Where does pelvic nerve injury occur during rectal surgery for cancer?

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Abstract

Aim Optimal treatment of rectal adenocarcinoma involves total mesorectal excision with nerve-preserving dissection. Urinary and sexual dysfunction is still frequent following these procedures. Improved knowledge of pelvic nerve anatomy may help reduce this and define the key anatomical zones at risk.

Method The MEDLINE database was searched for available literature on pelvic nerve anatomy and damage after rectal surgery using the key words ‘autonomic nerve’, ‘pelvic nerve’, ‘colorectal surgery’, and ‘genitourinary dysfunction’. All relevant French and English publications up to May 2010 were reviewed. Reviewed data were illustrated using 3D reconstruction of the foetal pelvis.

Results The ligation of the inferior mesenteric artery and dissection of the retrorectal space can cause damage to the superior hypogastric plexus and/or hypogastric nerve. Anterolateral dissection in the ‘lateral ligament’ area and division of Denonvilliers’ fascia can damage the inferior hypogastric plexus and efferent pathways. Perineal dissection can indirectly damage the pudendal nerve.

Conclusions In most cases, the pelvic nerves can be preserved during rectal surgery. Complete oncological resection may require dissection close to the nerves where the tumour is located anterolaterally where it is fixed and when the pelvis is narrow.

Keywords Surgery, rectal cancer, anatomy, pelvic nerve injury, computer-assisted anatomic dissection (CAAD)

Introduction

Optimal treatment of adenocarcinoma of the rectum is based on surgery in which the rectum, with the surrounding mesorectum, is resected as an intact capsule with lymphadenectomy [total mesorectal excision (TME)]. TME is combined with nerve-preserving dissection in an attempt to avoid urinary and sexual dysfunction [1–4]. Lymph nodes at the origin of the inferior mesenteric artery (IMA) [5–7] are also removed [8–10]. Sphincter-saving or abdominoperineal resection (APR) is carried out depending on the level of the tumour [11–15]. With TME and nerve preservation, the rates of genitourinary dysfunction remain around 5–40% [12,16–18]. These rates may be higher after APR [12,19,20].

Urinary and sexual dysfunction is attributed to somatic and autonomic pelvic nerve damage [21,22]. There are two distinct anatomical compartments in the lower pelvis, above and below the levator ani muscle. Each is innervated by different nerve pathways [23]. The supralelevator pathway is formed by autonomic nerves including the pelvic splanchnic nerves (PSN, parasympathetic); the superior hypogastric plexus (SHP) with hypogastric nerves (HN, sympathetic); and the inferior hypogastric plexus (IHP). The infralelevator pathway consists of somatic nerves including the pudendal nerve (PN) and its terminal branches.

Conventional pelvic and perineal dissections are used to study pelvic nerve anatomy, and these are performed through surgical intrapelvic, gluteal and perineal approaches on fresh or frozen cadavers. The standard
means of documenting these dissections is by hand drawings and photography. While dissection of pelvic nerves is technically difficult, the combination of immunostaining and computerized imaging can improve the definition of pelvic organs and clarify their innervation. Three-dimensional (3D) models help to gain a better understanding of complex anatomic structures [24].

In this review of the anatomical and surgical literature, an attempt was made to clarify the anatomy of the pelvic autonomic and somatic nerve pathways with their different sites at risk during surgery for rectal cancer.

Method

Search strategy
Two investigators searched the published literature in the Pubmed database (US National Library of Medicine, Bethesda, Maryland) on pelvic nerve anatomy and nerve damage after rectal cancer surgery up to 2010. The key words used were autonomic nerve, pelvic nerve, colorectal surgery, sexual dysfunction and urinary dysfunction. The ‘related articles’ algorithm was employed to identify additional articles. Bibliographies of original reports and reviews were scanned for additional references.

Inclusion criteria
All anatomic original articles, reviews and editorial letters that described pelvic and perineal neuroanatomy were included. Descriptions of surgical techniques were included if based on surgical anatomy of the pelvic nerves and nerve preservation techniques. Clinical studies of genitourinary dysfunction following rectal surgery were also identified.

Exclusion criteria
Only publications in French or English were included. Clinical studies on nonfunctional surgical complications, such as sepsis or adhesive small bowel obstruction, were excluded. Data from patients with recurrence after rectal cancer surgery were also excluded as were anatomical studies and case reports. Data from duplicate studies were analysed without duplication.

