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Contents

Bimonthly Volume 11 Number 4 July 20, 2021

ACADEMIC ACTIVITY REPORT

OPINION REVIEW

REVIEW

MINIREVIEWS

LETTER TO THE EDITOR

World Journal of Methodology

Bimonthly Volume 11 Number 4 July 20, 2021

Contents

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REVIEW

Fascinating history of groin hernias: Comprehensive recognition of anatomy, classic considerations for herniorrhaphy, and current controversies in hernioplasty

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Abstract

Groin hernias include indirect inguinal, direct inguinal, femoral, obturator, and supravesical hernias. Here, we summarize historical turning points, anatomical recognition and surgical repairs. Groin hernias have a fascinating history in the fields of anatomy and surgery. The concept of tension-free repair is generally accepted among clinicians. Surgical repair with mesh is categorized as hernioplasty, while classic repair without mesh is considered herniorrhaphy. Although various surgical approaches have been developed, the surgical technique should be carefully chosen for each patient. Regarding as interesting history, crucial anatomy and important surgeries in the field of groin hernia, we here summarized them in detail, respectively. Points of debate are also reviewed; important points are shown using illustrations and schemas. We hope this systematic review is surgical guide for general surgeons including residents. Both a skillful technique and anatomical knowledge are indispensable for successful hernia surgery in the groin.

Key Words: Inguinal hernia; Groin; History; Anatomy; Hernioplasty; Herniorrhaphy

Core Tip: Groin hernias include indirect inguinal, direct inguinal, femoral, obturator, and supravesical hernias. Groin hernias have a fascinating history in the fields of anatomy and surgery, and the concept of tension-free repair is generally accepted

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among clinicians. Although various surgical approaches have been developed, the surgical technique should be carefully chosen for each patient. Surgical repair with mesh is categorized as hernioplasty, while classic repair without mesh is considered herniorrhaphy. Points of debate are also reviewed; important points are shown using illustrations and schemas. Overall, both a skillful technique and anatomical knowledge are indispensable for successful hernia surgery in the groin.

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INTRODUCTION

The etymology of the term "hernia" originates from the Latin word for "prolapse," and the earliest evidence of an inguinal hernia was recorded in approximately 1552 BC in ancient Egypt[1,2]. In the early 1950s, the term "groin hernia" was first used by Henri Fruchaud (1894–1960)[3]. Hernias in the groin include indirect inguinal, direct inguinal, femoral, obturator, and supravesical hernias[4]. Herniorrhaphy has been performed to treat inguinal and femoral hernias since the 18th century. Edoardo Bassini (1844–1924) established a modern herniorrhaphy technique[5]; thereafter, groin herniorrhaphy became the most common technique performed in the field of general surgery[4]. Recent studies have shown that approximately 750000 patients undergo this procedure yearly in the United States[4,6]; the direct annual cost is 2.5 billion dollars[4].

In 1804, Astley Cooper (1768–1841) stated, "No disease of the human body, belonging to the province of the surgeon, requires in its treatment a greater combination of accurate anatomical knowledge with surgical skill than hernia in all its varieties."[7] Notably, herniorrhaphy treatment of pediatric patients is useful for accurate evaluation of the skills of general surgeons and residents[8]. Sir William Heneage Ogilvie (1887–1971) once stated, "I know more than a hundred surgeons whom I would cheerfully allow to remove my gallbladder but only one to whom I should like to expose my inguinal canal."[9] Notably, both technical skill and anatomical recognition are crucial for safe and reliable surgery. Irving L. Lichtenstein (1920–2000) established the concept of tension-free repair (TFR) in 1986[10,11]. Various meshes, including biological mesh, are currently available for groin surgery[12]. Surgical repair with mesh is categorized as hernioplasty, while classic repairs without mesh are termed herniorrhaphy. Many physicians focus on the preperitoneal (posterior) space (PPS)[3,7,13-21], topographic nerves[22-31], and regional vessels[4,32-34].

This review discusses existing knowledge regarding groin hernia. It summarizes historical turning points in the anatomy and surgery of groin hernias, described the current status of anatomical recognition and surgical repair, examines points of contention, and considers future perspectives. Despite the current global pandemic due to Chinese Wuhan pneumonia (so-called COVID 2019), general surgeons including residents thrive. We hope that this review including milestones of history, anatomy, and surgery will be informative for surgeons involved in the treatment of groin hernias.

ETIOLOGY

Inguinal hernias constitute 75% of abdominal wall hernias and have the lifetime risks of inguinal hernias are 27% in men and boys and 3% in women and girls[35]. Indirect (external or lateral) inguinal hernias (IIHs) outnumber direct (internal or inner) inguinal hernias (DIHs) by a ratio of approximately 2:1[35]. Suspected congenital causes for persistent patency of processus vaginalis include cryptorchidism, lack of carbachol response, absence of cholinergic receptors, absence of myofibroblasts, absence of apoptotic nuclei, failed apoptosis of smooth muscle, catecholaminergic

activity related to luteinizing and gonadotropin-releasing hormones, and deficiencies involving epithelial–mesenchymal transition[36-42]. Possible risk factors for groin hernias include elevated abdominal pressure (*e.g.*, by constipation, coughing, and obesity)[6], diabetes[6], smoking[6], collagen distribution[43,44], peritoneal dialysis [45], radical prostatectomy[46], and family history[47].

SYMPTOMS AND EVALUATION

Groin hernias are extremely common and can often be diagnosed by simple anamnesis collection and a physical examination[48]. Surgical repair is elective unless incarceration or strangulation is present[48]. Palpation of both testes in the scrotal sac should be performed during the clinical examination to rule out cryptorchid testis[49]. Local pain in the scrotal sac, which may indicate testicular torsion, should never be overlooked. From an immunological perspective, testicular torsion requires urgent surgery[50]. An undescended testicle harbors an increased risk of infertility and malignancy; thus, it requires orchiopexy in early childhood[48]. The development of autoimmune antisperm antibody induced by testicular torsion influences testicular function and subsequently causes male sterility[50].

The inguinal canal (IC) is traversed by the spermatic cord (SC) in men and boys, and by the round ligament (RL) of the uterus in women and girls. The RL is attached to the uterus and is accompanied by a pouch of parietal peritoneum in the IC, known as the canal of Nuck[51]. A hydrocele of the canal of Nuck is a differential diagnosis for groin hernia[51]. Hydroceles of the SC and testis are also differential diagnoses for groin hernia; deliberate surgery is required for SC hydroceles[52]. Hydroceles in infancy may resolve without surgery[48].

The bladder may be involved in groin hernias[53,54]; thus, injury to the urinary tract should be avoided. Notably, immature infants at birth may easily develop bladder prolapse[55]; therefore, the body weight at birth should be checked before surgery to avoid serious iatrogenic injuries[56].

In 1559, Caspar Stromayr (1530–1567) classified inguinal hernias as either IIH or DIH[57]. Inguinal hernias are currently classified as indirect or direct and primary or recurrent[6]. Some classifications are based on anatomical findings in relation to the development of the hernia (*e.g.*, posterior floor integrity, enlarged inguinal rings, and hernia size)[58,59]. The severity of the groin hernia may be difficult to determine prior to surgery; size alone may not be associated with severity in some patients[6]. However, the size of the groin hernia affects the choice of the surgical approach because surgeries performed under local or conduction anesthesia are contraindicated for huge hernias[59]. The European Hernia Society has proposes a simple classification (based on Aachen's classification[60]), which is used worldwide[61,62]. Briefly, this classification is based on orifice size and anatomical localization[60,61]. The size of the hernia orifice is recorded as 1 (≤ 1 finger), 2 (1-2 fingers), or 3 (≥ 3 fingers)[60]. Thus, a hernia orifice of 2.5 cm is considered a size 2 hernia[60]. For anatomical localization, the criteria are lateral (L), medial (M), and femoral (F)[60,61]. In addition, hernias are regarded as primary (P) or recurrent (R)[60,61].

HISTORY

Groin hernias have an interesting anatomical and surgical history[1,11,63-65] (Table 1). Pierre Franco (1500–1561) and Ambroise Paré (1510–1590) used conservative treatments with a strong bandage[1,66]. Specific anatomical structures in the IC were clarified in the 18th century[1]; the first report of successful transabdominal repair was described in 1716 by Demetrius Cantemir (1673–1723)[1]. Lorenz Heister (1683–1758) first reported successful bowel resection *via* laparotomy for a strangulated hernia[67].

Franz Kaspar Hesselbach (1759–1816) was the first to describe various anatomical structures [*e.g.*, cribriform fascia (Hesselbach's fascia) and interfoveolar ligament (Hesselbach's ligament)]. Hesselbach also defined the inguinal triangle (*i.e.*, "Hesselbach's triangle"), which is superolaterally bounded by the inguinal ligament (IL), the exterior border of the abdominal rectus muscle, and the inferior epigastric vessels[68,69].

Henry O. Marcy (1837–1924) stated that failure to close the internal (deep) inguinal ring (IIR), or low ligation of the hernia sac, could result in recurrence; he described an accurate reconstruction technique in 1871[70]. Marcy's repair was the first implementation of high ligation of the sac and closure of the IIR[70].

