in males than in females because of the presence of the cavernous nerve. The more extensive nerve network in males may also be due to urogenital organs that are not present in females (e.g., seminal vesicles, prostate gland, vas deferens) requiring autonomic innervation, and thus an additional nerve fiber supply is needed.

In an analysis of specimens from non-nerve sparing radical prostatectomy, Hisasue et al. [19] found that the size of the specimen, weight, body mass index, and age did not influence the number of nerves in the NVB. This report and the results of our study suggest that males have more nerves than females in the NVB, and that this tendency is purely a sex difference and is independent of other factors. It is unclear why males have more nerves in this region, but this may be explained by the presence of the cavernous nerve. The nerves in the NVB in males may be injured more easily than those in females.

The ganglion was included as a single nerve in this study. Kinugasa et al. [20] pointed out that a nerve network is important for sexual function and urination. However, since the current study was planned as a morphologic examination, rather than a functional examination, we did not measure the number of ganglions. In a future study, we would like to examine characteristics such as numerical changes in ganglions, functional characteristics, and sex differences based on the knowledge obtained in this study.

The sizes of nerves were evaluated based on the nerve cross-sectional area and diameter. Many nerves in a specimen cut from a block may not cross exactly and are cut diagonally. Therefore, it is hard to define the area or diameter of a nerve section as reflecting the exact size of the nerve. However, because all specimens used in the study were made to the same standard, evaluation of the mean of nerve area and diameter in a sufficient number of specimens should be reliable. Our results showed that the area and diameter of nerves in NVBs became significantly smaller in the deep pelvis in all subjects and in males alone, but not significant in females. Smaller nerves are more easily damaged. Thus, this interesting result suggests that the cavernous nerve in the NVB in males may be susceptible to damage during surgery, and that this may be related to onset of sexual dysfunction postoperatively. This hypothesis is only speculative, but it is consistent with the smaller NVB in males being more susceptible to heat or mechanical damage. The minimum nerve area did not depend on the pelvic depth, and the smallest nerve should be identifiable under an optical microscope. This suggests that a little unevenness in the depth of nerve evaluation under a microscope should not influence the measurement of the minimum nerve area.

Kiyoshima et al. [21] reported bundle formation in the NVB region in only 52 % of the subjects, and Lee et al. [22] found approximately 40 % of the cases without a clear NVB structure in an evaluation by magnetic resonance imaging before total

Table 4 Comparison of males and females in groups H and L

	Group H males	Group H females	p	Group L males	Group L females	p
Number of nerves	90±37	74±36	0.19	86±32	64±23	*0.02*
Mean nerve area (×10^3 μm^2)	19.1±10.4	13.6±11.6	0.12	9.7±5.0	9.4±4.3	0.84
Minimum nerve area (μm^2)	520±210	600±260	0.3	450±180	570±300	0.12
Maximum nerve area (×10^3 μm^2)	327±268	157±172	*0.02*	96.6±69.5	71.5±46.7	0.19
Mean nerve diameter (μm)	85±13	75±23	0.11	68±15	66±14	0.75
Minimum nerve diameter (μm)	20±4	20±3	0.63	19±4	20±5	0.41
Maximum nerve diameter (μm)	400±210	300±140	0.08	210±70	190±60	0.27

The significance of the items set in italic prostatectomy, with the further finding that the recovery of erectile function after nerve-sparing total prostatectomy was poor in these cases [22]. It is difficult to identify nerves macroscopically during surgery, and the cavernous nerve may be mistaken as a lump in the NVB. The cavernous nerve runs on the dorsal side of the NVB [23] and thus on the rectal side in front of the hypogastric fascia or Denonvilliers fascia, which is an important consideration in TME or PME in rectal surgery. Postoperative sexual dysfunction may still occur after nerve-sparing surgery, and this may be due to the anatomical and morphological characteristics of the nerves of NVBs that are apparent in the current study. These findings show that the nerve became smaller in the deep pelvis, especially in males, and this may make macroscopic judgment of nerve preservation difficult in the deep pelvis, even in a nerve-sparing operation. Thus, nerves may undergo mechanical damage due to the operation or heat damage caused by energy devices.