Selection of studies
Two of the authors selected studies based on titles or abstracts. Studies that met the inclusion criteria were selected for review. If it was not clear from the abstract whether a study fulfilled the inclusion criteria, the full article was retrieved for further evaluation.

Data extraction and quality assessment of included material
The following data elements were extracted from each anatomic article including publication year, article type, sample size, anatomical subject type, dissection methodology, documentation and illustration modalities and anatomical results including nerve pathways. Additional data were extracted for patients having surgery for rectal cancer from articles on rectal surgery and genitourinary dysfunction, to include planes of rectal dissection, frequency of genitourinary dysfunction and the clinical functional consequences of nerve injury. Data were extracted by two investigators and validated by a third investigator.

Illustrations
The key anatomical zones at risk of pelvic nerve injury during rectal surgery were illustrated by computer-assisted anatomical dissection (CAAD) models. The CAAD reconstruction was obtained from digitized, immunostained histological sections of human male foetuses using Winsurf software [25,26].

Results

Study selection
A total of 189 studies were identified that fell within the scope of this review out of 224 and 41 found on computerized and manual analysis. Of these, 77 were eligible. These consisted of 9 that gave background information and 36 on anatomy. Twenty-one papers gave useful data on rectal surgical anatomy, and 11 studies were included for their clinical analysis of genitourinary complications after rectal surgery (Fig. 1).

Anatomy of the pelvic nerves (Figs. 2 and 3A)

Nerve pathways of the suprarelevator compartment

Superior hypogastric plexus (SHP) and hypogastric nerves (HN) The SHP is a network of pre- and postganglionic fibres anterior to the body of L5 arising from T10-L3 and is a continuation of the preaortic sympathetic trunks [27]. It forms the origin of two HN that run over the sacral promontory situated 1 cm on either side of the midline and 2 cm medial to the ureter and iliac artery [28]. They vary in gross anatomy, sometimes consisting of fine filaments that spread out over a width of about 1 cm and
sometimes being 5–8 mm wide [29,30]. They join the IHP on each side.

The HN were thought to be sympathetic nerves [31–33]. However, we have recently shown that the pelvic autonomic nervous system is more complex than previously thought, as adrenergic [labelled with anti-tyrosine-hydroxylase (TH) antibody] and cholinergic fibres [labelled with anti-vesicular acetylcholine transporter (VACHT) antibody] were found to coexist within ‘sympathetic’ and ‘parasympathetic’ nerves. In these studies, all fibres within the HN were positive for anti-tyrosine-hydroxylase, and some fibres were positive for anti-VACHT also [25]. SHP and HN damage causes ejaculatory dysfunction (retrograde ejaculation, loss of ejaculation) [34] and urinary urgency and incontinence [16,17,35].

Pelvic splanchnic nerves (PSN) or erectile nerves (Eckard)
The PSNs have been considered to be parasympathetic nerves and generally arise from the ventral roots of S3 to S4 in men [21] and S2 to S4 in women [36]. In some exceptional cases, branches may originate from S5 [37], but never from S1 [38]. These nerves enter the pelvis through the sacral foramina, posterior to the parietal fascia that covers the piriformis muscle and crosses the retrorectal space, to enter the visceral compartment through the visceral fascia about 4 cm from the midline [28,39].

Small branches of the PSNs that run medially to enter the mesorectum have been identified. These contain the specific parasympathetic fibres of the rectum [40] and make up the medial segment of the IHP. They lie in the lateral ligament that joins the parietal fascia overlying the pelvic sidewall to the fascia propria medially [21]. Sato and Sato [41] showed that the superoanterior part of the ‘lateral ligaments’ contained the middle rectal artery and the inferoposterior part contained the PSNs. However, other authors do not consider the ‘lateral ligaments’ to exist and report that the middle rectal artery is a small, inconstant and frequently unilateral vessel [42].

We have recently demonstrated that the PSNs contain both ‘adrenergic’ and ‘cholinergic’ fibres [25]. These are responsible for detrusor contractility and vaginal lubrication and genital swelling during sexual arousal [43].

Figure 1 Search strategy and study selection (to May 2010).
Damage to these nerves causes erectile dysfunction and decreased blood flow to the vagina and vulva, which can reduce vaginal lubrication [28].