Table 1 History of anatomy and surgery for groin hernia

Name	Year	Remarks
G. Falloppio (1523-1562)		Importance of the IL (Etiology)
F. Poupart (1661- 1709)		Poupart's ligament (*i.e.*, the inguinal ligament)
P. Camper (1722-1789)		Camper's fascia (Anatomy)
A. Scarpa (1752-1832)		Scarpa's fascia (Anatomy)
D. Cantemir (1673-1723)	1716	Successful surgery (*via* a laparotomy)
L. Heister (1683-1758)		Bowel resection for strangulated hernia
P. Roland Arnaud de Ronsil	1724	Obturator hernia
C. Amyand (1660-1749)	1735	Amyand's hernia
AG. Richter (1742-1812)	1777	Strangulated hernia
AP. Cooper (1768-1841)		Cooper's ligament (Anatomy)
HO. Marcy (1837-1924)	1806	Marcy's repair (Anterior approach)
FK. Hesselbach (1759-1816)	1871	Hesselbach's triangle (Anatomy)
WJ. Mitchell Banks (1842–1904)	1882	Simple high ligation in infants and children
E. Basssini (1844-1924)	1887	Bassini's repair (Anterior approach)
WS. Halsted (1852-1922)		Modified Bassini's repair
EW. Andrews (1824-1904)		Modified Bassini's repair
L. Tait (1845-1899)	1891	Transabdominal approach
J. Lucas Championniere (1843-1913)	1892	Simple high ligation in infants and children
G. La Roque (1876-1934)	1919	Transabdominal approach
GL. Cheatle (1865-1951)	1920	TEP approach
RH. Russel (1860-1933)	1925	Sac removal in infants and children
A. Henry (1886-1962)	1936	Transabdominal approach
CB. McVay (1911–1987)	1939	McVay's repair (Anterior approach)
BJ. Anson (1894-1874)		Importance of the TF
WJ. Potts (1895-1968)	1945	Potts' method in infants and children
EE. Shouldice (1981-1965)	1953	Shouldice's repair (Anterior approach)
H. Fruchaud (1894-1960)	1956	The PPS (Anatomy)
CE. Koop (1916-2013)	1957	Koop's fixation
FC. Usher (1908-1980)	1958	Monofilament polypropylene mesh (Anterior approach)
LM. Nyhus (1923-2008)	1959	IPT repair (Preperitoneal approach)
J. Rives (1873-1985)	1965	Mesh placement in the PPS (Preperitoneal approach)
RE. Stoppa (1921-2006)	1969	Prosthetic reinforcement in the PPS (Preperitoneal approach)
P. Fletcher	1979	Laparoscope use (Laparoscopic approach)
R. Gel	1982	Laparoscopic repair (Laparoscopic approach)
IL. Lichtenstein (1920-2000)	1986	Mesh plug (Anterior approach)
		The concept of TFR
S. Bogojavalensky	1989	Laparoscopic repair with mesh plug (Laparoscopic approach)
L. Schultz	1990	The first series of laparoscopic repair (Laparoscopic approach)
JL. Dulucq	1991	Mesh placement in the PPS (Endoscopic approach)
FK. Toy and RT. Smoot, Jr.	1991	Intraperitoneal onlay mesh repair (Laparoscopic approach)
RJ. Fitzgibbons, Jr.	1991	Intraperitoneal onlay mesh repair (Laparoscopic approach)

AT. Spaw and LP. Spaw	1991	Triangle of doom (Anatomy)
AI. Gilbert	1992	Sutureless technique (Anterior approach)
ME. Arregui	1992	TAPP repair (Laparoscopic approach)
GS. Ferzli	1992	TEP repair (Endoscopic approach)
JM. Himpens	1992	TEP repair (Endoscopic approach)
JB. McKernan and HL. Laws	1993	TEP repair (Endoscopic approach)
EH. Phillips	1993	TEP repair (Endoscopic approach)
R. Annibali, TH. Quinn and RJ. Fitzgibbons Jr.	1993	Triangle of pain (Anatomy)

IL: Inguinal ligament; IPT: Iliopubic tract; PPS: Preperitoneal (posterior) space; TAPP: Transabdominal preperitoneal; TEP: Totally extraperitoneal; TF: Transversalis fascia; TFR: Tension-free repair.

Bassini[5] elucidated the anatomy of the anterior IC in 1884, then ushered safe and effective surgery into the modern era by describing Bassini's repair in 1887[5,71]. Notably, Bassini advocated the importance of Marcy's theory and emphasized floor reconstruction involving approximation of the internal abdominal oblique muscle (IAOM) and transverse abdominal muscle with the transversalis fascia (TF), combined with a shelving edge of the IL[5,71].

William Stewart Halsted (1852–1922) and Edmund W. Andrews (1824–1904) modified Bassini's repair[72-74]. The antiseptic concept was accelerated in the 19th century after Joseph Lister (1827–1912) introduced antisepsis[72]; additionally, Halsted was the first to use surgical gloves for aseptic technique during surgery[75]. Modified Bassini's repair (*i.e.*, "North American Bassini" repair) was implemented worldwide, although its use was associated with a higher recurrence rate[76]. Subsequently, Arthur Keith (1866–1955) described a shutter mechanism in 1923[13].

Chester Bidwell McVay (1911–1987) first employed Cooper's ligament for repair in 1939[77]; McVay's method involved repair of a femoral hernia through the posterior wall of the IC[78]. McVay and Barry J. Anson (1894–1874) focused on the importance of the TF[79]. Initially, the arch of the transverse abdominal muscle was approximated to Cooper's ligament, the iliopubic tract (IPT), and the IL. Subsequently, a relaxing incision was placed in the anterior rectus sheath.

In 1919, George La Roque (1876–1934) utilized abdominal and cutaneous incisions, then ligated the retracted hernia sac from the abdominal cavity[1]. In 1936, Arnold Henry (1886–1962) devised an analogous approach by means of a lower abdominal midline incision. In 1920, a totally extraperitoneal approach was first executed by George Lenthal Cheatle (1865–1951) as a radical curative operation for both inguinal and femoral hernias using a lower mid-abdominal preperitoneal approach[80].

Lloyd M Nyhus (1923–2008) introduced IPT repair in 1959[15], in accordance with the concept of the preperitoneal (posterior) approach[81]. The anterior rectus sheath was divided, and the abdominal rectus muscle was retracted medially; the TF was then exposed and the PPS was accessed. The IIH sac was ligated, and the defect was closed by approximating the conjoint tendon to the IPT and IL. Thereafter, based on the concept of the preperitoneal approach, prosthetic reinforcement in the PPS was first described by Jean Rives (1873–1985) in 1965 for unilateral hernias[16] and by René Stoppa (1921–2006) in 1969 for bilateral inguinal hernias[82].

Edward Earle Shouldice (1890–1965) introduced a multiple layer repair of the posterior inguinal wall in 1953[14]. The TF was divided from the IIR to the pubic tubercle and lifted from the peritoneum. Shouldice's repair proposed an imbrication of the TF and strengthening of the posterior wall of the IC by using four layers of the fascia and aponeuroses of the IAOM. Henri Fruchaud clarified the preperitoneal anatomy in the early 1950s[3]; preperitoneal and laparoscopic approaches were thereafter realized based on his work.

Jean Rives placed mesh into the PPS in 1965[16], and René Stoppa used a large Dacron prosthesis to reinforce the TF[83]. In 1986, Irving L. Lichtenstein first introduced a mesh plug made by rolling a piece of flat polypropylene into the shape of a cigarette to fill a femoral defect[10,11]. The mesh was fixated with interrupted sutures; this "cigarette plug" was used to repair inguinal, femoral, and recurrent hernias. Hence, Lichtenstein established a TFR technique that ushered a new surgical era[10,11]. Classic hernia repairs used sutures under tension, which led to a high recurrence rate; TFR dramatically improved the rates of recurrence and infection[84]. Prosthetic

mesh was used to reinforce the TF; specifically, polypropylene mesh was superiorly fixed to the IL, lateral edge of the rectus sheath, and conjoint tendon. Francis Usher (1908–1980) introduced the use of monofilament polypropylene mesh in 1958[85,86] and parietalized the SC[87]. Thereafter, Arthur I Gilbert (1913–2001) improved TFR with a sutureless technique[88,89]. Lichtenstein was first to coin the term "tension-free hernioplasty"[90]; the concept of TFR revolutionized hernia surgery[11,63]. The advantageous simplicity of "mesh-plug hernioplasty" was first described in 1993[91]; thereafter, this procedure became preferable and spread worldwide[92,93].

Although Lichtenstein's repair produced excellent results, George E Wantz (1923–2000) warned that polypropylene mesh did not cover the entire myopectineal orifice (MO) and that Lichtenstein's repair was therefore inadequate to prevent a femoral hernia[94]. Notably, he also stated that incomplete coverage of the MO by the mesh could predispose patients to subsequent DIH[94].

WALL LAYERS

Petrus Camper (1722–1789), Antonio Scarpa (1752–1832), and Franz Kaspar Hesselbach provided detailed descriptions of inguinal structures, particularly of important ligaments[1]. Following elaborate anatomical studies, François Poupart (1661–1709) in 1695 recognized the importance in hernia pathology of the IL[1], which had been described previously by Gabriele Falloppio (1523–1562)[1]. Astley P. Cooper published original anatomical views regarding the IC in 1804 and 1807[1]. Part of the aponeurosis of the external abdominal oblique muscle composes the IL, although the IAOM is observed under the aponeurosis of the external abdominal oblique muscle at the groin. The IL is also known as the Fallopian ligament or Poupart's ligament.

