Supra and infralevator neurovascular pathways to the penile corpora cavernosa

G. BENOIT[1,2,3], S. DROUPY[1,2,3], J. QUILLARD[3], V. PARADIS[3] AND F. GIULIANO[1,3]

[1] *Laboratoire de Chirurgie Expérimentale, Faculté de Médecine Paris Sud, CHU de Bicêtre,* [2] *Laboratoire d'Anatomie UER Biomédicale des Saints Pères, Paris, and* [3] *Service d'Urologie et Laboratoire d'Anatomie Pathologique, CHU de Bicêtre, Bicêtre, France*

(*Accepted 27 July 1999*)

ABSTRACT

The aim of this study was to provide a comprehensive description of both penile innervation and vascularisation. Eighty-five male cadavers were examined through gross and microscopic anatomical analysis. The pelvic nerve plexus had both parasympathetic and sympathetic roots. It was distributed to the external urethral sphincter giving rise to cavernous nerves which anastomosed in 70% of the cases with the pudendal nerve in the penile root. Accessory pudendal arteries were present in the pelvis in 70% of the cases, anastomosing in 70% of the cases with the cavernous arteries that originated from the pudendal arteries. Transalbugineal anastomoses were always seen between the cavernous artery and the spongiosal arterial network. There were 2 venous pathways, 1 in the pelvis and 1 in the perineum with a common origin from the deep dorsal penile vein. It is concluded that there are 2 neurovascular pathways destined for the penis that are topographically distinct. One is located in the pelvis and the other in the perineum. We were unable to determine the functional balance between these 2 anastomosing pathways but experimental data have shown that they are both involved in penile erection. These 2 neurovascular pathways, above and below the levator ani, together with their anastomoses, form a neurovascular loop around the levator ani.

Key words: Penis; vasculature; pudendal artery; pelvic plexus.

INTRODUCTION

The location of the penis at the junction of 2 anatomically distinct regions, i.e. the pelvis and the perineum, separated by the levator ani muscles, suggests that both supra and infralevator neurovascular pedicles are destined for the penis. According to classical anatomical data, the pathway for the neural proerectile fibres is represented by the cavernous nerves, the antierectile fibres arising from the lumbosacral sympathetic chain and travelling in the pudendal nerve (Giuliano et al. 1995) with somatic fibres. Arteries to the penis originate from the internal pudendal arteries and the venous drainage travels via the deep dorsal vein to the periprostatic venous plexus. Recent anatomical studies have suggested a more complex organisation of these structures, describing nervous connections in the penile 'hilum' and accessory pudendal arteries (Breza et al. 1989; Narayan et al. 1995).

We reviewed the results of 4 anatomical studies performed from 1987 to 1997 in our institution to provide a comprehensive overview of the neurovascular structures destined for the penis. We sought to provide evidence for 2 different neurovascular pathways, their origin in the internal iliac vessels, the sacral anterior roots, and the lumbosacral sympathetic chain, their termination in the penis and the existence of a loop surrounding the levator ani muscles.

MATERIALS AND METHODS

Specimens

Eighty-five fresh unfixed human male cadavers aged 48–90 y were studied. Causes of death and information about erectile function were unknown but none had undergone pelvic or penile surgery.

Correspondence to Professor G. Benoit, Service d'Urologie Centre, Hospitalo-Universitaire de Bicêtre, Avenue du Général Leclerc 94275, le Kremlin Bicêtre Cedex, France.

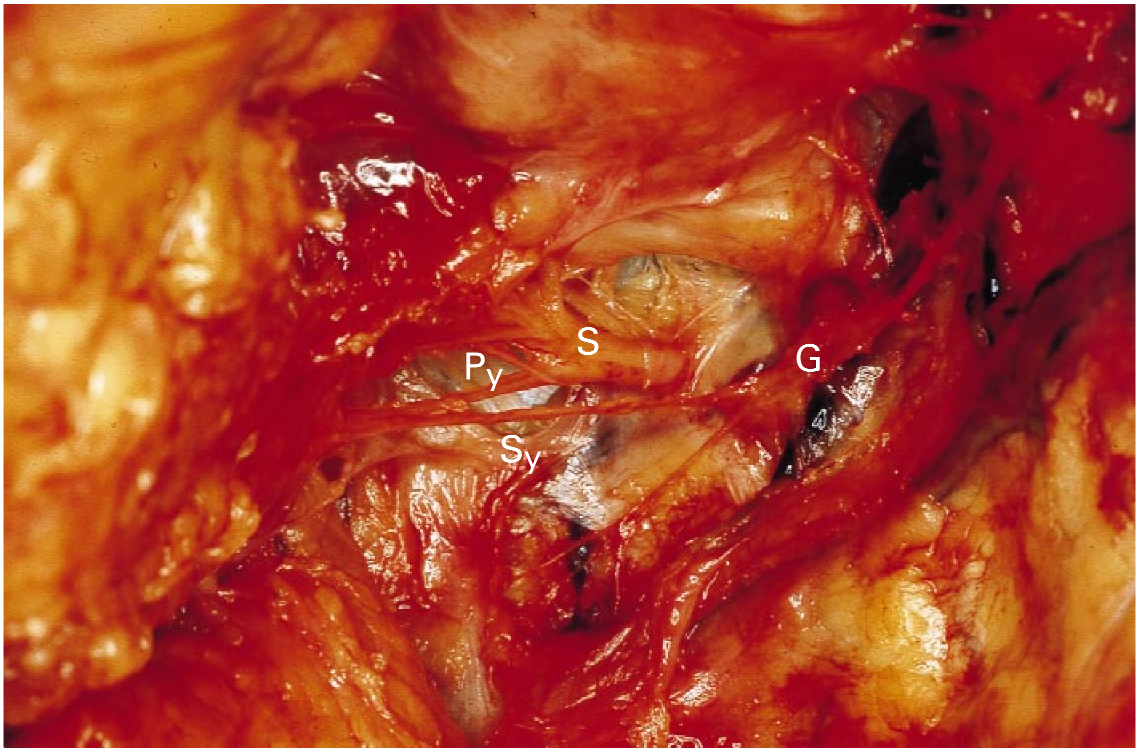

Fig. 1. Origin of the pelvic plexus. Human anatomical dissection. G, sympathetic ganglia; S, sacral root; Parasympathetic fibres (PS), S, sympathetic fibres.