The inferior hypogastric plexus (IHP) The IHP is a network of sympathetic and parasympathetic fibres arising from HNs and PSNs nerves. It lies outside the fascia propria in the superficial layer of the parietal fascia. The pararectal fascia and perirectal adipose tissue separate the lateral surfaces of the rectum from the IHP [44]. The IHP is a plaque of nerves measuring $3 \times 4$ cm and is located retroperitoneally and laterally on both sides of the rectum close to the prostate and seminal vesicle in men. In females, it radiates from an area anterolateral to the rectum, passes lateral to the cervix and the vaginal fornix and extends to the lateral vaginal wall and base of the bladder. The bulk of the plexus is localized at the level of the vaginal fornix. At this site, fibres and ganglia of the IHP are both sympathetic and parasympathetic. Adrenergic positivity is stronger in the anterior part of the plexus, whereas cholinergic positivity is stronger in its posterior third [25].

The efferent fibres of the IHP innervate the bladder, ureters, seminal vesicles, prostate, membranous urethra, corpora cavernosa, and uterus and vagina. One of these, the cavernous nerve, is mainly responsible for erectile function [23]. In men, this arises from two neurovascular bundles just anterior to the lateral borders of rectoprostatic Denonvilliers’ fascia between the rectum and the prostate and seminal vesicles. The nerve penetrates the urogenital diaphragm parallel to the urethra [45]. The female anatomy of the cavernous nerves is poorly understood [46]. The neurovascular bundles are believed to be similar in women. The cavernous nerves originate along the lateral surface of the vagina and travel within the vesicovaginal septum to pass through the urogenital diaphragm [37].

Because the IHP consists of both sympathetic and parasympathetic efferent fibres, any damage to this plexus may cause severe disturbances in urogenital and sexual function including erection and ejaculation. Injury to the cavernous nerve results in erectile dysfunction [47].

Figure 2 Anterolateral view of foetal pelvic tridimensional reconstruction using computer anatomic assisted dissection (CAAD) with immunolabelled pelvic nerves. Blue arrows show key zones at risk during total mesorectal excision (TME): (1) inferior mesenteric artery (IMA) ligation; (2) superior hypogastric plexus (SHP); (3) hypogastric nerves (HN); (4) inferior hypogastric plexus (IHP); and (5) its afferent terminal branches for genito-urinary organs. Other abbreviations: common iliac artery and vein (CIA, CIV), corpus cavernosum (CC), dorsal nerve of the penis (DNP), external and internal iliac arteries (EIA, IIA), pelvic splanchnic nerve (PSN), prostate (P), pudendal nerve (PN) and ureter (U).

Figure 3 (a) Intra-abdominal view of foetal pelvic tridimensional reconstruction using CAAD with immunolabelled pelvic nerves. Same reconstructed view (b) and intra-operative view (c) after rectal resection during total mesorectal excision (TME). Nerves fibres destined to the rectum and accompanying the inferior mesenteric artery (IMA) and superior rectal artery (SRA) are resected during IMA ligation, but the superior hypogastric plexus (SHP) and hypogastric nerves (HN) must be preserved. Other abbreviations: common iliac artery and vein (CIA, CIV), inferior hypogastric plexus (IHP), pelvic diaphragm (PD) and ureter (U).
Levator ani nerve (LAN) The levator ani nerve, otherwise known as the perineal branch of S4, provides motor innervation to the levator ani muscles (iliococygeal, pubococygeal and puborectal), thereby contributing to urinary continence (hammock function) [48]. It originates from S3, S4 and/or S5 and crosses the superior surface of the pelvic floor underneath the lateral parietal fascia, running about 4 cm lateral to the midsagittal plane. At the level of the ischial spine, it runs 3.2 cm medial to the ischial spine according to Barber et al. [49]. According to Wallner et al. [50], it runs 4 cm lateral to the tip of the coccyx and 9 mm caudal to the ischial spine.

A weaker pelvic floor resulting in the loss of support of the urethra and bladder neck may contribute to loss of sphincter tone and urinary incontinence [22,49-51].