The abdominal wall at the groin is classically considered to have nine layers[95]: skin, subcutaneous fat, superficial fasciae (Camper's and Scarpa's fasciae), innominate (unnamed or untitled) fascia, IL, IAOM, TF, PPS [superficial parietal layer (SPL) and deeper visceral layer (DVL)], and peritoneum. This classification involves the innominate (unnamed or untitled) fascia, which is a thin membrane on the IL, and does not indicate division of the PPS into the SPL (*i.e.*, anterior subperitoneal fascia) and DVL (*i.e.*, posterior subperitoneal fascia) (Figure 1). The PPS comprises preperitoneal fat.

The IC is a passage in the anterior abdominal wall that conveys the SC in men and boys, whereas it conveys the RL in women and girls. The IL is bordered by the aponeurosis of the external abdominal oblique muscle anteriorly, the IAOM and transverse abdominal muscle superiorly, the IL and lacunar ligaments inferiorly, and the TF posteriorly.

PREPERITONEAL (POSTERIOR) SPACE AND MYOPECTINEAL ORIFICE

In the early 1950s, Henri Fruchaud reported that all hernias at the groin result from a defect of the TF and pass through the myopectineal orifice (MO) (all three triangles of the groin)[3]. The oval-shaped MO is the origin of all groin hernias[4] (Figure 2). In 1965, Jean Rives proposed reinforcement of the TF with a prosthesis placed in the preperitoneal (posterior) space (PPS), if local structures are weak[16]. Although an "on-lay patch," (placed on the anterior side of the TF) was historically used, the importance of an "under-lay (in-lay) patch" placed between the TF and peritoneum is now widely accepted. Hence, general surgeons commonly recognize the concept of optimal repair at the PPS. The PPS is observed between the TF and peritoneum; adequate creation of an extended PPS is important for optimal surgery[64,96]. Several physicians [Astley P. Cooper in 1807[7], William James Lytle (1896–1986) in 1945[13], Edward Earle Shouldice in 1953[14], Henri Fruchaud in 1956[3], Lloyd M. Nyhus in 1959[15], Jean Rives in 1965[16], R. Fowler Jr. in 1975[17], René Stoppa in 1977[18,19], Raymond C. Read in 1992[20], and Maurice E. Arregui in 1997[21]] historically made mention of this important space[97] (Table 2). In particular, anatomical recognition of the SPL and DVL was a milestone for further developments of surgical repair techniques[97]. The anterior subperitoneal fascia is recognized as the SPL, while the posterior subperitoneal fascia is recognized as the DVL[29] (Figure 3).

Anatomical recognition of the MO is also crucial for reliable treatment[98,99], and laparoscopic exploration easily reveals this orifice[4]. Full coverage of the MO is considered optimal surgery[98-100]. This orifice should be fully reinforced in a TFR manner to prevent IIHs, DIHs, femoral hernias, and obturator hernias[98-102]. Mesh implantation into an extended cavity of the PPS is currently considered optimal

Table 2 Preperitoneal (posterior) space and myopectineal orifice

Name	Year	SPL (Posterior sub-peritoneal fascia)	DVL (Anterior sub-peritoneal fascia)
AP. Cooper	1807	TF-inner portion	-
WJ. Lytle	1945	Preperitoneal fascia	-
EE. Shouldice	1953	Preperitoneal fascia	-
H. Fruchaud	1956	PPS at the MO	-
LM. Nyhus	1959	PPS	-
J. Rives	1965	Inguinal PPS	-
R. Fowler	1975	Preperitoneal fascia-membranous layer	Preperitoneal fascia-areolar layer
RE. Stoppa	1977	Urogenital fascia	Urogenital fascia
		Umbilico-prevesical fascia	Umbilico-prevesical fascia
		Spermatic sheath	Spermatic sheath
RC. Read	1992	TF-posterior lamina	-
ME. Arregui	1997	Attenuated rectus sheath	Umbilical prevesicular fascia
		TF-posterior lamina	Preperitoneal fascia

DVL: Deeper visceral layer; MO: Myopectineal orifice; PPS: Preperitoneal (posterior) space; SPL: Superficial parietal layer; TF: Transversalis fascia.

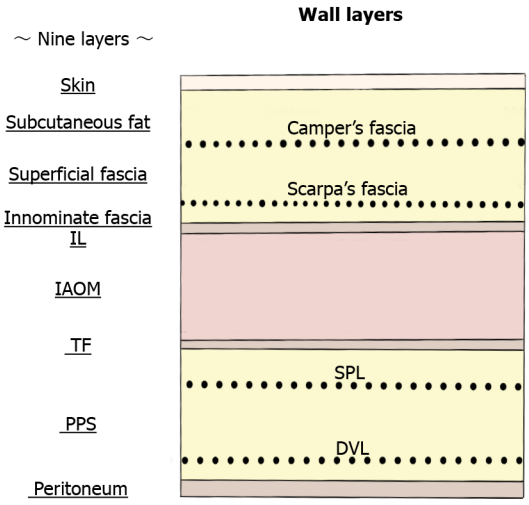

Figure 1 Wall layers. The abdominal wall at the groin contains the following components: skin, subcutaneous fat, superficial fasciae (Camper's and Scarpa's fasciae), innominate (unnamed or untitled) fascia, IL, IAOM, TF, PPS [SPL (anterior subperitoneal fascia) and DVL (posterior subperitoneal fascia)], and peritoneum. DVL: Deeper visceral layer; IAOM: Internal abdominal oblique muscle; IL: Inguinal ligament; PPS: Preperitoneal space; SPL: Superficial parietal layer; TF: Transversalis fascia.

surgery[98-102].

Some physicians have performed detailed investigations of the layer in which the bladder exists[19,21,103] (Figure 4). The terms "spermatic sheath" and "urogenital fascia" established by René Stoppa[19] and "umbilical prevesical fascia" established by Maurice E. Arregui[21] have become widespread.

PEDIATRIC HERNIORRHAPHY

Many pediatric surgeons focus on herniorrhaphy in infants and children[104-107]. Notably, a contralateral hernia develops after unilateral surgery in 8% to 11% of patients[108,109]. The low incidence of contralateral hernia after unilateral herniorrhaphy does not justify routine contralateral groin exploration[108,109].

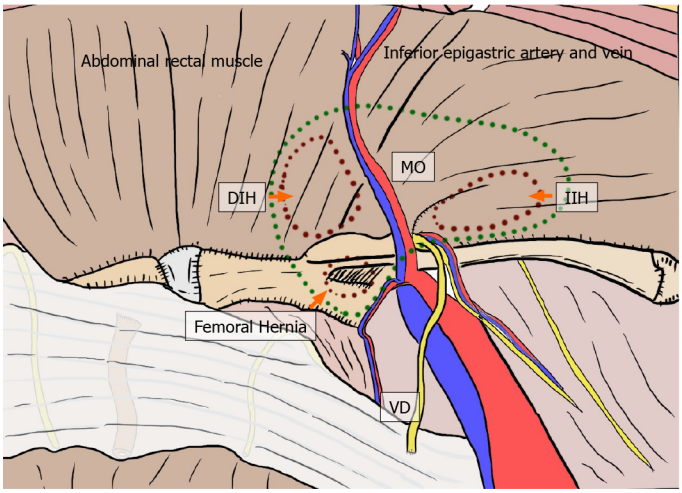

Figure 2 Myopectineal orifice. The oval-shaped myopectineal orifice (green dotted circle) is the origin of all groin hernias (brown dotted circles). DIH: Direct inguinal hernia; IIH: Indirect inguinal hernia; MO: Myopectineal orifice; VD: Vas deferens.

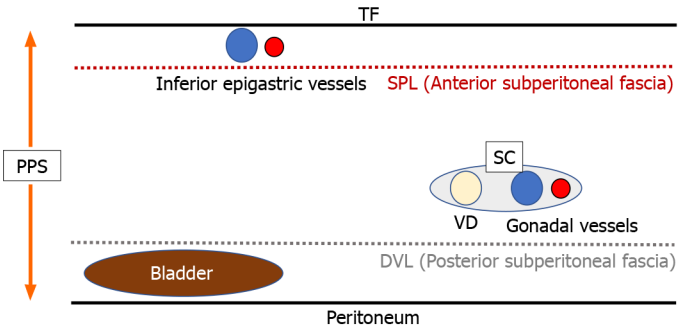

Figure 3 Preperitoneal space. DVL: Deeper visceral layer; PPS: Preperitoneal space; SC: Spermatic cord; SPL: Superficial parietal layer; TF: Transversalis fascia; VD: Vas deferens.

Just Lucas-Championnière (1843–1913) described a simple high ligation technique in 1892[110]. William Mitchell Banks (1842–1904) in 1882[111] and Willis J. Potts (1895–1968) in 1950[104,107] described high ligation by means of a partial incision of the IC without opening the external (superficial) inguinal ring. Alexander Hug Ferguson (1853–1912) added anterior wall repair in 1899[112].

P. Turner in 1912[113] and A. MacLennon in 1914[114] advised simple removal of the sac to the IIR through a very small incision. In 1925, Robert Hamilton Russell (1860–1933) strongly emphasized surgical removal of the sac solely in infants and children[115]. In 1938, Gertrude Marianne Amalia Herzfeld (1890–1981) used a small incision over the external inguinal ring, pulled down and ligated the sac, and closed the external inguinal ring with a single stitch[116]. In 1945, Jerome S. Coles (1911–1996) advised transfixation and ligation of the proximal end as high as possible[117].

