RESEARCH ARTICLE

New Insights into Autonomic Nerve Preservation in High Ligation of the Inferior Mesenteric Artery in Laparoscopic Surgery for Colorectal Cancer

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Abstract

Aim: To take a deeper insight into the relationship between the root of the inferior mesenteric artery (IMA) and the autonomic nerve plexuses around it by cadaveric anatomy and explore anatomical evidence of autonomic nerve preservation in high ligation of the IMA in laparoscopic surgery for colorectal cancer. Methods: Anatomical dissection was performed on 11 formalin-fixed cadavers and 12 fresh cadavers. Anatomical evidence-based autonomic nerve preservation in high ligation of the IMA was performed in 22 laparoscopic curative resections of colorectal cancer. Results: As the upward continuation of the presacral nerves, the bilateral trunks of SHP had close but different relationships with the root of the IMA. The right trunk of SHP ran relatively far away from the root of IMA. When the apical lymph nodes were dissected close to the root of the IMA along the fascia space in front of the anterior renal fascia, the right trunk of SHP could be kept in suit under the anterior renal fascia. The left descending branches to SHP constituted a natural and constant anatomical landmark of the relationship between the root of IMA and the left autonomic nerves. Proximal to this, the left autonomic nerves surrounded the root of the IMA. Distally, the left trunk of the SHP departed from the root of IMA under the anterior renal fascia. When high ligation of the IMA was performed distal to it, the left trunk of SHP could be preserved. The distance between the left descending branches to SHP and the origin of IMA varied widely from 1.3 cm to 2.3 cm. Conclusions: The divergences of the bilateral autonomic nerve preservation around the root of the IMA may contribute to provide anatomical evidence for more precise evaluation of the optimal position of high ligation of the IMA in the future.

Keywords: Autonomic nerves preservation - inferior mesenteric artery - high ligation - colorectal cancer - anatomy

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Introduction

Based on the oncological, technical and anatomical considerations, the position of ligation of the IMA has been debated on performing "high ligation" and "low ligation" in surgeries for the tumor of left colon and rectum (Lange et al., 2008; Titu et al., 2008; Cirocchi et al., 2012). Though there is still no consistent evidences of the survival benefits (Hida and Okuno, 2013), it is proved that high ligation of the IMA may improve lymph node removal rates (Adachi et al., 1998), accuracy of tumor staging (Titu et al., 2008). Though high ligation of the IMA causes a reduction of blood supply to distal colon (Seike et al., 2007; Tsujinaka et al., 2012), it simultaneously contributes to low anastomosis with no tension in low anterior resection of rectal cancer (Buunen et al., 2009; Hida and Okuno, 2013). In fact, the rate of ischemic necrosis of anastomosis is very low in clinical observations (Tsujinaka et al., 2012; Park et al., 2012) and no statistically significant difference between the high and low ligation of the IMA is found in the rate of anastomotic leakage (Rutegard et al., 2012; Polistena et al., 2013). In recent decades, laparoscopic surgery becomes more and more popular in surgeries for gastrointestinal cancer (Biondi et al., 2013; Liao et al., 2013). High ligation of the IMA is proved much easier than low ligation with no prolonged operative time or bleeding during the medial-to-lateral dissection (Sekimoto et al., 2011; Kim el al., 2013). Therefore, nowadays high ligation of the IMA is still preferred for most surgeons in surgeries for colorectal cancer.

However, it is widely accepted that high ligation of the IMA takes a risk of damage to the autonomic nerve plexuses around it (Moszkowicz et al., 2011; Acar and Kuzu, 2012) which may cause postoperative urogenital dysfunction (Liang et al., 2007). One common view on preservation of the autonomic nerve plexuses in high ligation of the IMA is preserving the pre-aortic connective tissue intact and dissecting the root of the IMA a certain distance away from its origin. However the distance varies widely from 0.5cm to 2cm in literatures (Morino et al.,