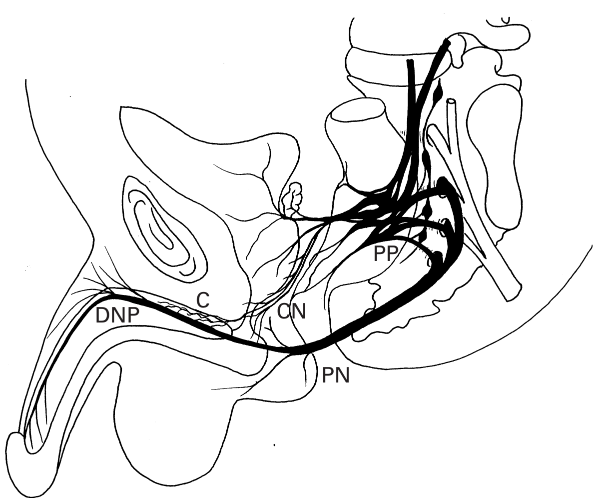

Fig. 2. Schematic representation of penile innervation. Left lateral view. PP, pelvic plexus; CN, cavernous nerves; PN, pudendal nerve; DNP, dorsal nerve of the penis; C, connecting fibres between the CN and the DNP.

Method of dissection

In all cadavers, pelvic dissection was carried out through a horizontal incision. An extraperitoneal approach was used to dissect the bladder, the prostate and branches of the internal iliac arteries. The pelvic fascia and pubovesical ligaments were sectioned. The penis was freed by cutting the suspensory ligaments as well as the attachment of the corpora cavernosa to the ischial bones. The periprostatic venous plexus and the deep dorsal vein of the penis were freed from the pubic bone and the pubic bone was then removed. The internal pudendal arteries were dissected to their terminal branches. The rectum, bladder, prostate, penis, perineum, and the pelvic and pudendal neuro-vascular pedicles were removed en bloc to allow ex situ dissection under a stereomicroscope.

Dissection of nerves, arteries and veins

Nerves. In 10 cadavers, the posterior roots of the pelvic plexus were dissected free from the end of the sacral sympathetic chain to visualise anastomoses between the sacral sympathetic chain and the pelvic nerve. Tissues were fixed in paraformaldehyde. Microscope examination at the optical level was performed on the fixed harvested structures of the sympathetic chain, pelvic nerve and pudendal nerve. Nerve sections (5 µm) were processed with haematin/eosin/saffran and Masson trichrome stains. These sections were also processed for histofluorescent staining (glyoxylic acid) and histochemical analysis (thiocholine) to differentiate catecholaminergic (sympathetic) and cholinergic (parasympathetic) nerves (de Latorre, 1980). In 20 other cadavers, the dissection was performed from the lateral aspects of the prostate to

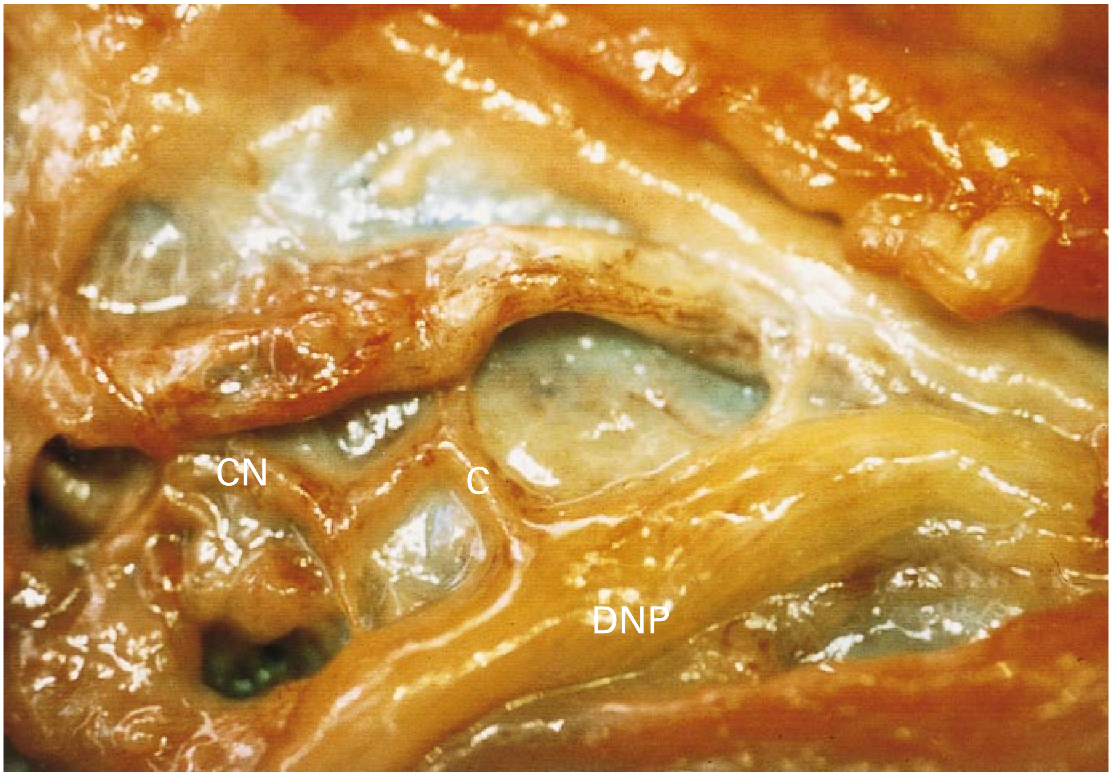

Fig. 3. Connecting fibres (C) between the cavernous nerves (CN) and the dorsal nerve of the penis (DNP). Human anatomical dissection at the level of the suspensory ligament.

the penis, in order to individualise all the branches of the pudendal and cavernous nerves, and to search for the presence of anastomoses between these 2 nerves.

Arteries

In 20 cadavers the terminal aorta was ligated, the right and left common femoral arteries were catheterised and the iliac arterial system was injected retrogradely with 500 ml of red-coloured latex, and dissected. The origin and distribution of penile arteries were studied after corporotomy and separation of the corpus spongiosum from the corpora cavernosa. Accessory pudendal arteries were defined as arteries nor originating from the terminal extrapelvic portion of the internal pudendal artery and supplying the penis through at least one of the following branches: bulbourethral, cavernous or dorsal arteries.

Veins

In 30 cadavers the corpora cavernosa and the 2 femoral veins were injected with 300 ml of blue-coloured latex in order to fill the whole pelvic venous system. The origin and distribution of perineal and pelvic veins were then studied.