Willis J. Potts performed a high ligation in 1945[104,107,118]; and Potts' method thereafter spread as the standard surgical technique worldwide. Charles Everett Koop (1916–2013) immobilized the edge of a high ligation by suturing the dorsal side of the IAOM. Koop's fixation prevented postoperative infertility due to uterine retroflexion and reduced postoperative recurrence[119]. The bilateral RLs are cut during herniorrhaphy for bilateral inguinal hernias; thus, Koop's fixation should be routinely performed for bilateral inguinal hernias in female patients[120].

In the field of pediatric herniorrhaphy, surgeons also recognize the importance of the PPS. Laparoscopy has been used to assist repair in the PPS[121,122]; and Takehara *et al*[123] first described laparoscopic percutaneous extraperitoneal closure in 2006. Laparoscopic percutaneous extraperitoneal closure is a simple technique that includes ligation around the IIR by means of a unique needle. This surgery avoids opening of the IC and involves minimal dissection around the testicular vessels and vas deferens (VD).

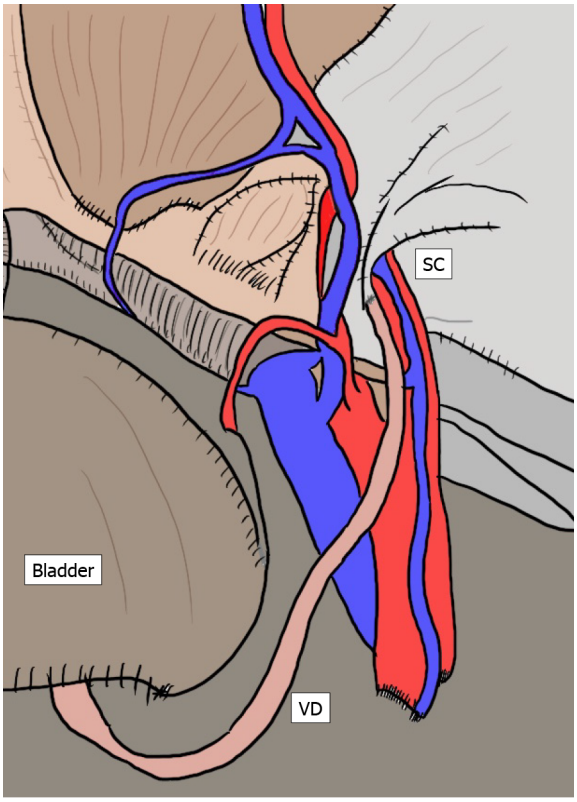

Figure 4 Vas deferens, spermatic cord and bladder. The vas deferens courses as the "preperitoneal loop" in the deeper visceral layer (DVL). The bladder exists in the DVL. DVL: Deeper visceral layer; PPS: Preperitoneal space; SC: Spermatic cord; SPL: Superficial parietal layer; TF: Transversalis fascia; VD: Vas deferens.

HERNIA SURGERY IN THE CURRENT ERA

Beginning in the latter half of the 20th century, prosthetic mesh was routinely used in accordance with the TFR concept; many surgeons recognized the importance of the PPS. Laparoscopy and endoscopy have therapeutic potential for hernia surgeries.

Laparoscopic transabdominal preperitoneal (TAPP) repair is based on the same principle (*i.e.*, therapeutic feasibility of the transperitoneal approach for groin hernia) as the technique published by Lawson Tait (1845–1899) in 1891[124]. P. Fletcher first employed a laparoscope to repair a groin hernia in 1979[64]. Subsequently, Ralph Ger in 1982[125], S. Bogojavalensky in 1989[126], Leonard Schultz in 1990[127], and Maurice E. Arregui in 1992 and 1993[128,129] reported their respective TAPP repair techniques.

Endoscopic totally extraperitoneal repair is based on the preperitoneal anatomy clarified by Henri Fruchaud in 1956[3]. Jean Louis Dulucq first reported mesh implantation into the PPS in 1991[130]; thereafter, George S. Ferzli in 1992[131], Jacques M. Himpens in 1992[132], and John Barry McKernan in 1993[133] performed this procedure. Edward H. Phillips was the first to use the term "totally extraperitoneal" in 1993 [134].

Laparoscopic intraperitoneal on-lay mesh repair does not involve groin dissection. Frederick K. Toy and Roy T. Smoot described this procedure in 1991[135], while Muhammed A. Memon *et al*. employed this procedure beginning in 1991[136].

Surgeons can now choose from among several approaches (*e.g.*, open *vs* laparoscopic/endoscopic and anterior *vs* preperitoneal), planes in which the mesh is placed (*e.g.*, layer in front of the TF *vs* the PPS), fixation devices (*e.g.*, suture, sutureless, tack, or glue), and prostheses (*e.g.*, soft *vs* hard meshes and sheeted *vs* three-dimensional meshes)[137].

TYPES OF MESHES AND TENSION-FREE HERNIOPLASTY

Many meshes are currently available[12]. Hernia repair with mesh is regarded as hernioplasty, while traditional repairs without mesh are regarded as herniorrhaphy.

The TFR concept by Irving L. Lichtenstein was a breakthrough idea[10,11,64], and the use of surgical mesh is superior to other techniques[138]. Mesh is inherently a foreign body;thus, postoperative removal may be required because of complications such as refractory infection[139].

In 1890, Theodor Billroth (1829–1894) used various prosthetic materials for hernia repair[140], although all failed due to infection, rejection, and recurrence[12]. Suitable materials for surgical procedures were seriously needed. The turning point in hernia surgery was the discovery of synthetic polymers (*e.g.*, nylon) by Wallace Hume Carothers (1896–1937) in 1935[11]. Francis Usher (1908–1980) introduced the use of monofilament polypropylene mesh in 1958[85,87]; he later compared nylon, orlon, Darcon, and teflon[141]. Monofilament polypropylene meshes (*e.g.*, Prolene; Ethicon, Inc., Cincinnati, OH USA) are available from many manufacturers in the current era. One of the first synthetic meshes used was Marlex, which comprised crystalline polypropylene and high-density polyethylene. Irving L. Lichtenstein first introduced a mesh plug that consisted of polypropylene mesh in 1986[10,11]. Polypropylene, polyester, and expanded polytetrafluoroethylene were initially used; thereafter, polyglactin 910, cellulose, polyvinylidene fluoride, poliglecaprone 25, omega 3, titanium, and collagen were employed as additional materials.

Current meshes are chemically and physically inert; they are also nontoxic, stable, and nonimmunogenic[12]. However, none are biologically inert, due to the mesh physiology[12]. The introduction of a foreign material into the body triggers a healing response characterized by one of three reactions: destruction, tolerance, or rejection [12]. All meshes have their own characteristics with respect to elasticity (tensile strength), pore size, weight (density), constitution, and material absorption[12].

Double-sided polypropylene mesh is designed as a bilayer polypropylene mesh with a connector between the layers; this mesh is fixated with fewer sutures than a monolayer polypropylene mesh. This system enables coverage of the MO and can repair IIHs, DIHs, and femoral hernias from an anterior approach. The on-lay patch covers the entire floor of the IC, while the under-lay patch is placed into the PPS. Robert Kugel placed a sutureless mesh in the PPS in 1999, and this mesh is known as the "Kugel hernia patch"[142]. This patch was later modified to a so-called "direct Kugel patch" for placement of the mesh by means of a minimal incision in the IL. Double-sided polypropylene mesh (*e.g.*, Prolene Hernia System; Ethicon, Inc.) and the direct Kugel patch have become widespread on a commercial basis. Furthermore, polypropylene mesh itself is currently employed in surgeries for other diseases[143].

Inguinal hernia repair is associated with a low incidence of complications that can be influenced by the type of mesh[144]. In terms of postoperative complication, lightweight and heavyweight meshes showed no differences regarding seromas, infections, erosion, and testicular atrophy[145-147]. Lightweight mesh may contribute to recurrence in patient with inguinal hernias[146], but has advantages in terms of chronic pain and foreign body sensations[145-147]. Moreover, partially absorbable synthetic mesh improves postoperative chronic pain, functional outcomes, and quality of life[148,149].

Surface modification methods and nanofiber-based technology are actively under exploration to retain material strength and biocompatibility[12]. Biological mesh has superior biocompatibility to the above-described meshes and does not trigger an inflammatory response from the body, although higher cost has hampered its widespread acceptance[12]. In patients who experience complications, biological meshes can be placed for temporary or permanent closure of defects after mesh removal due to chronic pain or infection[150,151].

Hence, mesh materials are currently well-developed, but each mesh should be used in the correct manner12 Many types of meshes are available, and surgeons should follow the manufacturers' instructions to avoid malfunctions[12]. Surgeons must also ensure that their knowledge is regularly updated regarding mesh applications[12].

RECURRENT HERNIA

Postoperative recurrence is a critical issue[47,152]. The reasons for inguinal hernia recurrence are most likely multifactorial and include both technical and nontechnical patient-related risk factors[47]. In one study, the overall reoperation rate was reportedly 3.8%[47], while the reoperation rates for IIH and DIH were 2.7% and 5.2%, respectively[47]. Notably, the right side has a higher recurrence rate than the left side [4,47,152].

Iatrogenic recurrence caused by lack of anatomical knowledge and inappropriate techniques should be avoided[47]. All surgeons, including trainees and residents, should ensure professional technique in clinical practice to reduce the risk of recurrence. Nontechnical patient-related factors that influence the risk of recurrence after surgery have not been studied in detail[47]. Female sex, DIH at the time of initial surgery, surgical treatment of a recurrent inguinal hernia, and smoking are considered risk factors for postoperative recurrence[47]. A significant relationship between the type of hernia at the time of initial surgery and reoperation has been identified with respect to hernia recurrence[47].