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2003; Nano et al., 2004; Liang et ai., 2008) and there is no anatomical evidences and functional evaluation to demonstrate the effectiveness of these different choices. Though in 1999, the American Society of Colon and Rectal Surgeons (ASCRS) defined low ligation of the IMA as the ligation below the origin of the left colic artery and high ligation as the ligation of the IMA at its aortic origin (Lowry et al., 2001). Ligation of the IMA at any position proximal to the origin of the left colic artery is often vaguely described as high ligation in the literatures (Lange et al., 2008; Rutegard et al., 2012). Conversely, limited anatomical researches on the relationships between the root of the IMA and the autonomic nerves around it present different opinions. Some researches proposed that the origin of the IMA was the only safe position of high ligation of the IMA with no risk of damage to the autonomic nerves (Nano et al., 2004; Zhang et al., 2006). But Höer believed that high ligation of the IMA led to damage of the sympathetic nerves because the IMA was surrounded by the dense and netlike inferior mesenteric plexus to a distance of 5 cm from its origin on the aorta (Hoer et al; 2000). To date, further anatomical researches focusing on the controversies are lacking.

Therefore, in the present study we aimed to take a deeper insight into the relationship between the root of the IMA and the autonomic nerve plexuses around it by anatomical observation on formalin-fixed and fresh cadavers and explore the anatomical evidences about whether the autonomic nerves can be preserved in high ligation of the IMA in laparoscopic surgeries for colorectal cancer.

Materials and Methods

More or less, the anatomical information from cadavers may be different with that in surgeries. In order to get the anatomical information approaching the real condition in surgeries, the morphology of the autonomic nerve plexuses and their relationships with the fascia around the root of the IMA were observed on both formalin-fixed and fresh cadavers in the present study. In this study, 11 formalin-fixed cadavers (6 male and 5 female) and 12 fresh cadavers (6 male and 6 female) who had passed away due to extra-abdominal conditions and were donated to Southern Medical University were dissected by macroscopic anatomy with the assistance of a BH-2 double-eyepiece standard dissection microscope (Olympus, Tokyo, Japan). The mean age of death was 76.7 years (range: 22–89). The cadavers with deformities, previous operations, other pathological changes and obvious adhesion in the abdominopelvic and retroperitoneal spaces were excluded. The formalin-fixed cadavers had been fixed via arterial injection of and then immersed in 10% formalin solution for about one year. The fresh cadavers dead within 48 hours were preserved at -20°C and thawed before the dissection. The anatomical results were documented with photographs by a digital camera (Canon Eos40D).

From May 2012 to March 2013, based on the anatomical results, the autonomic nerves preservation in high ligation of the IMA was performed in the laparoscopic colorectomy for 22 patients with advanced colorectal cancer by the experienced colorectal surgeon (Dr. Xiaofei Yang) in Guizhou provincial people's hospital. The key points of the surgical techniques and the reliability of the anatomical evidences were evaluated. The operative procedures were recorded on video. All the patients in this study knew about the surgery and signed the informed consents. The present study was approved by the Ethics Committee of Southern medical university.

Statistical analyses were performed with SPSS software for Windows (Statistical Product and Service Solutions, version 13.0, SSPS Inc, Chicago, IL, USA). The Data were presented as mean ± SD and the descriptive characteristics of the subjects were compared by two-sample t test. Values for $P < 0.05$ were considered statistically significant.

Results

Anatomical observations

It was shown in the meticulous anatomical dissection that the abdominal aortic plexus (AAP), superior hypogastric plexus (SHP), inferior mesenteric plexus (IMP) and the bilateral L1-L3 lumbar splanchnic nerves (LSNs) converged around the root of the IMA and connected with each other. The AAP, also named as "intermesenteric plexus" situated at the level between the origins of superior mesenteric artery and IMA. The SHP located at the level between the origin of IMA and the position where the SHP branched into bilateral hypogastric nerves (HGN) around the sacral promontory. As the main component of the vascular sheath, the IMP surrounded the root of IMA and its branches. The bilateral L1-L3 LSNs deriving from the sympathetic trunks ran from the posterolateral side to the anterior surface of the abdominal aorta in an oblique course and combined with some descending branches of AAP to form the bilateral trunks of SHP around the origin of the IMA. The bilateral trunks of SHP ran obliquely and caudally along the anterior surface of the abdominal aorta and converged with the counterpart below the aortic bifurcation to form the bunchy-like presacral nerves in the interilliac triangle. Fine communicating neural fibers or ganglions connected the bilateral trunks of SHP. As the origination of the presacral nerve and HGNs, the bilateral trunks of SHP had close relationships with the root of the IMA.