Corpus spongiosum

Corpus spongiosum dissection was performed after latex injection in 5 cadavers. A catheter was introduced into the distal portion of the corpus spongiosum, and green-coloured latex was injected, following which dissection was performed.

RESULTS

Penile innervation

Supralevator pathways (*above levator ani*)

The proximal pelvic nerves comprised 2 kinds of fibres: those originating in the thoracolumbar and sacral sympathetic chain and those originating from sacral anterior roots (Fig. 1). Fine nerve bundles, 0.1–0.2 mm in diameter, arose from the caudal sacral ganglia combining with fibres derived from the sacral anterior roots to form the pelvic splanchnic nerve (Fig. 1). In 15% of cases, these rami originated in the 2nd sacral sympathetic ganglion, in 15% of cases from the 3rd sacral sympathetic ganglion and in 70% from the 4th sacral sympathetic ganglion. By using a histofluorescent stain (glyoxylic acid) and a histochemical reagent (thiocholine), the following findings were demonstrated. (1) In sections of sacral anterior rami glyoxylic acid staining was negative, whereas thiocholine labelled numerous cholinergic fibres, confirming the somatic and parasympathetic nature of these nerves. (2) In sections of branches of the sacral anterior rami which join the pelvic splanchnic nerves, glyoxylic acid staining was negative, whereas the thiocholine reaction was strongly positive (parasympathetic fibres) (Benoit et al. 1991). (3) In sections of efferent bundles arising from the sacral sympathetic ganglia, glyoxylic acid staining was strongly positive (adrenergic fibres) and the thiocholine reaction was weakly positive (cholinergic fibres). (4) Finally, sections of pelvic splanchnic nerves were positive with glyoxylic acid and with thiocholine immunostaining, demonstrating that the pelvic splanchnic nerves are composed of adrenergic and cholinergic (sympathetic and parasympathetic) fibres.

Various types of bundles arising from the pelvic plexus were identified: fibres to the rectum, bladder, seminal vesicles and prostate gland and, in addition, to the external urethral sphincter and inferior vesical arteries.

Two to 5 terminal branches destined to the corpora cavernosa could be identified in each side (Fig. 2). They were located posterior and lateral to the prostate gland, accompanied by thin arteries and veins. These nerve bundles reached the prostatic apex, covered by veins and pelvic fascia. Numerous variations were observed concerning the distribution and location of these nerve bundles. In 14 out of 20 cadavers the fibres ended in the external urethral sphincter where numerous sympathetic fibres were demonstrated histologically (Benoit et al. 1988). These fibres penetrated throughout the external urethral sphincter posterior and lateral to the membranous urethra. The nerve bundles were thin, surrounded by striated muscle fibres and covered by a dense venous network. However, the major part of the nerve fibres emerged from the pelvic plexus and penetrated the levator ani following the membranous urethra. These fibres constitute the cavernous nerves leaving the pelvis towards the perineum.

Infralevator pathways

The pudendal nerve left the pudendal (Alcock's) canal and gave rise within the layers of the middle perineal fascia to 1 to 3 neural bundles destined for the external urethral sphincter, the medial part of levator ani and the deep transversus perinei muscles. Further distally, it reached the medial surface of the crura of the corpus cavernosum penetrated into the root of the penis above the blood vessels, and became the dorsal nerve of the penis.

In the penis

The cavernous nerves reached the dorsal surface of the corpora cavernosa. Some fibres penetrated the spongiosum of the bulb but most spread out on the surface of the corpora cavernosa. They were located in close contact with the tunica albuginea, constituting the deeper element covered by cavernous arteries, penile dorsal nerve branches and deep dorsal vein of the penis.

The cavernous nerves gave rise to 3 types of terminal branches: They were mainly grouped in fascicles following the cavernous arteries and penetrated the tunica albuginea of the corpora cavernosa obliquely in the same opening; other very thin branches followed the dorsal arteries. Three to 5 anastomotic bundles were identified on each side of each specimen connecting the cavernous nerves to the dorsal nerve of the penis (Figs 2, 3). These connecting fibres ended at a sharp angle in the dorsal nerve. They joined the dorsal nerve at regular intervals. In 2/20, the anastomoses joined the dorsal nerve in the same area, constituting a ganglion-like structure. The anastomoses were only observed on the fixed part of the penis (from the hilum to the suspensory ligament area) and not on the free part (pars pendula).

The cross-sections performed on these neural anastomoses displayed myelinated fibres (> 2 μm) with Masson trichrome staining.

The dorsal nerve coursed longitudinally on the dorsal surface of the corpora cavernosa, partially covering the dorsal artery. About half of the fibres were destined for the penile foreskin, perforating the penile fascia at the level of the suspensory ligaments. They gave several fan-shaped branches surrounding the corporal surface towards the glans. Few variations were observed concerning the course and distribution of the dorsal nerve: the right and left nerves were usually symmetric in size but the number of dividing branches could differ between sides.

The arterial system

The origin and distribution of penile arteries was found to be extremely variable.

Supralevator pathways

In 20 cadavers, 33 accessory pudendal arteries (APA) were found. At least 1 APA was found in 17 and 2 in 9 specimens. APAs originated from the inferior vesical artery in 15/33, obturator artery in 12/33, and external pudendal artery in 6/33.

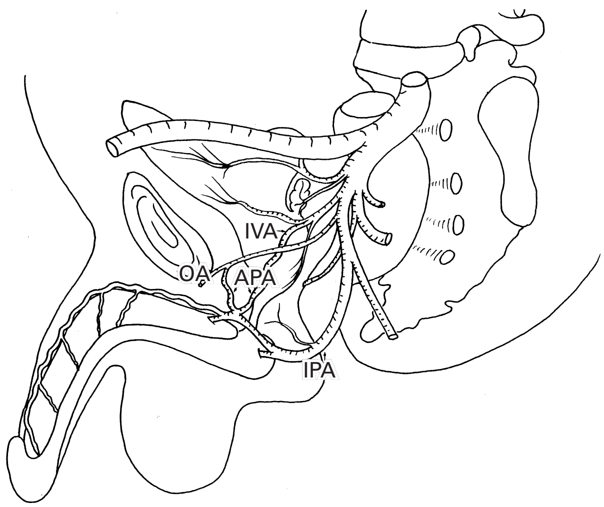

Fig. 4. Schematic representation of the penile arterial supply. Left lateral view. IPA, internal pudendal artery; APA, accessory pudendal artery; IVA, inferior vesical artery; OA, obturator artery.