Surgical repair is generally indicated[58,59], and a laparoscopic approach is strongly recommended for surgical repair of recurrent hernia[59].

OBTURATOR HERNIA

Obturator hernias are internal herniations through the obturator foramen, bordered by the obturator vessels and nerve. This type of hernia was first described by Pierre Roland Arnaud de Ronsil in 1724[153], although a patient had been described by Le Maire in 1718[153]. Notably, the Howship-Romberg sign [named after John Howship (1781–1841) and Moritz Heinrich Romberg (1795–1873)] is associated with obturator hernia[154]; however, this rare hernia generally exhibits nonspecific signs and symptoms[155]. Hence, the usefulness of computed tomography for diagnosis was suggested in 1983[156]. Actual image findings are shown in Figure 5A.

Obturator hernia should be considered a bilateral disease[157]; thus, unilateral repair may be inadequate[158,159]. The normal diameter of the obturator foramen is approximately 1.0 cm[160]. Hence, the bilateral obturator foramina should be routinely checked during surgery[157-159]; bilateral repair is required if even only a subtle dilation of the contralateral obturator foramen is observed during surgery[157-159].

SPECIAL SITUATIONS

Lorenz Heister was the first to successfully repair a strangulated hernia.67 Thereafter, August Gottlieb Richter (1742–1812) produced a two-volume treatise regarding hernias from 1777 to 1779, which included the first description of a strangulated hernia involving only part of the intestine.

Incarcerations of the ovary and appendix are often observed. Although ovarian resection is not required for ovary incarceration, incarceration of the appendix (known as "Amyand's hernia", which is an inguinal hernia that traps the appendix) sometimes requires appendectomy. In 1735, Claudius Amyand (1660–1749) performed the first successful appendectomy[161], which concerned an incarcerated hernia involving a swollen and perforated appendix. The reported incidence of Amyand's hernia among patients with appendicitis is < 0.1%[162], and left-sided Amyand's hernias have rarely been reported[163]. Amyand's hernia leads to further complications (*e.g.*, strangulation and perforation)[162], with a mortality rate of 14% to 30%[162]. Incarceration of the appendix may result in delayed perforation. Appendectomy should be considered[162,164], although it is not always necessary if a normal, uninflamed appendix is observed [162].

Pathophysiological hypotheses for prolapse of the uterus and its appendages have been proposed for both girls and women[165,166]. However, groin hernias involving the uterus and/or its appendages have not been described. The appendix has characteristic features and is completely distinct from the ileum, colon, and rectum[167]. In patients who exhibit a giant hernia involving incarceration of the ileocecal portion of the intestinal tract, only the appendix does not recover from ischemic changes, despite resolution of the strangulation (Figure 6). Thus, incarceration of the appendix has several reasons for a distinctive name (*i.e.*, Amyand's hernia).

In women and girls, the RL is attached to the uterus, near the origin of the fallopian tubes, and the extension of the parietal peritoneum follows the RL as it passes to the IC through the IIR[168]. A hydrocele of the canal of Nuck is a differential diagnosis for groin hernia[51,168,169], although this hydrocele is not conclusively diagnosed until surgery is performed on a suspected inguinal hernia[168]. Ultrasound is a powerful tool for making an accurate diagnosis and determining indications for surgical treatment[169]. Although hydrocele in infancy may resolve without surgical treatment [48], such treatment is generally indicated because of symptoms (*e.g.*, swelling and pain)[52,168,169]. Moreover, hydrocele of the canal of Nuck often accompanies with

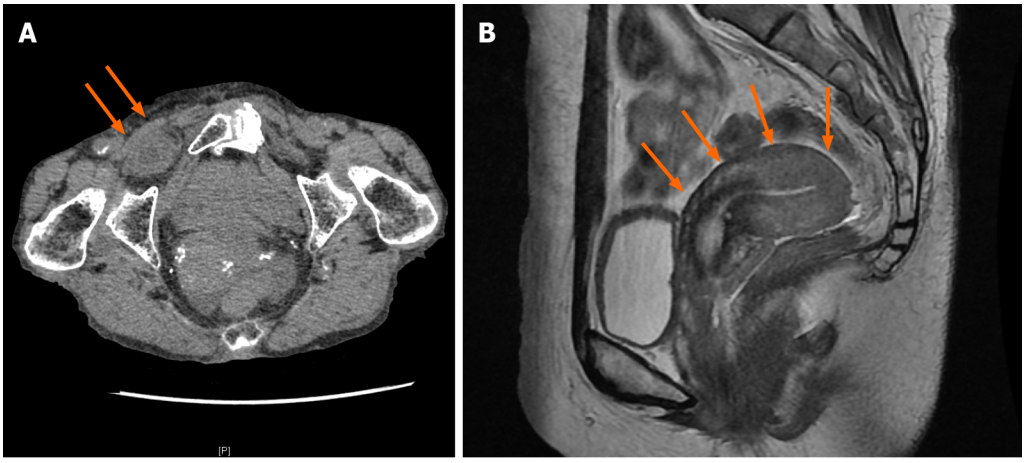

Figure 5 Actual image findings. Actual image findings of obturator hernia in computed tomography (A, orange arrows) and retroflexion of the uterus in magnetic resonance imaging (B, orange arrows) are shown, respectively.

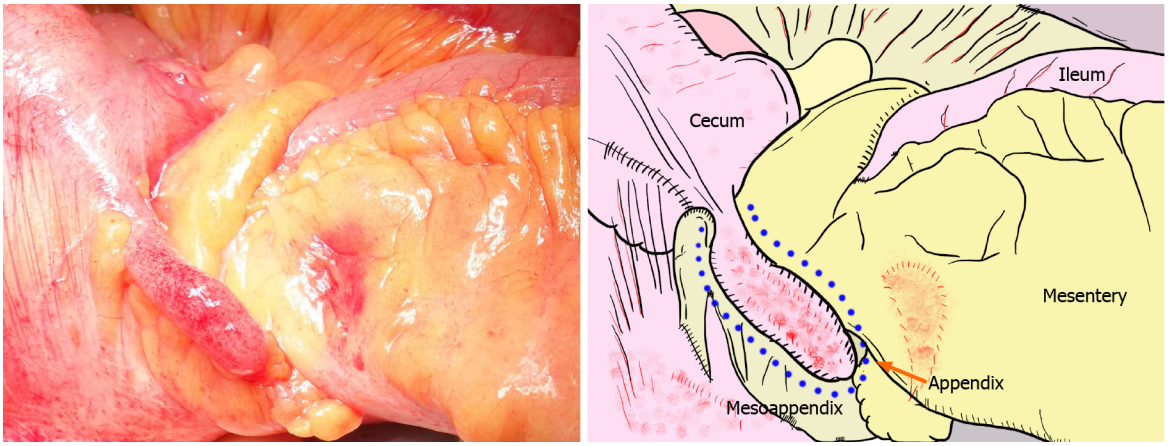

Figure 6 Amyand's hernia. Amyand's hernia is considered as an inguinal hernia that traps the appendix. In patients who exhibit a giant hernia involving incarceration of the ileocecal portion of the intestinal tract, only the appendix does not recover from ischemic changes, despite resolution of the strangulation.

ectopic endometriosis[52,168,169]. Hydrocele with persistent patency of the processus vaginalis requires resection[168,169]; this surgery prevents recurrences[168]. The genital branch of the genitofemoral nerve (Gb-GFN) and RL should be preserved[169]. The IIR is often enlarged by hydrocele; therefore, intentional closure of the IIR by Marcy's repair[70] is generally required[168,169].

POSTOPERATIVE COMPLICATIONS

Recurrence of groin hernias is extremely challenging for general surgeons, and neuropathy may be intractable[161,170,171]. Injury of the SC or VD results in refractory pain with burning[172]. Potential complications include testicular ischemia[173], testicular atrophy[174], bowel obstruction and/or necrosis due to mesh adhesion[175,176], vascular injury[177], visceral injury[176,177], wound infections[173], and hematomas[173]. Rarely, patients with groin hernias have experienced fatal outcomes [178,179].

AGENESIS AND STERILITY

Postoperative agenesis is a critical issue. In female patients, Koop's fixation should be routinely performed for bilateral inguinal hernias to prevent retroflexion of the uterus, which may cause female agenesis[120]. It is suggested to avoid division of the round ligament in open repair[60,61]. In male patients, both the surgical technique and mesh

material can influence the integrity of the SC and testicular function[180-182]. Contact with the mesh material may cause sterility in male patients[183]. Meshes inherently cause varying degrees of postoperative atrophy; therefore, biomechanical stability is extremely important[184]. Soft and hard meshes may result in unidirectional or matrix-like atrophy[12,185,186]. Soft mesh reduces chronic pain, but increases atrophic changes[12]. Biological mesh is predicted to become a powerful tool in the near future, although its cost remains high[12,187,188]. Testicular necrosis induces the formation of autoimmune antibodies to the body's own sperm[173], subsequently causing male sterility[50].

TOPOGRAPHIC NERVES AND NEUROPATHY

Thorough knowledge of peritoneal innervation is important because neurarchy has clinical implications. Some authors have extensively described the anatomy of the nerves located in the groin[22-31] (Figures 7 and 8). The peritoneum has both somatic and autonomic innervations, which are involved in various abdominal pathologies [29]. The parietal peritoneum receives its innervation from the spinal nerves of the 10th thoracic spine through the 1st lumbar spine[29-31]. This innervation is somatic and allows for the sensation of pain and temperature[29-31]. The visceral peritoneum receives autonomic innervation from the vagus nerve and sympathetic innervation that results in difficulty localizing abdominal sensations triggered by organ distension [29-31].