The IMA originated from the anterior surface of the abdominal aorta at the level about 5cm away from the bifurcation of abdominal aorta and ran ventrally and laterally into the sigmoid mesocolon. The anatomical relationships between the lateral trunks of SHP and the root of IMA were different bilaterally. On the right side of the IMA, the thick right L1-L2 LSNs combined with some fine descending branches of AAP to form the right trunk of SHP which ran relatively far away from the root of IMA. The right L1-L2 LSNs contributed most to the right trunk of SHP. Some fine branches originating from the right trunk of SHP ran caudally and ventrally to join the IMP along the root of the IMA, which we temporarily named as "the right ascending branches to IMP" (Figure 1a, 1c). In fresh cadavers, when the left mesocolon was freed from the fascia space between the anterior renal

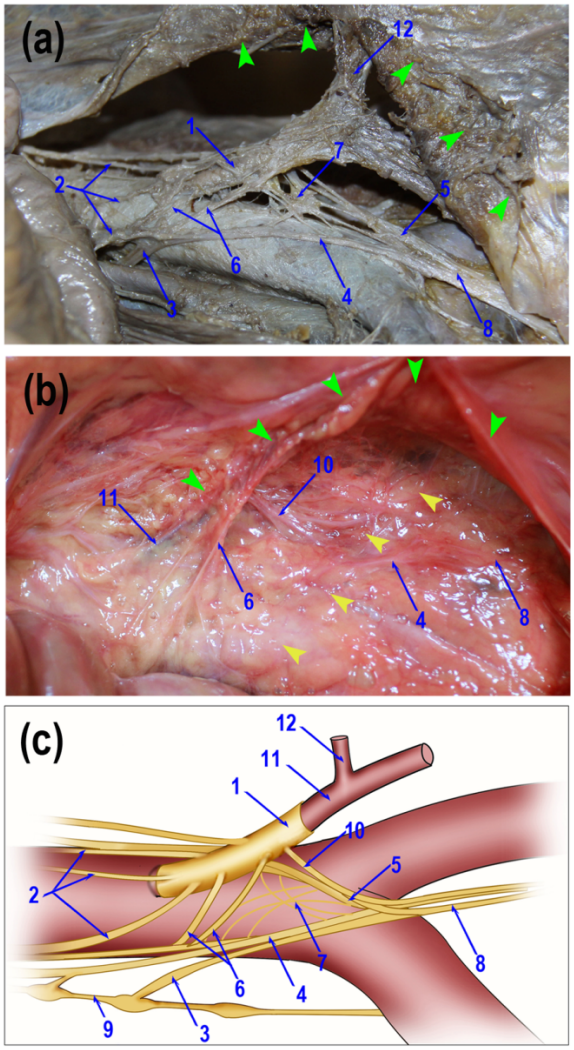

Figure 1. The Right View of the Relationship Between the Root of THE IMA and the Autonomic Nerve Plexuses Around It. (a) autonomic nerve plexuses around the root of the IMA in formalin-fixed cadaver. (b) the relationship between the nerve plexuses and fascia in fresh cadaver. (c) schematic representation. 1, inferior mesenteric plexus; 2, abdominal aortic plexus; 3, lumber splanchnic nerves; 4, the right trunk of SHP; 5, the left trunk of SHP; 6. the right ascending branches to IMP; 7, communicating branches of bilateral trunks of SHP; 8, presacral nerves; 9, sympathetic trunk; 10, the left descending branches to SHP; 11, inferior mesenteric artery; 12, left colic artery. Green arrowhead, mesocolon; yellow arrowhead, anterior renal fascia