In male sexual dysfunction after rectal surgery, several reports [13, 18, 24–26] have shown that the rate of erectile dysfunction is higher than that of ejaculation dysfunction. The cavernous nerve controlling erection is considered to be part of the parasympathetic system, and there are few peripheral parasympathetic nerves (that is, a low myelinated nerve ratio) among NVB nerves [27–29]. This suggests that damage to the cavernous nerve during surgery may not be easily compensated for after surgery. Thus, the high rate of postoperative erectile dysfunction may be related to the small nerves in the NVB region in the deep pelvis in males.

Nerve damage in the deep pelvis can easily occur, even in a nerve-sparing operation, and an improved understanding of the anatomical and morphological characteristics of the nerves of the NVB region may permit maneuvers during surgery that avoid damage. Avoidance of the use of devices that may cause heat damage, such as avoiding unnecessary use of a cautery for hemostasis, is also important. These factors may be particularly important in surgery around the Denonvilliers fascia in males. Nerve damage during surgery is not only caused by a small nerve size and may be dependent on multiple factors. The findings in this study may explain postoperative sexual and urinary dysfunction after lower rectal cancer surgery in terms of the morphological features of nerves. A future study is required to determine appropriate surgical techniques for nerve-sparing procedures, including traction for detachment, and to examine differences in thermal injury with the use of different energy devices. Deepening of knowledge on the nerves of the NVB is likely to contribute to postoperative functional preservation. Our current findings indicate that nerve damage and postoperative dysfunction after an intrapelvic operation are dependent on the anatomical and morphological features of these nerves.

Compliance with ethical standards Before death, the donors had signed documents agreeing to body donation and use in clinical studies. The format of the consent document met the Japanese law, as stated in the "Act on Body Donation for Medical and Dental Education."

Conflict of interest The authors declare that they have no competing interests.

References

1. Hojo K, Sawada T, Moriya Y (1989) An analysis of survival and voiding, sexual function after wide iliopelvic lymphadenectomy in patients with carcinoma of the rectum, compared with conventional lymphadenectomy. Dis Colon Rectum 32:128–133
2. Moriya Y, Sugihara K, Akatsu T, Fujita S (1995) Nerve-sparing surgery with lateral node dissection for advanced lower rectal cancer. Eur J Cancer 31A:1229–1232
3. Sugihara K, Moriya Y, Akatsu T, Fujita S (1996) Pelvic autonomic nerve preservation for patients with rectal carcinoma: oncologic and functional outcome. Cancer 78:1871–1880
4. Masui H, Ike H, Yamaguchi S, Oki S, Shimada H (1996) Male sexual function after autonomic nerve-preserving operation for rectal cancer. Dis Colon Rectum 39:1140–1145
5. Saito N, Sarashina H, Nunomura M, Koda K, Takiguchi N, Nakajima N (1998) Clinical evaluation of nerve-sparing surgery combined with preoperative radiotherapy in advanced rectal cancer patients. Am J Surg 175:277–282
6. Maeda K, Maruta M, Utsumi T, Sato H, Toyama K, Matsuoka H (2003) Bladder and male sexual functions after autonomic nerve-sparing TME with or without lateral node dissection for rectal cancer. Tech Coloproctol 7:29–33
7. Heald RJ, Husband EM, Ryall RD (1982) The mesorectum in rectal cancer surgery: the clue to pelvic recurrence? Br J Surg Oct 69:613–616
8. Nishizawa Y, Ito M, Saito N, Suzuki T, Sugito M, Tanaka T (2011) Male sexual dysfunction after rectal cancer surgery. Int J Colorectal Dis 26:1541–1548
9. Jacobs M, Verdeja JC, Goldstein HS (1991) Minimally invasive colon resection (laparoscopic colectomy). Surg Laparosc Endosc 1:144–150
10. Fleshman J, Sargent DJ, Green E et al (2007) Laparoscopic colectomy for cancer is not inferior to open surgery based on 5-year data from the COST Study Group trial. Ann Surg 246:655–662
11. Jayne DG, Thorpe HC, Copeland J et al (2010) Five-year follow-up of the Medical Research Council CLASICC trial of laparoscopically assisted versus open surgery for colorectal cancer. Br J Surg 97:1638–1645
12. Buunen M, Veldkamp R, Hop WC et al (2009) Survival after laparoscopic surgery versus open surgery for colon cancer: long-term outcome of a randomised clinical trial. Lancet Oncol 10:44–52
13. Jones OM, Stevenson ARL, Stitz RW, Lumley JW (2009) Preservation of sexual and bladder function after laparoscopic rectal surgery. Colorectal Dis 11:489–495
14. Morino M, Parini U, Allaix ME, Monasterolo G, Brachet Contul R, Garrone C (2009) Male sexual and urinary function after laparoscopic total mesorectal excision. Surg Endosc 23:1233–1240
15. Breukink SO, van Driel MF, Pierie JPEN, Dobbins C, Wiggers T, Meijerink WJ (2008) Male sexual function and lower urinary tract symptoms after laparoscopic total mesorectal excision. Int J Colorectal Dis 23:1199–1205
16. Asoglu O, Matlim T, Karanlik H et al (2009) Impact of laparoscopic surgery on bladder and sexual function after total mesorectal excision for rectal cancer. Surg Endosc 23:296–303