Precise knowledge of the topography of these nerves is essential for performance of high-quality repair with optimal patient outcomes[4,22-31,34]. Six nerves are of particular interest in the field of groin hernia repair[4,22-31,34], and the inguinal neuroanatomy should be thoroughly understood by all surgeons[34] (Figures 7 and 8). These six nerves of interest are the iliohypogastric, ilioinguinal, femoral (including the anterior cutaneous branch), genitofemoral (GFN) (femoral and genital branches), lateral femoral cutaneous (LFCN), and obturator nerves (Figure 8). The reported incidence of postoperative pain and/or discomfort ranges from 14.7% to 17.3%, but the intensity of persistent chronic pain or discomfort after surgery is not sufficiently severe to disturb daily activities in most patients[34,189]. However, a lack of anatomical knowledge and the use of an inadequate surgical technique may result in poor outcomes with refractory neuropathy and intractable chronic pain[4,22-31,34]. Notably, intractable and refractory pain may be an indication for removal of mesh and/or resection of entrapped nerves[190].

The femoral nerve is generally well protected by the psoas tendon. Therefore, injury to this nerve during surgery is extremely rare[34]. Additionally, intraoperative injury to the obturator nerve is only anecdotal because this nerve is well hidden[34].

Although branches of the GFNs course to the lower limbs, more common nerve injuries are observed in GFN branches in the trunk, as well as the LFCN[4,34] (Figure 8). The estimated risks of intraoperative injuries are 58.2% in the LFCN, 31.2% in the femoral branch of the GFN (Fb-GFN), and 4.7% in the Gb-GFN[34]. Although the courses of the obturator and femoral motor nerves are largely predictable and consistent, the courses of the sensory nerves (*i.e.*, GFN and LFCN) demonstrate great variability and are involved in refractory symptoms (*e.g.*, chronic and continuous pain) [34]. Wide variation in the number and course of sensory nerves that traverse the PPS creates considerable potential for overlap with the Gb-GFN, Fb-GFN, and LFCN[4,34]. Notably, the ilioinguinal nerve has a wide area in which injury can occur[4,34]. Respecting these proper dissection planes and ensuring knowledge of relevant neuroanatomy will minimize contact and corresponding risk of injury[4,34].

Injury to the iliohypogastric nerve results in postoperative neuralgia and muscular atrophy[191] (Figure 8). Additionally, injury to the ilioinguinal nerve may cause refractory pain[4,34] (Figure 8).

Nerve preservation during surgery requires a carefully considered approach[4,34,192]. Subtle factors during surgery (*e.g.*, skeletonization, direct detection, countertraction, and mesh contact) may cause postoperative neuropathy and chronic pain[34,190,192,193]. Unnecessary procedures for nerve identification should be avoided if possible; anatomical recognition of the route of each nerve (without direct exposure or complete skeletonization) is generally sufficient during surgery[4,34,192].

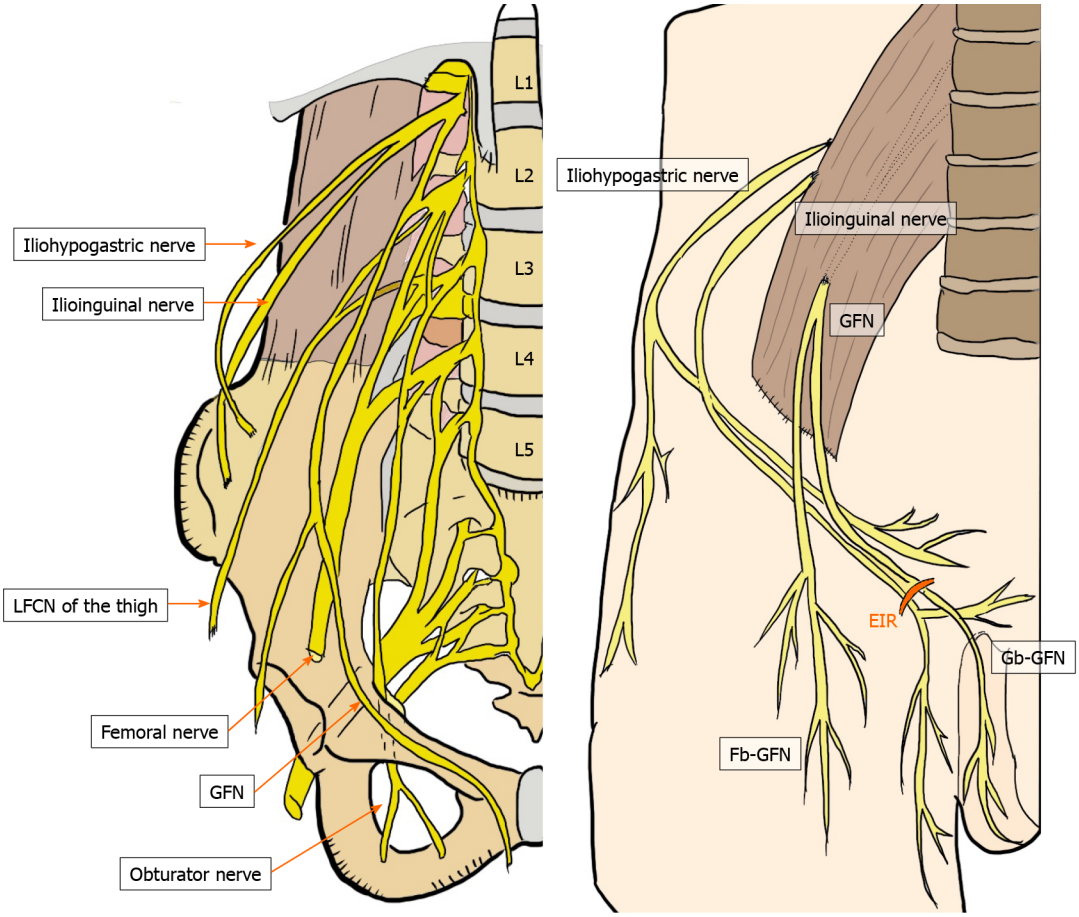

Figure 7 Topographic nerves located in the groin. These six nerves of interest are the iliohypogastric, ilioinguinal, femoral (including the anterior cutaneous branch), genitofemoral (femoral and genital branches), lateral femoral cutaneous of the thigh, and obturator nerves. EIR: External inguinal ring; GFN: Genitofemoral nerve; Fb-GFN: The femoral branch of the GFN; Gb-GFN: The genital branch of the GFN; LFCN: Lateral femoral cutaneous nerve.

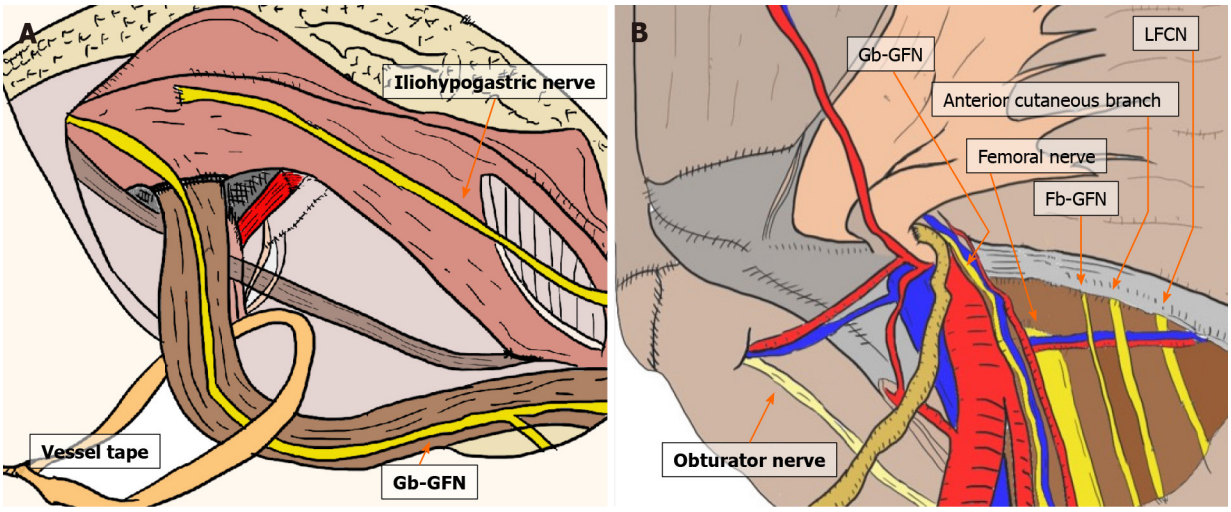

Figure 8 Topographic nerves located in the groin. Respective anterior (A) and laparoscopic (B) views are shown. Fb-GFN: The femoral branch of the genitofemoral nerve; Gb-GFN: The genital branch of the genitofemoral nerve; LFCN: Lateral femoral cutaneous nerve.