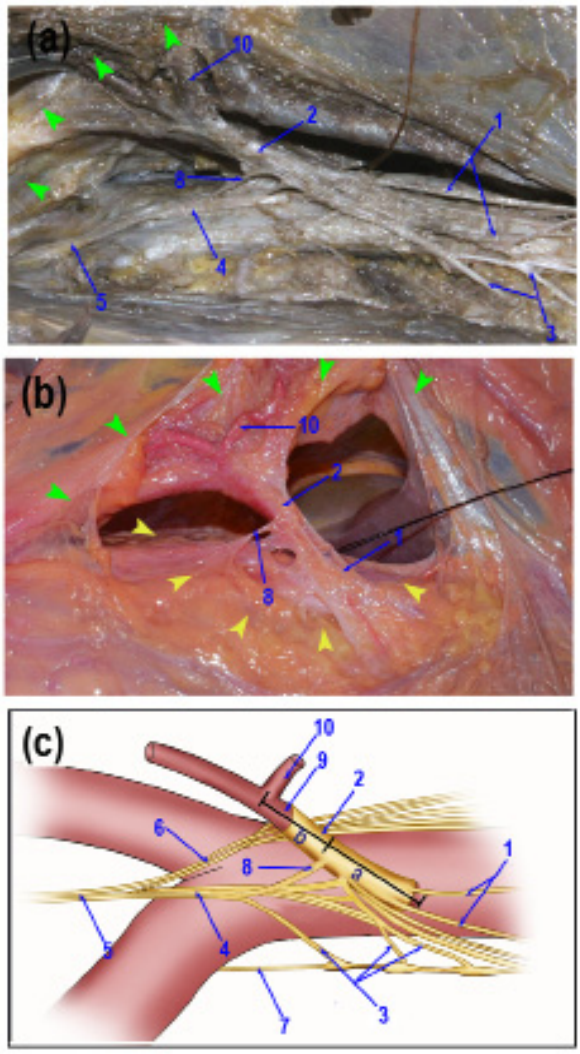

Figure 2. The Left View of the Relationship Between the Root of the IMA and the Autonomic Nerves Around It. (a) autonomic nerve plexuses around the root of the IMA in formalin-fixed cadaver. (b) the relationship between the nerve plexuses and fascia in fresh cadaver. (c) schematic representation. 1, abdominal aortic plexus; 2, inferior mesenteric plexus; 3, lumber splanchnic nerves; 4, the left trunk of SHP; 5, presacral nerve; 6, the right trunk of SHP; 7, sympathetic trunk; 8, the left descending branches to SHP; 9, inferior mesenteric artery; 10, left colic artery. a, the distance between the origin of THE IMA and the left descending branches to SHP; b, the distance between the origin of the left colic artery and the left descending branches to SHP. Green arrowhead, mesocolon; yellow arrowhead, anterior renal fascia

fascia and the left mesocolon and retracted ventrally, it was shown that the right ascending branches to IMP were tented simultaneously to run across the fascia space and the right trunk of SHP still attached to the anterior surface of the abdominal aorta under the anterior renal fascia (Figure 1b). Different from the right side, the left descending fibers of AAP were much thicker. The descending fibers of AAP and the left L1-L2 LSNs attached closely to the left side of the IMA and mingled with the IMP. Proximal to the origin of the left colonic artery, some neural branches departed from IMP on the left side of the IMA and ran caudally and dorsally to join the left trunk of SHP. The most distal descending neural branches were temporarily named as "the left descending branches to SHP" (Figure 2a, 2c). The left descending branches to SHP were a natural landmark of the anatomical relationship between the IMA and the autonomic nerve plexuses on the left side of it. Proximal to it, the left descending fibers of AAP, the left L1-L2 LSNs and the IMP mingled on the left side of IMA. But distal to it, the left trunk of SHP and the IMP were separated completely into different fascia spaces. In fresh cadavers, when the left mesocolon was freed from the fascia space between the anterior renal fascia and the left mesocolon and retracted ventrally, the left descending branches to SHP were tented across the fascia space and could be identified clearly running caudally and dorsally from the left side of the IMA to the left trunk of SHP under

Table 1. The Distances from the Left Descending Branches to SHP to the Origins of IMA and the Left Colic Artery in Both Sexes

Distance	Male (cm)	Female (cm)	Total
a	1.93±0.27	1.91±0.24	1.92±0.25
b	0.87±0.25	0.90±0.21	0.88±0.22

This distance was measured as Figure 2c. a, the distance between the origin of IMA and the left descending branches to SHP. b, the distance between the origin of the left colic artery and the left descending branches to SHP. Data are reported as means ± SD (cm)