APAs originating from the inferior vesical artery ran within the perivesical fat, on the anterolateral side of the prostate covered by prostatic veins and pubovesical ligaments. Thus in this case the APA formed the deepest vascular element in close contact with the prostate. When arising from an obturator artery, APAs ran transversely under the pelvic fascia on the surface of levator ani and joined the prostatic apex just behind the pubovesical ligaments. They then penetrated the periprostatic venous plexus and were located laterally in contact with the apex of the prostate. In this case, the APA was in very close contact with the insertion of the pubovesical ligament. The APAs usually joined the cavernous nerves in the lateral prostatic bundles and followed the membranous urethra below the pubic bone along with the cavernous nerves entering the root of the penis.

Some APAs arose from external pudendal arteries, coursed around the corpus cavernosum, and ended in a dorsal artery. In 1 case, we found a spongiosa artery, arising from an external pudendal artery, perforating the corpus spongiosum at the mid part of the penis.

The APAs originating from inferior vesical arteries gave branches to the bladder, prostate and external urethral sphincter. When these accessory penile arteries were present, the main arterial supply of the urethral sphincter arose from them (Fig. 4). After piercing the levator ani, the APAs usually gave multiple branches, with 70% of them being cavernous arteries, destined usually for both corpora.

According to the variable occurrence and importance of APAs we propose the following classification: type I: when the penile arteries arose exclusively from internal pudendal arteries: 3/20 (mean age: 78 ± 5 y); type II: when the penile arteries originated from both accessory and internal pudendal arteries, 14/20 (mean age: 72 ± 7 y); type III: when the penile arteries originated exclusively from APAs: 3/20 (mean age: 62 ± 13 y) (Fig. 5). In addition we examined for the presence of atherosclerotic lesions and sought correlations between the presence of APAs and atheromatous disease. In 12 cases, APAs were present and atherosclerotic occlusion of the internal pudendal arteries was not observed (mean age: 68 ± 8 y) while in 5 cases the APAs were present and the internal pudendal arteries were occluded by atheromatous disease: (mean age: 78 ± 8 y) (Droupy et al. 1997).

Infralevator pathways

Internal pudendal arteries left the pudendal canal and were located in the medial aspect of the corpora cavernosa crura, giving rise to the bulbourethral artery. Its terminal branches then entered the root of the penis and connected with branches of the APAs or gave rise to ascending anterior vesical and pre and retropubic arteries.

In the penis

When both internal pudendal and APA were present on the same side, anastomoses between them occurred in 70% of the cases in the root of the penis. We found many anastomoses between the right and left arterial supplies within the penis. First, in the penile root the right and left cavernous arteries usually communicated and, sometimes, fused into a large cavernous artery which penetrated the tunica albuginea and divided into the right or left corpora. More often, the cavernous artery penetrated into the corpora and gave rise to a proximal branch destined for the crus. The arterial supply of the distal part (pars pendula) was usually provided by a single large cavernous artery on each side.

The cavernous artery ran into the central part of the cavernous tissue giving rise to 2 kinds of branches: helicine arteries, and 3–7 branches forming with them a right angle, then crossing the ventral part of the corpora, perforating the tunica albuginea to end by anastomosing with spongiosa arteries.

It is noteworthy that these cavernosum-spongisum shunt arteries were observed in all specimens so far examined. Their outer diameter varied from 0.3 to 1 mm. These shunts did not give rise to other branches either to the sinusoidal spaces or the circumflex arteries, or to arteries of the glans. In 3 specimens, 1 branch arose from the dorsal artery and penetrated and supplied the distal part of the corpus cavernosum.