17. Stamopoulos P, Theodoropoulos GE, Papailiou J et al (2009) Prospective evaluation of sexual function after open and laparoscopic surgery for rectal cancer. Surg Endosc 23:2665–2674
18. Sartori CA, Sartori A, Vigna S, Occhipinti R, Baiocchi GL (2011) Urinary and sexual disorders after laparoscopic TME for rectal cancer in male. J Gastrointest Surg 15:637–643
19. Hisasue S, Hashimoto K, Kobayashi K et al (2010) Baseline erectile function alters the cavernous nerve quantity and distribution around the prostate. J Urol 184:2062–2067
20. Kinugasa Y, Murakami G, Uchimoto K et al (2006) Operating behind Denonvilliers' fascia for reliable preservation of urogenital autonomic nerves in total mesorectal excision: a histologic study using cadaveric specimens, including a surgical experiment using fresh cadaveric models. Dis Colon Rectum 49: 1024–1032
21. Kiyoshima K, Yokomizo A, Yoshida T et al (2004) Anatomical features of periprostatic tissue and its surroundings: a histological analysis of 79 radical retropubic prostatectomy specimens. Jpn J Clin Oncol 34:463–468
22. Lee SE, Hong SK, Han JH et al (2007) Significance of neurovascular bundle formation observed on preoperative magnetic resonance imaging regarding postoperative erectile function after nerve-sparing radical retropubic prostatectomy. Urology 69:510–514
23. Costello AJ, Brooks M, Cole OJ (2004) Anatomical studies of the neurovascular bundle and cavernosal nerves. BJU Int 94:1071–1076
24. Zugor V, Miskovic I, Lausen B et al (2010) Sexual dysfunction after rectal surgery: a retrospective study of men without disease recurrence. J Sex Med 7:3199–3205
25. Hendren SK, O'Connor BI, Liu M et al (2005) Prevalence of male and female sexual dysfunction is high following surgery for rectal cancer. Ann Surg 242:212–223
26. Sterk P, Shekarriz B, Günter S et al (2005) Voiding and sexual dysfunction after deep rectal resection and total mesorectal excision, prospective study on 52 patients. Int J Colorectal Dis 20: 423–427
27. Costello AJ, Dowdle BW, Namdarian B, Pedersen J, Murphy DG (2010) Immunohistochemical study of the cavernous nerves in the periprostatic region. BJU Int 107:1210–1215
28. Taguchi K, Tsukamoto T, Murakami G (1999) Anatomical studies of the autonomic nervous system in the human pelvis by the whole-mount staining method: left-right communicating nerves between bilateral pelvic plexuses. J Urol 161:320–325
29. Ganzer R, Stolzenburg JU, Wieland WF, Bründl J (2012) Anatomic study of periprostatic nerve distribution: immunohistochemical differentiation of parasympathetic and sympathetic nerve fibres. Eur Urol 62:1150–1156