Nerve pathways of the infralevator compartment

Pudendal nerve The pudendal nerve is a mixed nerve, containing both somatic (sensory and motor) and autonomic sympathetic fibres. It originates from the sacral plexus, frequently from roots S2 to S4 [52-54], sometimes L5 [37] and rarely from S1 to S5 [55]. These come through the anterior sacral foramina and unite to form the nerve trunk. This runs deep in the pudendal canal, deep in the pelvic floor musculature and passes through the ischio-anal fossa where it gives off three terminal branches: (i) the perineal nerve that supplies sensory innervation to the perineal skin and motor innervation to the ischiocavernous, bulbocavernous and superficial transverse perineal muscles and to the striated urethral rhabdosphincter; (ii) the inferior rectal nerve that provides motor innervation to the external anal sphincter and sensory innervation to the perianal skin; and (iii) the dorsal penis nerve or clitoris nerve that is also a mixed nerve that supplies the corpus cavernosus [32,47,56].

Damage to the pudendal nerve may cause urinary incontinence and sensory sexual impotence because of its role in orgasm [57]. Faecal incontinence after rectal cancer surgery has been linked to pudendal nerve injury, even when the anal sphincter is not damaged [55,58].

Key zones at risk of pelvic nerve injury during rectal surgery (Fig. 2)

Pelvic nerve damage may occur during ligation of the IMA, at certain points of TME and through the perineal dissection of APR.

Ligation of the inferior mesenteric artery

High ligation of the IMA at its origin from the aorta is intended to achieve complete removal of regional lymph nodes [59]. There is a general agreement on how damage to the nerves should be avoided during this manoeuvre. The IMA is palpated between two fingers. The nerve plexus is identified as tight cords of nerve fibres that are palpable posterior to the IMA [21]. Division is then performed leaving a short arterial stump (1-2 cm) preserving the pre-aortic connective tissue containing the pre-aortic plexus, SHP and inferior mesenteric plexus [60].

The presacral space at the transition of the mesosigmoid to the mesorectum is then carefully dissected to displace progressively the HN dorsally. Damage to nerves during ligation of the IMA may cause failure of ejaculation [27].

Total mesorectal excision (TME) (Fig. 3)

The main goal of TME is to remove the rectum entirely within the envelope of the fascia propria [2,9,61,62], without breaking into the mesorectum. The cancer and regional lymphovascular drainage are removed in their entirety minimizing the risk of local recurrence [63,64]. In this technique, urogenital dysfunction should be avoided by pelvic autonomic nerve preservation (PANP) [65].

Posterior rectal dissection Sharp dissection is carried out in the avascular plane between the visceral (rectum and mesorectum) and the nervous structures (autonomic nerve plexuses) [65]. There is still some controversy, however, concerning the anatomical basis for this, especially concerning the course of the autonomic nerves. The avascular plane of loose areolar tissue corresponding to the retrorectal space lies between the parietal fascia posteriorly (presacral parietal fascia and prehypogastric nerve fascia) and the fascia propria anteriorly (visceral nerve plexus) [63,67]. Dividing the loose connective tissue opens the retrorectal space and allows mobilization of the rectum [21,29].

The correct plane of dissection should expose and preserve the SHP at the level of the sacral promontory. The HNs lie posterior to the peritoneum and directly anterior to the visceral fascia. To spare them, a change in the level of dissection, just medial to the nerve, has to be made from posterior to anterior to the fascia propria. The superior rectal artery lies immediately anterior to the fascia propria at the sacral promontory and can act as a landmark to find the plane [21,29].

The HNs can be damaged if the correct plane is not followed or if direct vision is compromised owing to bleeding [36] (Fig. 3C).

Lateral rectal dissection TME involves dissection of the lateral ligaments that run close the IHP [47,68]. There is
a considerable confusion concerning their nature. Jones et al. [42] consider them to be an artefact produced by surgical dissection. For some authors, the lateral ligaments join the parietal fascia to the fascia propria and contain the middle rectal or an accessory middle rectal artery [30,62]. Part of the IHP lies inside the lateral ligament and gives off branches to the rectum on each side about 2 cm below the peritoneal reflection.

Clausen et al. [47] consider the lateral ligament to be the only remaining connection between the lateral side of the pelvis and the mesorectum. Injury to the autonomic nerves is most likely when the ligament is dissected too close to the parietal pelvic fascia containing the IHP. Extensive manual traction during the operation may displace the IHP from the lateral pelvic wall rendering it more vulnerable [69]. There is no oncological need to dissect the ‘lateral ligament’ lateral to its insertion into the parietal pelvic fascia. This is because all lymphatics are located within the mesorectum with the primary regional lymphatic drainage arranged along the branches of the superior rectal artery [41].