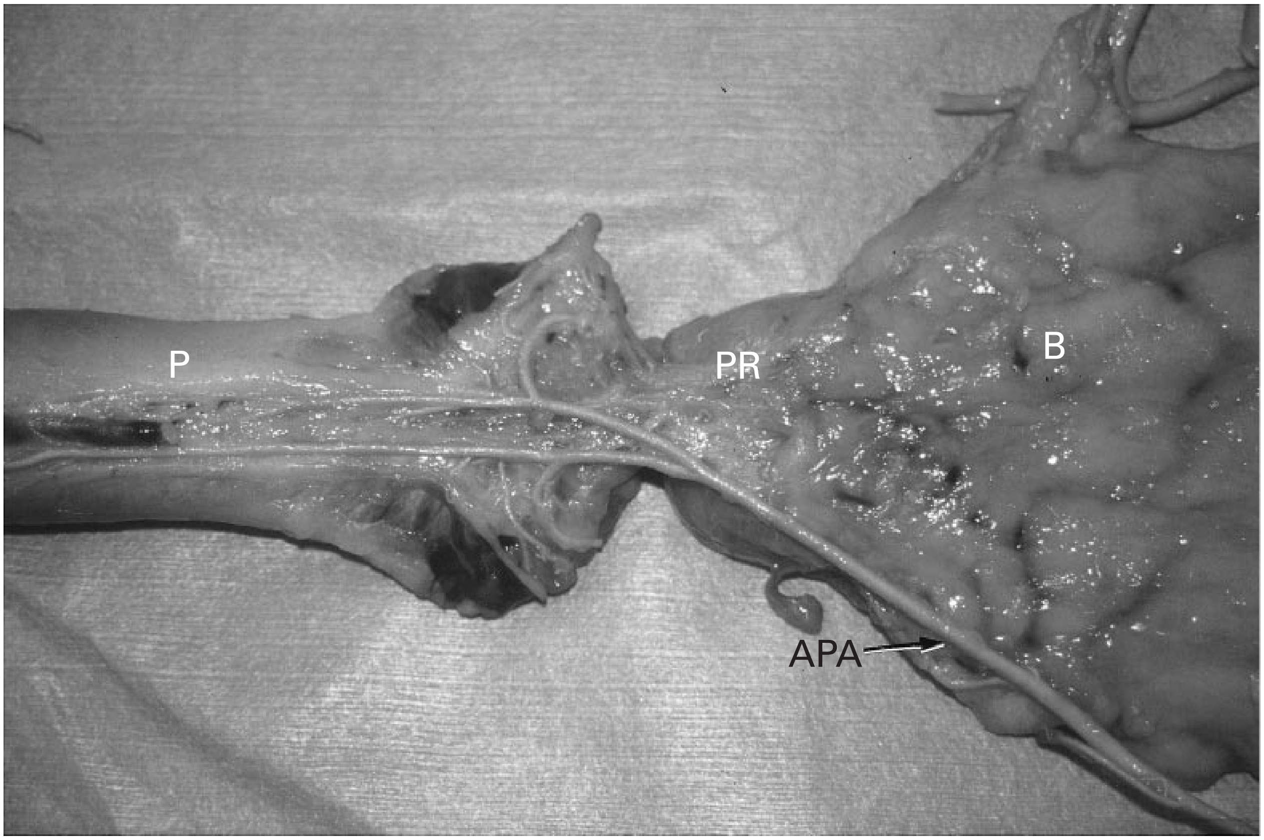

Fig. 5. Accessory pudendal artery (APA) arising from an inferior vesical artery (type III). Human anatomical dissection after arterial cast. The APA is the exclusive arterial supply of the penis (P). PR, prostate; B, bladder.

Venous system

In the penis

The superficial drainage was located between the deep and superficial fascia of the penis. These veins united at the penile crus, forming 1 or 2 superficial dorsal veins which drained into the major saphenous veins. Multiple small veins issuing from the glans drained into the deep dorsal vein. Numerous emissary veins draining the corpus spongiosum and corpora cavernosa, perforated the tunica albuginea, emptied into the circumflex veins and coursed around the lateral surface of the corpora cavernosa to the deep dorsal vein.

Infralevator pathways

Emissary veins from the proximal third of the penis formed the cavernous veins, ran medially in the hilum penis above the arteries and nerves and drained into the internal pudendal veins. Veins of the penile crus and bulbospongiosa veins also drained into the internal pudendal veins directly or via the cavernous veins. The deep dorsal vein coursed along the groove between the 2 corpora cavernosa and entered the pelvis through the medial suspensory ligament to drain into the preprostatic venous plexus.

The corpora drained into 2 venous networks. The circumflex and dorsal veins drained into the preprostatic plexus and the deep drainage system (i.e. the cavernosal crural veins and bulbospongiosal veins) drained into the pudendal veins finally joining the internal iliac veins.

Beneath the levator ani, the internal pudendal veins coursed along the ischiopubic branches.

Supralevator pathways

The preprostatic plexus represented the anterior venous crossroads. It received the deep dorsal penile vein, which bifurcated to form its inferior angle. This plexus comprised 2 outflows: a superficial one, the preprostatic outflow receiving the anterior vesical vein and a deeper one, the presphincteric one. The inferior angle of the preprostatic plexus was common to these 2 outflows, and corresponded to the division of the deep dorsal penile vein, representing the real root of this plexus. Thus the preprostatic plexus has 2 outflows, one on the surface draining into the lateral prostatic vein and a deeper one draining into the internal pudendal vein.

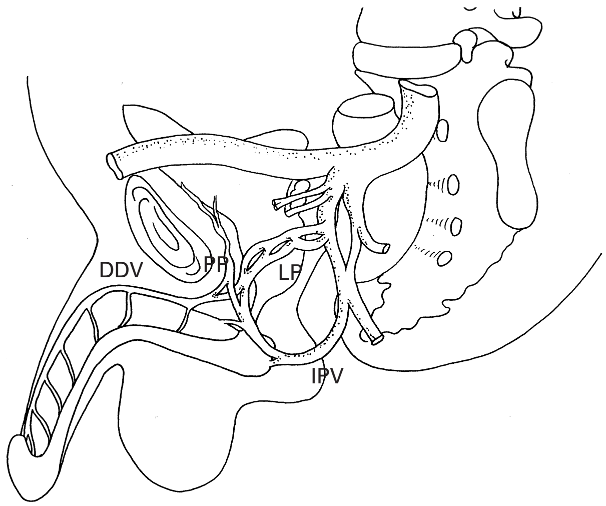

Fig. 6. Schematic representation of the penile venous drainage. Left lateral view. IPV, internal pudendal vein; PP, preprostatic venous plexus; LP, lateroprostatic veins; DDV, deep dorsal vein of the penis.

Numerous variations occurred with one or other of the layers of the preprostatic plexus predominating: when the surface layer was predominant, the anterior vesical vein was large, when the deep layer predominated, the anterior vesical vein was missing. The inferior angle was always present and the internal pudendal and lateral prostatic vein merged from the lateral angles of the plexus.

Accordingly, the erectile tissue drained into 2 venous channels: a supralevator pathway into the lateral vesicoprostatic veins and an infralevator pathway into the internal pudendal veins. These 2 veins formed the anterior trunk of the internal iliac vein where they ended (Figs 6, 7) (Benoit et al. 1984).

DISCUSSION

We provide evidence for connections between the cavernous nerves and the dorsal nerve of the penis, the arterial supply to the penis arising from accessory and internal pudendal arteries, constant anastomoses between cavernous and urethral arteries and constant anastomoses between pelvic and perineal veins at the level of the preprostatic plexus.

Nerves

The pelvic plexus (inferior hypogastric plexus) is an integrating centre which acts as a relay between preganglionic axons arising from the hypogastric and pelvic nerves and postganglionic neurons destined for all the pelvic viscera including the penis (Calabrisi, 1956).

Sympathetic fibres to the pelvis arise from the thoracolumbar spinal cord (Pick & Sheehan, 1946), and then reach the pelvic plexus via 2 outflows, the