Table 2. The Details of Patients and Tumors

Parameter	Value[a]
No. of cases	22
Age (years)	64.7±5.5
Sex (M/F)	12/10
Body mass index (weight/height^2, kg/m^2), mean (range)	
Male	26.1 (20.9~33.6)
Female	25.8 (21.7~34.2)
Laparoscopic curative resection	
Sigmoid colon cancer	7
Rectal cancer	15
TNM stage (pathologic)	
I	2
II	9
III	11

[a]Data are presented as mean ± SD

the anterior renal fascia (Figure 2b). The left descending branches to SHP were identified in all the cadavers. The distances from the position of the left descending branches to SHP leaving the IMP to the origin of IMA on the aorta and to the origin of the left colic artery were measured respectively (Figure 2c). The distance between the position of the left descending branches to SHP leaving the IMA and the origin of IMA is variable from 1.3cm to 2.3cm (median 1.92 cm, SD 0.25 cm). The distance between the position of the left descending branches to SHP leaving the IMP and the origin of the left colic artery was 0.5 cm to 1.3cm (median 0.88 cm, SD 0.22 cm). Statistical analysis showed that there was no significant difference ($P > 0.05$) between both sexes (Table 1).

Anatomical evidence-based surgical technique

The medial approach was adapted in the 22 laparoscopic curative resection of colorectal cancer. The surgical procedures of the preservation of the autonomic nerves in high ligation of the IMA were as follows: By gentle retracting the sigmoid mesocolon ventrally, the root of the sigmiod mesocolon was identified clearly. Then the retroperitoneum was incised about 1cm away from the right side of the root of the sigmoid mesocolon at the level between the origin of the IMA and the sacral promontory. Surgical dissection was performed carefully in the fascia space between the retroperitoneum and the anterior renal fascia. In front of the abdominal aorta and in the interilliac triangle above the sacral promontory, at least, part of the lateral trunks of SHP or the presacral nerves which appeared compact, bunchy-like and in silvery white color with nourishing capillaries overlaying its surface could

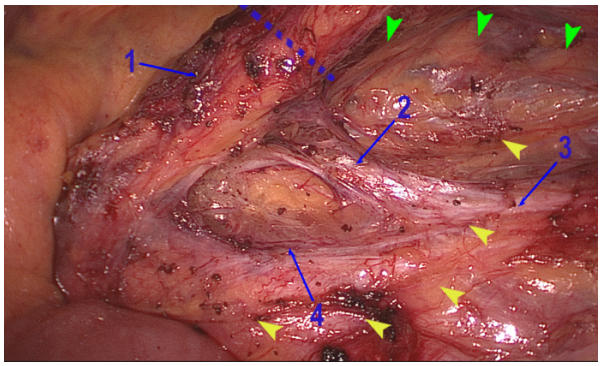

Figure 3. Photo-documentation of the Landmark and Position for the Preservation of the Autonomic Nerves during High Ligation of the IMA in Laparoscopic Surgery for Colorectal Cancer. 1, inferior mesenteric artery; 2, landmark of high ligation of THE IMA, i.e. the left descending branches to SHP; 3, the left trunk of SHP; 4, communicating branches of bilateral trunks of SHP. Green arrowhead, mesocolon; yellow arrowhead, anterior renal fascia. Blue dotted line, the position of high ligation of the IMA

always be identified through the fine and semitransparent anterior renal fascia even in obese patients. Once the SHP was identified, the correct surgical plane was confirmed. Surgical dissections continued upward following the fascia space. On the right side of the IMA, dissection was performed close to the right side of the root of the IMA and the lymph nodes in the accumulated fat around the root of the IMA were removed to the origin of the IMA with the anterior renal fascia kept intact. Sometimes the tented right ascending branches to IMP could be identified through the fine overlaying fascia. Subsequently, meticulous dissection continued laterally to the left side of the IMA in this fascia space. The left descending branches to SHP which appeared uniquely in silvery white color with nourishing capillaries overlaying its surface could be identified tenting across the fascia space and ran from the left side of IMA to the left trunk of SHP under the anterior renal fascia. Finally, take it as the anatomical landmark, and the root of the IMA was ligated distal to the position where the left descending branches to SHP departed from the left side of the IMA (Figure 3).