PLICAE AND FOSSAE

The initial laparoscopic view of the groin reveals five plicae (perineal folds) that serve as guiding landmarks[4,34]. The median umbilical plica, observed at the midline, contains the obliterated urachus and is less clinically relevant to surgical repair[4,34]. The medial umbilical plica (MUP) is the most prominent landmark present on the

initial view[4,34]. This plica is easily recognized and contains remnant umbilical vessels[4,34]. The MUP should not be routinely cut because the umbilical vessels may still be patent and cause bleeding[4,34]. Although the lateral umbilical plica may be difficult to identify depending on the body habitus and fat distribution, recognition of this plica is important[4,34]. This plica contains the inferior epigastric vessels, which divide the groin into a medial compartment (*i.e.*, space of Retzius) and a lateral compartment (*i.e.*, space of Bogros)[4,34]. External palpation of the surface anatomy allows precise localization of the anterior superior iliac spine and pubic tubercle, thereby delineating the IPT that divides the groin into an upper and a (critical) lower part[4,34]. The space of Bogros extends laterally from the space of Retzius toward the anterior superior iliac spine[4]. These spaces must be developed to allow adequate room for hernia repair and mesh placement[4].

These plicae create three flat fossae recognizable on each side, corresponding to possible hernia defects[4,34]. The hernia presentation can be more easily evaluated by a laparoscopic view than by endoscopic or anterior view[4,34] (Figure 9). The lateral fossa, located in the triangle between the lateral umbilical plica and IPT, corresponds to the point of the IIR from which an IIH originates[4,34]. The medial fossa is located between the lateral umbilical plica and MUP; this fossa is inferiorly limited by the IPT [4,34]. A DIH is located in this region, passing through Hesselbach's triangle[4,34]. The supravesical fossa is located medial to the MUP and cranial to the IPT, pubic bone, and urinary bladder[4,34]. This weak point may rarely become the origin of a supravesical hernia[4,34]. A femoral hernia develops within the region of the femoral canal (*i.e.*, the triangle below the IPT, medial to the femoral vein, and superior to the pubic bone and Cooper's ligament)[4,34].

The pubic symphysis, a cartilaginous joint between the superior pubic rami, symphysis denotes the midline[4]. Cooper's ligament, a lateral extension of the lacunar ligament, forms the periosteum of the superior pubic rami[4].

SIGNATURE TRIANGLE

Although the IIH enters the IIR lateral to the inferior epigastric vessels, a DIH protrudes through Hesselbach's triangle medial to the inferior epigastric vessels[4]. Important nerves are located on the lateral side of the IIR and travel from the pelvic interior to the thigh, coursing under the IPT[4,34]. In contrast, most important vessels course on the internal side of the IIR[4,34]. The VD travels downward, crossing the iliac vessels medially[4,34]. Hence, the VD comprises the "preperitoneal loop" in the DVL. Thereafter, the VD changes its direction at a 90-degree angle and dives down to the urogenital space to join the prostate gland[4,34].

The basic anatomical principles of the laparoscopic view were first described by Albert T. Spaw and Lynn P. Spaw in 1991, based on human cadaveric dissections[194]. They coined the term the "triangle of doom," which delineates the region between the VD and spermatic vessels. However, the neuroanatomy in the PPS was not considered [194]. Thereafter, James Rosser first described the inguinal neuroanatomy in 1994 and roughly delineated the anatomical course of the inguinal nerves[22]. Arnold S. Seid and Edwin Amos provided a more precise description of the nerves[23]; they postulated that the "triangle of doom" should be extended further laterally to the anterior superior iliac spine. Currently, the "triangle of doom" is regarded as an inverted V-shaped area bound laterally by the gonadal vessels (in both sexes) and medially by the VD (in men and boys) or RL (in women and girls)[4,32-34]. The external iliac artery and vein, deep circumflex iliac vein, Gb-GFN, and femoral nerve are involved in this area[4,32-34] (Figure 10).

In 1993, the most comprehensive analysis of inguinal neuroanatomy was performed by Riccardo Annibali, Thomas Quinn, and Robert J. Fitzgibbons Jr.[24,25] They defined the "triangle of pain" as the area lateral to the testicular vessels and inferior to the IPT [24,25]. Reinhard Bittner used the term "trapezoid of disaster" for this area[34]. The course of the nerves and their variations were recently described in detail[26-28]. The "triangle of pain" involves the Fb-GFN, LFCN, femoral nerve, and anterior cutaneous branch of the femoral nerve[4,32-34]. Notably, subtle injury (or greater) to the nerves located within the "triangle of pain" is a risk factor for intractable pain[4,32-34] (Figure 11).

The iliac vessels are accompanied by fatty tissue and lymph nodes[4,32-34], and over-dissection may lead to bleeding, potential nerve injury, or lymphatic leakage[4, 32-34]. Dissection of this region should be performed with substantial caution regarding identification of the corona mortis, a vascular connection between the epigastric

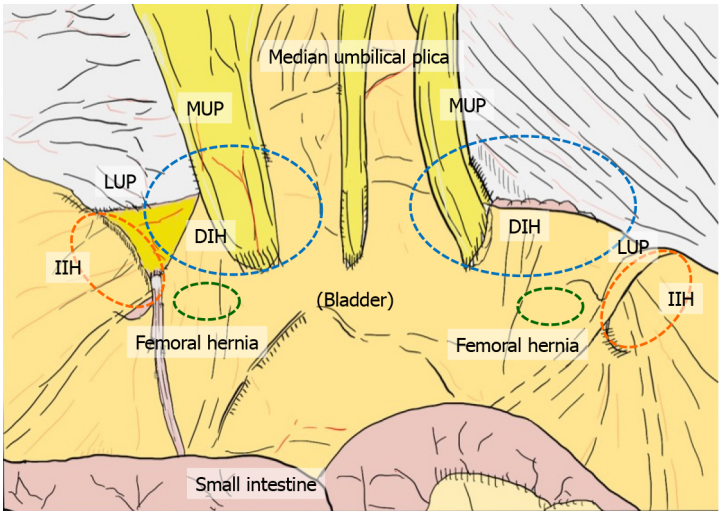

Figure 9 Plicae and fossae. Plicae create three flat fossae recognizable on each side, corresponding to possible hernia defects. Hernia presentation can be more easily evaluated by a laparoscopic view than by an endoscopic or anterior view. DIH: Direct inguinal hernia; IIH: Indirect inguinal hernia; LUP: Lateral umbilical plica; MUP: Medial umbilical plica.

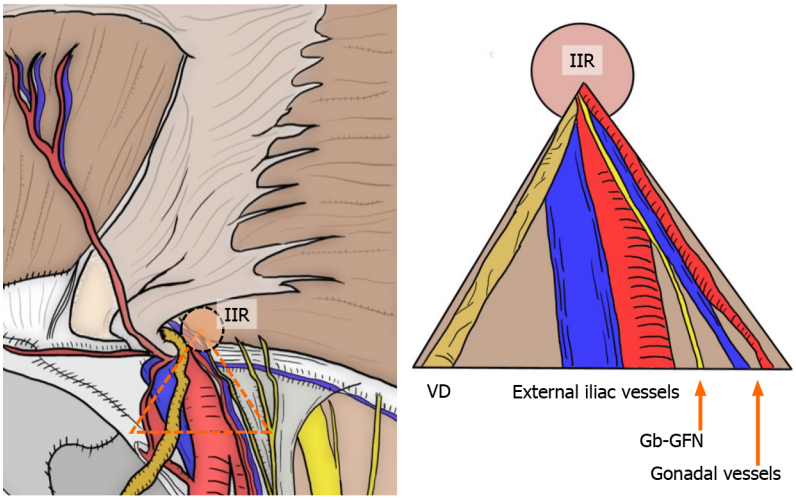

Figure 10 "Triangle of doom". The "triangle of doom" (orange dotted triangle) delineates the region between the VD and spermatic vessels. Currently, the "triangle of doom" is regarded as an inverted V-shaped area bound laterally by the gonadal vessels (in both sexes) and medially by the VD (in men and boys) or RL (in women and girls). Gb-GFN: The genital branch of the genitofemoral nerve; IIR: Internal inguinal ring; RL: Round ligament; VD: Vas deferens.

and obturator vessels[4,32-34]. The corona mortis is classically defined as an arterial anastomosis between the obturator and inferior epigastric arteries by means of the ectopic obturator artery[4,32-34]. The existence of the obturator artery results in annular communication among the inferior epigastric, common iliac, internal iliac, external iliac, and obturator arteries[4,32-34] (Figure 12). The frequency of this variant ranges from 20% to 30%[34]; moreover, several variants of anastomosing vascular branches may exist between the pubic artery/vein and the epigastric and obturator vessels[4,32-34]. Collectively, this variable deep venous circle is regarded as the "circulation of Bendavid." It is composed of the suprapubic, retropubic, deep inferior epigastric, and rectusial veins.4 These small vascular tributaries may form a network investing the pubic bone, Cooper's ligament, and the direct and femoral spaces[4,32-34]. These vessels and the underlying pubic bone are covered by a very thin membrane (*i.e.*, DVL) that should not be disrupted[4,32-34]. Brisk bleeding is difficult to control because of the dual vascular supply from the obturator and iliac vessels[4,32-34].