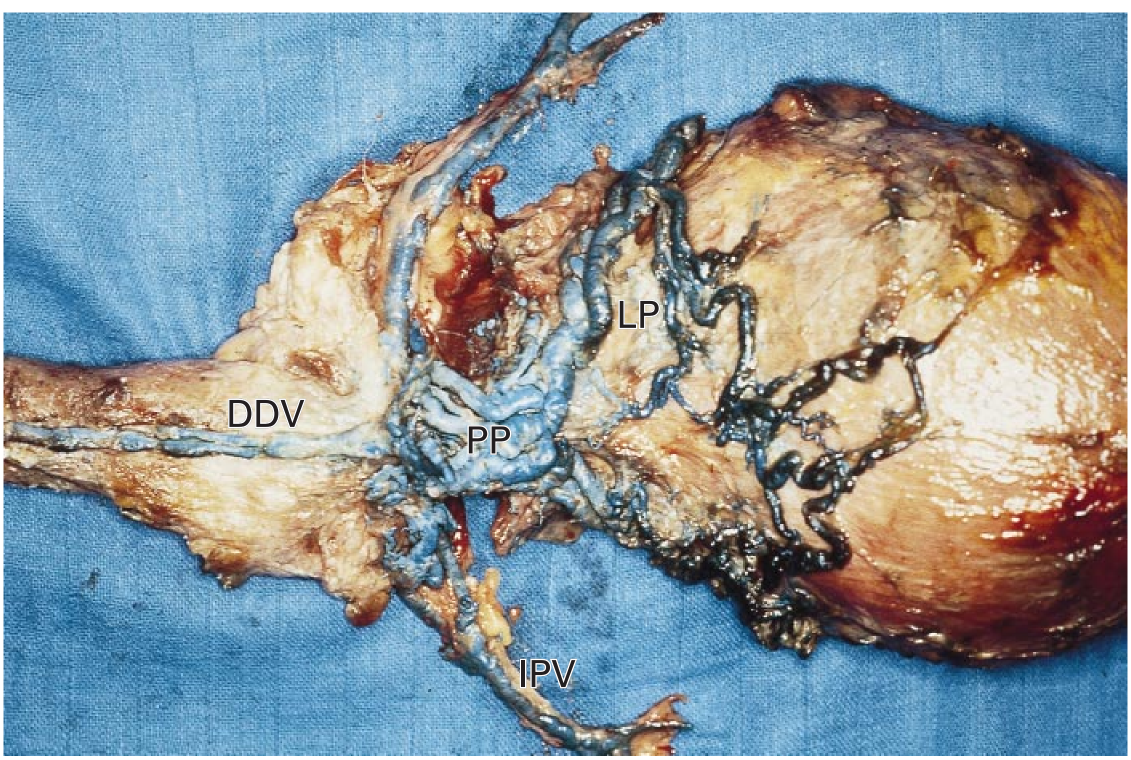

Fig. 7. Penile venous drainage. Human anatomical dissection after cast with latex. IPV, internal pudendal vein; PP, preprostatic venous plexus; LP, lateroprostatic veins; DDV, deep dorsal vein of the penis.

prevertebral hypogastric nerve (Latarjet & Bonnet, 1913; Learmonth, 1931; Kuo et al. 1984), and the paravertebral sacral sympathetic chain and further out the pelvic nerves. Parasympathetic fibres are conveyed by the pelvic nerves from the sacral spinal cord to the pelvic plexus (Kokotas et al. 1978). In the human male, earlier cadaver dissections demonstrated that small trunks issued from the sacral sympathetic chain, joining the pelvic nerves. Cordier & Colouma (1933) found such rami derived from S1 in 5%, S2 in 15%, S3 in 100%, S4 in 100% and S5 in 25% of cases. We have provided histochemical evidence for the presence of both cholinergic and adrenergic nerve fibres in the pelvic roots of the pelvic plexus (Benoit et al. 1991).

Thus the pelvic nerve is a mixed autonomic nerve containing both efferent sympathetic and parasympathetic fibres (Huselboch & Coggeshall, 1982; Downie et al. 1984; Kuo et al. 1984; Lepor et al. 1985).

The hypogastric nerves are classically considered as sympathetic pathways (Langley & Anderson, 1805–1806; Benoit et al. 1987; de Groat et al. 1993). However, stimulation of the superior hypogastric plexus can result either in erection or detumescence (Brindley, 1988).

The role of the pelvic plexus is mainly proerectile in that electrical stimulation of the pelvic plexus and of the cavernous nerves causes erection. Classically efferent and afferent penile innervation is conveyed by cavernous nerves and terminal branches of the pudendal nerves. The cavernous nerves convey sympathetic (de Groat et al. 1993; Gil Vernet, 1964) and parasympathetic fibres originating from the pelvic plexus (Downie et al. 1984). Pudendal nerves arise from the sacral plexus and contain motor fibres destined for the perineal muscles, sensory fibres and also probably sympathetic fibres as has been shown in male rats (Katagiri et al. 1986; McKenna & Nadelhaft, 1986; Lavoisier et al. 1988).

The role of the sympathetic fibres of the cavernous nerve remains unknown as the antierectile response elicited in animals by stimulation of the sympathetic chain was still present after unilateral or bilateral section of the cavernous nerves near their origin (Giuliano et al. 1995).

Narayan et al. (1995), in human cadavers, described extensive communications between branches of the dorsal nerve of the penis and cavernous nerves which began 1 cm distal to the origin of sphincteric branches of the pudendal nerve and continued along the penile shaft. The nature of these branches has not been determined. These anastomoses are neuronal as we showed using histological labelling, but our material, procured from unfixed cadavers, did not allow us to perform immunochemistry so we could not identify them neurochemically.

Muller (1836) described a few fine branches of the pudendal nerve accompanying the cavernous nerves as they pass over the anterior margin of levator ani towards the urethral sphincter. Concerning 'sphincteric branches' arising from the pelvic plexus, we do not know if they innervate the leiomyosphincter or the rhabdomyosphincter. But their course indicates that they could be injured directly during apical and lateral surgical dissection of the prostate. Accordingly, we propose that a nerve-sparing procedure during radical prostatectomy is not only important for erection but also probably for continence.

Results of nerve-sparing surgery on penile erection depend on the technique and the patient's age (Walsh & Donker, 1982; Lue et al. 1983, 1984; Walsh et al. 1983; Weiss et al. 1985). Spontaneous improvement may be explained by incomplete cavernous nerve lesions (because this nerve consists of numerous separate fascicles), or by possible reinnervation by other pathways such as from the contralateral or perhaps the pudendal nerve. In addition, the fibres arising from the pelvic plexus destined for the external urethral sphincter may also be involved in the autonomic control of leiomyosphincter motility during ejaculation.

Sympathetic efferents have been identified in the dorsal penile nerve. In the rat, the sensory branch of the pudendal nerve contains a large number of sympathetic postganglionic axons originating in the sympathetic chain (Halata & Munger, 1986). The physiological role of this sympathetic component is antierectile. One might expect that these fibres would reach distal penile targets and represent a pathway for local vasomotor control. Antierectile fibres from the sympathetic chain have been shown to reach the penis through the pudendal neve (Bradley & Teague, 1977; Sachs, 1982). Dorsal penile nerve afferents convey sensory information from the penis and are considered responsible for various sexual responses.