The surgical outcomes

Guided by the detailed anatomical information from the cadaver dissections, the autonomic nerves preservation in high ligation of the IMA was successfully performed on all 22 patients in laparoscopic curative resection of colorectal cancer. The important anatomical landmarks, i.e. the left descending branches to SHP and the SHP in front of the abdominal aorta and in the interilliac triangle could be identified in all the cases under the well-illuminated and magnified view of laparoscopy. The mean operation time which was calculated from opening the retroperitoneum on the right side of the root of the sigmoid mesocolon to high ligation of the IMA was 22.8±3.3 min (range, 17-32 min). The mean blood loss during the high ligation of the IMA was 16.0±6.8 (range, 10-30 ml), and no intraoperative complications was found. The details of the patients and tumors were shown in Table 2.

Discussion

With the improvement of oncologic results (Heald et al., 1998; Okamoto et al., 2006; Park et al., 2013), the autonomic nerves preservation becomes more and more important for better postoperative quality of life in surgeries for colorectal cancer (Fukunaga et al., 2007; Nagpal and Bennett, 2013). Though the root of inferior mesenteric artery (IMA) is widely accepted as one of the crucial areas at risk of damage to the autonomic nerves (Moszkowicz et al., 2011; Acar et al., 2012), reliable surgical techniques of the autonomic nerves preservation in high ligation of the IMA has been vague for lacking of definite anatomical evidences. It is demonstrated in the present study that the relationships between the root of the IMA and its bilateral autonomic nerve plexuses are different and guided by the anatomical evidence, the bilateral autonomic nerves can be preserved clearly in high ligation of the IMA in laparoscopic surgeries for colorectal cancer.

The AAP, SHP, IMP and bilateral L1-L3 LSNs connect with each other like a network around the root of the IMA, but it is clear that the presacral nerve is the downward continuation of the bilateral trunks of SHP and branches into bilateral HGNs below the sacral promontory (Paraskevas et al., 2008; van Schaik et al., 2001). Intraoperative damage of the SHP and HGNs may lead to the postoperative ejaculative and voiding disorders (Maurer, 2005; Liang et al., 2008). Therefore, it is critically important to preserve the bilateral trunks of SHP in high ligation of the IMA. In previous literatures, the descriptions of the relationships between the bilateral trunks of SHP and the root of the IMA are limited and vague. The bilateral trunks of SHP are named arbitrarily as the inferior mesenteric plexuses (Liang et al., 2008), paraorta trunks (Nano et al., 2004), preaorta plexus (Hida et al., 1999), lateral trunks of SHP (Paraskevas et al., 2008) or sympathetic trunks at the IMA level (Cheung et al., 2009). In Grey's anatomy, there is no definite nomination and descriptions about the bilateral trunks of SHP. According to their formation and course and in order to avoid misunderstanding with other autonomic nerve plexuses, we are in agreement with Paraskevas (Paraskevas et al., 2008) to name them as the lateral trunks of SHP. Definite nominations and locations of the autonomic nerve plexuses around the root of the IMA may contribute to a consistent anatomical description of their relationships with the root of the IMA.

It is shown in the previous anatomical observations on formalin-fixed cadavers that the autonomic nerve plexuses around the root of the IMA including the bilateral trunks of SHP are all tented around the root of the IMA when the left mesocolon is retracted ventrally (Hoer et al., 2000; Zhang et al., 2006; Acar and Kuzu, 2012). So Höer believed that high ligation of IMA would damage the sympathetic autonomic nerves (Hoer et al., 2000) and Acar proposed that high ligation should be done 1-2cm distal from the origin of the IMA (Acar and Kuzu, 2012). In the present study, in addition to the morphology of the autonomic nerves around the root of the IMA, their relationships with the surgical plane were observed. It is shown that around the root of the IMA, the SHP, AAP and LSNs locate under the anterior renal fascia (van Schaiket al., 2001; Liang et al., 2008; Matsubara et al., 2009) and the IMP lies in the root of the left mesocolon. When surgical dissection is performed in the fascia space between the left mesocolon and the anterior renal fascia and the left mesocolon is retracted ventrally, only those neural branches running across the fascia space are tented around the root of the IMA and the SHP and AAP are still kept in suit under the anterior renal fascia. The anatomical relationships between the autonomic nerve plexuses and the fascia around the root of the IMA are the important anatomical basis of the preservation of the bilateral trunks of SHP in high ligation of the IMA. We think that the important relationships between these autonomic nerve plexuses and the surgical plane were neglected in the previous literatures because of the removal of the fascia overlaying these autonomic nerve plexuses.