During TME, the IHP is rarely seen except in very thin patients and at this level, sharp dissection without the need for clamping or ligation of any important anatomical structure is possible.

**Anterior rectal dissection (Fig. 4)** Denonvilliers’ fascia is very important in rectal dissection. Heald [70] considers that it should be resected in TME surgery because it forms the anterior surface of the mesorectum. However, Lindsey et al. [69] suggest that the rectoprostatic fascia should be resected only for specific oncological indications, for example, in the presence of an anterior rectal tumour where the anterior circumferential margin might be threatened. The rectoprostatic fascia is formed during embryonic life by fusion of the two peritoneal leaves of the rectovesical pouch [71]. Richardson [72] identified a dense double layer of elastin posterior to the prostate and seminal vesicles and anterior to the thin anterior mesorectum and the fascia propria [69]. This layer is more closely opposed to the prostate than to the rectum. In women, the posterior layer of the rectovaginal septum is the fascia propria of the rectum, and the anterior layer is the true equivalent of the rectoprostatic fascia in men [73]. The pos tero-lateral neurovascular bundle [26] is at risk during deep dissection of the anterior extramesorectal rectum away from the prostate and seminal vesicles.

There is no consensus concerning the anatomical plane of anterior dissection. Lindsey et al. [69] described three planes including (i) the close rectal plane that lies immediately on the rectal musculature inside the fascia propria, (ii) the mesorectal plane situated immediately outside the fascia propria; and (iii) the extramesorectal plane that allows resection of the rectoprostatic fascia but involves a high risk of damage to the autonomic nerves at this site.

In practice, therefore, the mesorectal plane within the fascia propria protects the pelvic nerves and is appropriate for posterior or posterolateral rectal tumours. The extramesorectal plane should be used when the anterior circumferential margin is threatened by the tumour. Distinguishing the different planes is not so easy during surgery, however, especially if there is bleeding, a fixed or very low tumour or a narrow pelvis. Care is also needed when performing the dissection with scissors and bipolar coagulation. The use of robot-assisted dissection may improve dissection in this area as it has carried out for radical prostatectomy [69,74].

**Abdominoperineal resection (APR) (Fig. 5)**

Major complications can occur after APR, which involves resection of the levator ani [75]. The extensiveness of pelvic dissection is directly related to the severity of subsequent bladder and genital dysfunction. These are more frequent and severe for APR than for sphincter-preserving procedures, including intersphincteric resection [19,20]. Enker et al. [12] reported preservation of sexual function in 57% of patients undergoing APR and in 85% of patients undergoing sphincter preservation. Permanent impotence has been reported by Santangelo.
The dorsal nerve of the penis (DNP) and inferior rectal nerve (IRN). Other terminal branches of PN are shown, including the dorsal nerve of the penis (DNP) and inferior rectal nerve (IRN).

et al. [76] in 44% and 25% of patients undergoing APR and low anterior resection.

There are several possible explanations for this difference. Inadvertent damage to the pelvic nerves during the perineal phase of dissection may occur, particularly at the level of the prostate [20]. At about 2 cm above the point where the rectum passes through the levator ani, the fascia propria of the rectum and the parietal pelvic fascia become inseparable and the levator ani nerve is close to the surgical dissection plane [22,50]. The dorsal nerve of the penis/chlitoris is the terminal branch of the PN and may play an important role in erection and ejaculation through mediating bulbocavernous muscle contraction [28,56]. These nerves should not be directly damaged during APR since they are not close to the zone of dissection. However, they may be damaged as a result of excessive traction or prolonged electrocoagulation in the anterolateral plane of dissection.

The primary aim of rectal cancer surgery is survival of the patient and to reduce the risk of local recurrence. The second aim is to maintain function by minimizing injury to the pelvic nerves. In most cases, bladder and sexual dysfunction can be avoided by identifying and preserving the nerves subserving them. Ligation of the IMA and dissection of the retrorectal space are usually uncomplicated manoeuvres and damage to the SHP and the HN readily can be avoided. However, difficulties can arise during anterior and lateral dissection where the anatomical planes may not be clear. Here, the IHP can be damaged especially its efferent pathways. If the pelvis is narrow or the tumour is anterolateral and fixed, careful dissection using bipolar scissors may be preferable [77]. In the future, robot-assisted dissection might help to reduce the rate of nerve damage.

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