There are 2 nervous pathways one supralevator, i.e. the cavernous nerve, and the other infralevator, i.e. the pudendal nerve, which are connected to each other at their origin proximally at the level of the anterior sacral roots and the sympathetic chain, and distally at the level of the penile root. Do these proposals have any clinical interest for pelvic surgery? We do not know if these anastomoses in the penile root could be supplementary between the 2 pathways in cases of cavernous nerve lesions. Nevertheless, Sachs (1982) described partial glans erection after bilateral cavernous nerve section; this could suggest that proerectile fibres of the glans may travel through the pudendal nerve.

Physiologically, the autonomic supralevator pathway is mostly proerectile and the infralevator anti-erectile. A better understanding of these anastomoses is warranted to clearly understand the pathophysiology of erectile failure following surgical lesions of the pelvic plexus or the cavernous nerves.

Arteries

During embryogenesis, arterial development follows nerve axis growth. The nerve plexi remain stable but some vessels may partially or totally regress. This rule seems to be applicable to the penis and should explain penile neurovascular variations (McKay, 1889).

For centuries, many authors have considered that the origins of penile arteries were the inferior vesical arteries (Soemmering, 1800; Harrison, 1825; Levi, 1900; Zuckerkandl, 1900; Parson, 1902; Poirier & Charpy, 1912; Dubreuil-Chambardel, 1925; Adachi, 1928; Juskiewenski et al. 1982). Quain (1882) referred to them as the 'accessory pudic artery'. Levi (1900) dissected 60 male cadavers and 20 fetuses where accesory pudendal arteries were present in 30% of the cadavers, and in 25% of the fetuses. More recently, Breza et al. (1989) dissected 10 formalin preserved male cadavers: accessory pudendal arteries were found in 7.

In our experience, more than 70% of the accessory pudendal arteries arise from inferior vesical arteries, more than 70% of the penile arteries having a supralevator origin are cavernous arteries, and anastomoses between accessory pudendal and pudendal arteries are present in approximately 70% of the cases (Droupy et al. 1997).

During pharmacoarteriography, the presence of an accessory pudendal artery is easy to detect during erection but uncertain in the flaccid state; furthermore, opacification of the whole internal iliac arterial system is necessary to show evidence of accessory penile branches.

According to different authors, accessory pudendal arteries exist in 6–12% of cases, accessory cavernosal branches in 29–57% and cavernous arteries are absent in 2–4% of cases (Ginestie, 1976; Bookstein & Lang, 1987; Jarow et al. 1993). In order to explain contrary findings in terms of frequency between radiological data and cadaver dissection series, some authors have postulated that accessory pudendal arteries (APA) might be revascularisation pathways related to atheromatous obstruction of the internal pudendal arteries the incidence of which increases with age (Ginestie, 1976). The fact is that anastomoses of variable importance exist normally between supra and infralevator arteries. We have provided evidence that APAs are not only revascularisation pathways but in most cases congenital variations. APAs from inferior vesical and obturator arteries could be injured during pelvic surgery and especially radical prostatectomy. Consequences for erectile dysfunction are a subject of discussion as their role has never been proven for erection.

Concerning the functional aspect of supralevator penile arteries, our data suggest that they are essential for erection if they are the main supply for the corpora cavernosa. In these cases, radical prostatectomy will result in an acute decrease of penile inflow (Abosief et al. 1989, 1994). When both supra and infralevator arteries supply the penis, the respective participation of each source is unquantifiable so that consequences of an iatrogenic injury are unpredictable (Polascik & Walsh, 1995).

We did not identify the description by Wagner et al. (1982, 1985) and Juskiewenski et al. (1982) of spongiocavernous shunts between the cavernous arteries and the spongious corpora. No arteriovenous or arteriotissular anastomoses were seen. On the contrary our results show constant arterioarterial anastomosis between the cavernous arteries and the spongiosal arterial network.

Cavernospongiosum arterial shunts are permeable during the tumescence phase of erection during intraurethral pharmacologically induced erections (Bookstein & Lang, 1987; Padma-Nathan et al. 1996). The direction of the flow is from the cavernous artery to the spongiosum artery during physiological erection and probably from the spongiosal to the cavernous artery during intraurethral pharmacologically induced erections. Hypotheses concerning the role of these arteries in pathological situations have to be considered. Firstly, atherosclerosis of the cavernospongiosum arteries could be implicated in spongiosal and glans flaccidity during erection. On the other hand a persistent flow into these arteries during erection may result in erectile dysfunction. Finally, some urethral surgery may injure cavernospongiosum shunts during corpus spongiosum dissection.

Veins

In every case there are both supra and infralevator venous flow pathways. They are in different pressure ranges, the supralevator one being in the abdominal area, reflecting the pressure of the different pelvic organs (Benoit et al. 1984). The infralevator venous flow is into the perineal area. Recently, an intrapelvic venous congestion syndrome has been reported related to preprostatic venous incompetence (Kamoi et al. 1996).

Supra and infralevator venous pathways draining the penis have been well known since described by Santorini in 1739 (Santorini, 1739; Farabeuf, 1905). In 1947, when Millin raised the advantages of retropubic prostatectomy, Beneventi & Noback (1949) published an anatomical study of the blood vessels of the prostate describing the anatomy of the lateral vesicoprostatic venous plexus and its relations to the venous drainage of the penis (Keeler, 1980; Kaufman & Katske, 1982).

The large anterior anastomosis of the preprostatic plexus allows the ligation of the supralevator veins with no adverse effect on erection, because it does not interrupt the infralevator drainage. The ligation of the deep dorsal vein has a variable effect because it does not interrupt the crural vein ending in the pudendal vein (Kim & McVary, 1995).

CONCLUSIONS

There are 2 different neurovascular pathways for the penis, one above and the other below levator ani. Some components show variations (arteries) while others are constant (nerves and veins). These 2 pathways have a looped shape with a common origin and a common ending in front of the levator ani. Our data demonstrate the anatomical reality of a neurovascular penile loop connected from the pelvic region, to the hilum of the penis and probably to the erectile corpora. Connections between the right and left pedicles exist for the nerves, arteries and veins in the hilum of the penis. Physiologically and anatomically the supra levator nerves are mostly proerectile and the infralevator ones antierectile. This anatomical system seems to be very flexible allowing some compensatory connections in case of neurovascular lesion. A better understanding of these pathways could help in assessing the functional role of the accessory cavernous arteries and nerve anastomoses. This plasticity hypothesis may enable the development of techniques of penile rehabilitation after pelvic surgery (Montorsi et al. 1997).