Moreover, the divergences of the bilateral relationships between the lateral trunks of SHP and the root of the IMA bring about the different preservation of the bilateral autonomic nerves in high ligation of the IMA. In consistent with Nano (Nano et al., 2004), the right trunk of SHP runs relatively far away from the origin and the course of the IMA. When the dissection of the apical lymph nodes on the right side is performed close to the root of the IMA along the fascia space in front of the anterior renal fascia, the tented right ascending branches to IMP are dissected with no disturbance to the right trunk of SHP which is kept in suit under the anterior renal fascia. Different from the right side of the IMA, the left descending branches to SHP is a natural anatomical landmark of the relationship between the IMA and the autonomic nerve plexuses. The autonomic nerves on the left side of the IMA will be damaged inevitably if the left side of the IMA is isoated or ligated proximal to the left descending branches to SHP. When the dissection is performed along the fascia space in front of the anterior renal fascia and the left mesocolon is lifted ventrally, the left descending branches to SHP are tented cross the fascia space from the IMP on the left side of the IMA to the left trunk of SHP under the anterior renal fascia and can be identified easily. In all the 23 cadaveric dissections and 22 laparoscopic surgeries for colorectal cancer, the left descending branches to SHP are identified constantly. Therefore, we propose the left descending branches to SHP are an effective anatomical landmark of the autonomic nerves preservation on the left side of the IMA. High ligation of the IMA distal to it with the anterior renal fascia intact may preserve the autonomic nerves on the left side of the IMA completely. The bilateral trunks of SHP and presacral nerve appear compact and buncky-like and the overlaying anterior renal fascia is fine (Paraskevas et al., 2008). It is not difficult to identify the SHP on the anterior surface of the lower part of the abdominal aorta and in the interilliac triangle above the sacral promontory by the medial approach in laparoscopic surgery in colorectal cancer (Liang et al., 2007; Liang et al., 2008). In the present study, the complete preservation of the bilateral trunks of SHP was feasible with no increased operative time, intraoperative bleeding.

Therefore, based on the anatomical evidences in the

present study, we can make the following conclusions: (1) if high ligation of the IMA is performed at its origin on the aortic artery, the right trunk of SHP can be preserved safely, but the autonomic nerves on the left side of the IMA will be inevitably damaged. (2) according to the results of our measurement, the distance between origins of the IMA and the left descending branches to SHP varies widely. So if high ligation of the IMA is performed at the position a certain distance from its origin, it may be unreliable to protect the autonomic nerves on the left side of the IMA. Moreover, a residual root of the IMA may decrease the extent of en bloc dissection of the apical lymph nodes metastasis to the origin of the IMA.

The debate on the optimal position of high ligation of the IMA in surgeries for colorectal cancer may attribute to hoping to keep a balance between radical dissecting apical lymph nodes metastasis and preserving the autonomic nerves to avoid the postoperative urogenital dysfunction. However, because the positions of high ligation of the IMA are inconsistent, the extent of apical lymph nodes dissection is consequently different which may disturb the accurate evaluation of the clinical value of the apical nodes dissection. Moreover the reliability of autonomic nerve preservation is unclear for lacking of the definite anatomical evidences in the previous literatures. So it is very hard to evaluate the optimal position of high ligation of the IMA. In the present study, this is the first time to give the detailed anatomical evidences of the different bilateral preservation of the autonomic nerves in high ligation of the IMA in surgeries for colorectal cancer. Based on the divergences of the relationships between the root of the IMA and the bilateral autonomic nerves, more precise evaluation are expected to clarify the optimal position of high ligation of the IMA in laparoscopic surgery for colorectal cancer in the near future. Can the urogenital function be preserved if only the right trunk of SHP is preserved with high ligation at the origin of the IMA? Will the radicality of the colorectal cancer be disturbed if bilateral autonomic nerve preservation is preserved completely with high ligation of the IMA distal to the left descending branches to SHP?

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