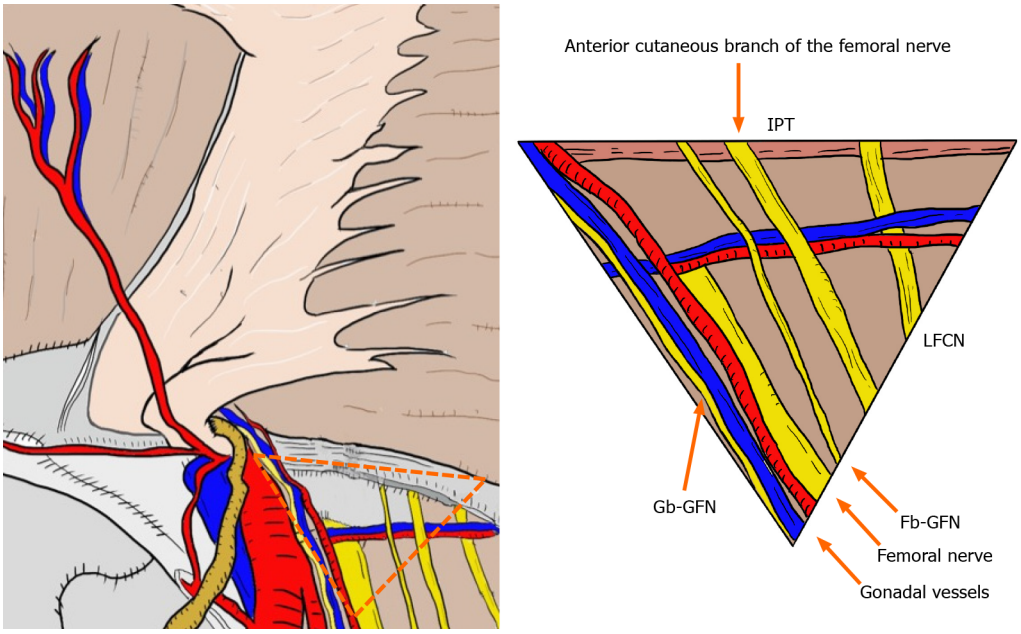

Figure 11 "Triangle of pain". The "triangle of pain" (orange dotted triangle) is defined as the area lateral to the testicular vessels and inferior to the iliopubic tract. The "triangle of pain" involves the femoral branch of the genitofemoral nerve, lateral femoral cutaneous nerve, femoral nerve, and anterior cutaneous branch of the femoral nerve. Subtle injury (or greater) to the nerves located within the "triangle of pain" is a risk factor for intractable pain. Fb-GFN: The femoral branch of the genitofemoral nerve; Gb-GFN: The genital branch of the genitofemoral nerve; IPT: Iliopubic tract; LFCN: Lateral femoral cutaneous nerve.

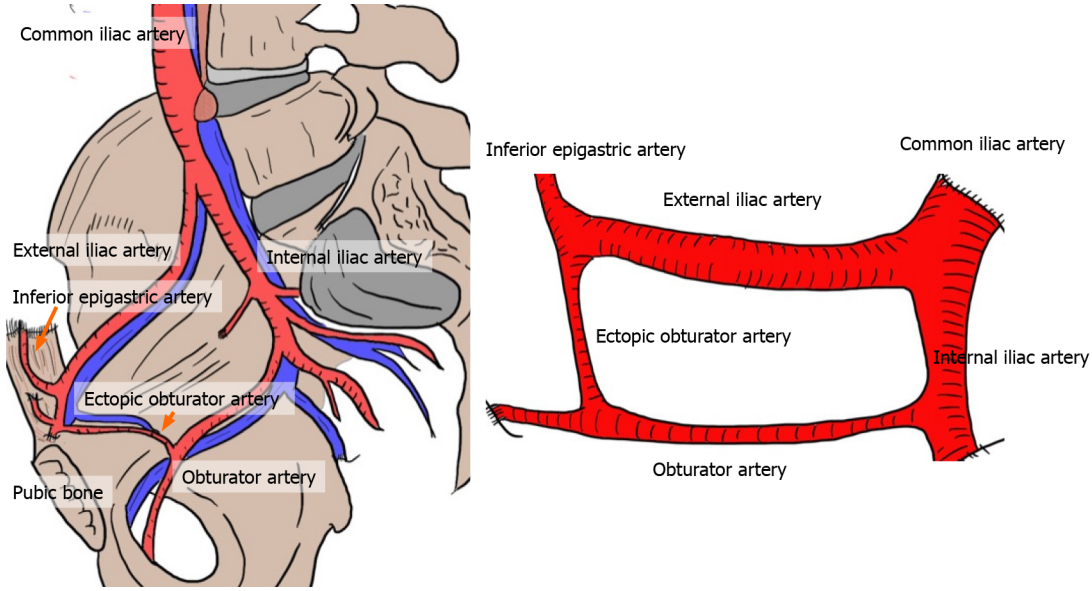

Figure 12 Corona mortis. The corona mortis is classically defined as the arterial anastomosis between the obturator and the inferior epigastric arteries by means of the ectopic obturator artery. The existence of the obturator artery results in annular communication among the inferior epigastric, common iliac, internal iliac, external iliac, and obturator arteries. Brisk bleeding is difficult to control because of the dual vascular supply from the obturator and iliac vessels.

PERSPECTIVE FOR THE FUTURE

Although TAPP and totally extraperitoneal repairs have a higher cost than conventional repair[4,195], the cost-effectiveness of TAPP repair has been documented in other medically advanced countries (*e.g.*, nations in Europe, as well as the United States and Japan)[196,197]. The direct cost and contribution margin are nearly equivalent between robotic and laparoscopic surgery[198], although robotic surgery results in a higher cost for unilateral groin hernia[199].

Robotic surgery is employed in the field of hernia repair[200-202]; the articulate robotic arms are advantageous for approaches without any visual disturbance by the medial umbilical ligament and bowels. Moreover, a singleport robotic surgery system

(da Vinci SP system; Intuitive Surgical, Inc., Sunnyvale, CA, United States) is currently available. General surgeons thus have a very promising frontier in this field.

Although the cost of biological mesh is still high[12,187,188], this mesh may resolve critical problems (*e.g.*, female agenesis, male sterility, neuropathy, and chronic pain) associated with synthetic mesh[203,204]. Currently, surgeons await less expensive, ethically responsible biological mesh to arrive on the world market. The advantages of biological mesh, compared with synthetic mesh, require long-term assessment in a large, multicenter, well-designed, and randomized controlled trial[205,206].

DISCUSSION

Some organizations (*e.g.*, the European Hernia Society and the Society of American Gastrointestinal and Endoscopic Surgeons) currently provide comprehensive inguinal hernia guidelines, and well-known surgeons have discussed herniology in detail[207-214]. However, many physicians may feel that no definitive criteria are available for the selection of surgical procedures. Indeed, the physician's choice, commercial basis, or cost-effective reasoning may be unchallenged in most instances. The surgical procedure should be carefully chosen based on sex (male or female) and age (pediatric, reproductive adult, or older adult). From the perspective of female fertility and male virility, female agenesis and male sterility should be avoided. Mesh material inherently causes varying degrees of postoperative atrophy[12,101,184-186]; moreover, mesh contact is associated with female agenesis, male sterility, neuropathy, and chronic pain[101,139,180-183]. Direct contact with mesh may also cause obstruction of the VD and SC[101]. Retroflexion of the uterus may cause female agenesis (Figure 5B). Only biological mesh can resolve these critical problems[203,204]. Although the TFR concept is important[11,64,90], careless use of synthetic mesh should be avoided in younger patients of reproductive age[180-183]. Potts' repair (accompanied by Koop's fixation in female patients) may be the optimal first choice for younger patients of reproductive age, as well as adolescents and children.

Based on its TFR concept and technical simplicity, so-called "mesh-plug hernioplasty" has spread worldwide[91-93]. However, the mesh should entirely reinforce the MO. Incomplete coverage of the MO results in long-term hernia recurrence after hernioplasty[94]. A DIH or femoral hernia may become a recurrent hernia, especially in female patients, who intrinsically have a wide pelvic space[94]. Female patients should undergo surgical repair at the PPS that fully covers the entire MO, as well as the obturator foramen[94], although "mesh-plug hernioplasty" is effective in men of advanced age[92].

Notably, from the perspective of technical skills, pediatric herniorrhaphy actually reflects the individual ability of each surgeon[8]. Antibiotics are not routinely administered after surgery[215]. Although antibiotics are not indicated for elective surgery using synthetic material[185], antibiotics may be appropriate if a trainee or resident performed surgery with a prolonged operative time and using synthetic material[216]. Administration of antibiotic prophylaxis in open mesh repair in high-risk patients in a low-risk environment is suggested[60,61].

Thorough knowledge of the inguinal anatomy is mandatory for successful herniorrhaphy and hernioplasty, and high-quality repair is required in the treatment of groin hernias. Surgical repair performed solely to prevent prolapse is inadequate and places patients with groin hernia at high risk. Important nerves and vessels should be carefully preserved. Hernia repair without careful consideration (*i.e.*, hernia repair that involves reinforcement of the abdominal wall alone) causes intractable symptoms, such as neuropathy and agenesis. Complacency may lead surgeons to presume that the learning curves for herniorrhaphy and hernioplasty are very short. High-quality repair is of utmost importance for groin hernias. Additionally, a combination of anatomical knowledge and high surgical skill level is crucial and indispensable for successful treatment of groin hernias. The frontier is large for general surgeons including residents.

CONCLUSION

Both anatomical recognition and a skillful technique are essential for successful herniorrhaphy and hernioplasty for groin hernias. In particular, in-depth anatomical knowledge of the nerves and vessels at the PPS and MO is a critical consideration. Surgeons must also avoid female agenesis, male sterility, neuropathy, and chronic

pain. The optimal surgical technique should be carefully chosen based on sex and age (pediatric, reproductive adult, or older adult).

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