ACKNOWLEDGEMENT

The authors gratefully acknowledged Dr K. E. McKenna for critical reading of the manuscript.

REFERENCES

ABOSEIF S, BREZA J, ORVIS BR, LUE TF, TANAGHO EA (1989) Erectile response to acute and chronic occlusion of the internal pudendal and penile arteries. *Journal of Urology* **14**, 398–402.

ABOSEIF S, SINOHARA K, BREZA J, BENARD F, NARAYAN P (1994) Role of penile vascular injury in erectile dysfunction after radical prostatectomy. *British Journal of Urology* **73**, 75–82.

ADACHI B (1928) *Das Arteriensystem der Japaner*, Band II, pp. 122–126. Kyoto: Verlag der Kaiserlich-Japanishen Universität zu Kyoto.

BENEVENTI FA, NOBACK GJ (1949) Distribution of the blood vessels of the prostate gland and urinary bladder, application to the retropubic prostatectomy. *Journal of Urology* **62**, 663–671.

BENOIT G, DELMAS V, GILLOT C (1984) Le plexus veineux de Santorini. *Annales d'Urologie* **16**, 393–396.

BENOIT G, DELMAS V, GILLOT C, JARDIN A (1987) The anatomy of erection. *Surgical and Radiological Anatomy* **9**, 263–272.

BENOIT G, QUILLARD J, JARDIN A (1988) Anatomical study of the infra-montanal urethra in man. *Journal of Urology* **139**, 866–868.

BENOIT G, QUILLARD J, MONOD P, GIULIANO F, BARON JC, MOUKARZEL M et al. (1991) Identification of the afferents of the pelvic plexus. *Progrès en Urologie* **1**, 67–73.

BOOKSTEIN JJ, LANG EV (1987) Penile magnification pharmacoarteriography: details of intrapenile anatomy. *American Journal of Radiology* **148**, 883–888.

BRADLEY W, TEAGUE C (1977) Synaptic events in pudendal motoneurons in the cat. *Experimental Neurology* **56**, 237–240.

BREZA J, ABOSEIF SR, ORVIS BR, LUE TF, TANAGHO EA (1989) Detailed anatomy of penile neurovascular structures: Surgical significance. *Journal of Urology* **141**, 437–443.

BRINDLEY GS (1988) The Ferrier lecture, 1986. The actions of parasympathetic and sympathetic nerves in human micturition, erection and seminal emission, and their restoration in paraplegic patients by implanted electrical stimulators. *Proceedings of the Royal Society of London B, Biological Sciences* **235**, 111–120.

CALABRISI P (1956) The nerve supply of the erectile cavernous tissue of the genitalia in the human embryo and foetus. *Anatomical Record* **125**, 713–723.

CORDIER P, COULOUMA (1993) Les nerfs érecteurs. *Bulletin de l'Association des Anatomistes* (Paris) **143**, 144–199.

DE GROAT WC, BOOTH AM, MAGGI CA (1993). *The Autonomic Nervous System. Neural Control of Penile Erection*, pp. 465–513. London: Hardwood.

DE LATORRE JC (1980) Improved approach to histofluorescence using the SPG method for tissue monoamines. *Journal of Neuroscience Methodology* **3**, 1–7.

DOWNIE JW, CHAMPION JA, NANCE DM (1984) A quantitative analysis of the afferent and extrinsic efferent innervation of specific regions of the bladder and urethra in cats. *Brain Research Bulletin* **12**, 735–741.

DROUPY S, BENOIT G, GIULIANO F, JARDIN A (1997) Penile arteries in humans. Origin, distribution, variations. *Surgical and Radiological Anatomy* **19**, 161–167.

DUBREUIL-CHAMBARDEL L (1925) *Variations des Artères du Pelvis et des Membres Inférieurs*. Paris: Masson.

FARABEUF LH (1905) *Les Vaisseaux Sanguins des Organes Génito-urinaires du Périnée et du Pelvis, I*. Paris: Masson.

GIL VERNET S (1964) L'innervation somatique et végétative des organes génito urinaires. *Acta Urologica Belgica* **3**, 265–293.

GINESTIE JF (1976) *L'Exploration Radiologique de l'Impuissance*, pp. 25–58. Paris: Maloine.

GIULIANO F, RAMPIN O, BENOÎT G, JARDIN A (1995) Neural control of penile erection. *Urology Clinics of North America* **22**, 747–766.

HALATA Z, MUNGER B (1986) The neuroanatomical basis for the protopathic sensibility of the human penis. *Brain Research* **37**, 205–230.

HARRISON R (1825) *Surgical Anatomy of the Arteries of the Human Body*, *II*. Dublin: Longman.

HULSEBOCH CE, COGGESHALL RE (1982) An analysis of the axon populations in the nerves of the pelvic viscera in the rat. *Journal of Comparative Neurology* **211**, 211–220.

JAROW J-P, PUGH VW, ROUTH WD, DYER RB (1993) Comparison of duplex ultrasonography to pudendal arteriography. *Investigative Radiology* **28**, 806–810.

JUSKIEWENSKI S, VAYSSE PH, MOSCOVICI J, HAMMOUDI S, BOUISSOU E (1982) A study of the arterial blood supply of the penis. *Anatomia Clinica* **4**, 101–107.

KAMOI K, TERASAKI T, KOJIMA M, WATANABE U (1996) The possible use of transrectal sonography in predicting venous congestion syndrome as revealed by three dimensional magnetic resonance venography. *Journal of Urology* **155** (#463), p426A.

KATAGIRI T, GIBSON SJ, SU HC, POLAK JM (1986) Composition and central projections of the pudendal nerve in the rat investigated by combined peptide immunocytochemistry and retrograde fluorescence labelling. *Brain Research* **372**, 313–322.

KAUFMAN JJ, KATSKE FA (1982) Simple technique to control venous bleeding during radical retropubic prostatectomy and cystectomy. *Urology* **3**, 309–313.

KEELER LL (1980) Cutting maneuver for puboprostatic ligaments. *Urology* **16**, 521–523.

KIM ED, McVARY KT (1995) Long-term results with penile vein ligation for venogenic impotence. *Journal of Urology* **153** (3), 655–658.

KOKOTAS NS, SCHMIDT RA, TANAGHO EA (1978) Motor innervation of the urinary tract studied by retrograde axonal transport of protein. *Investigative Urology* **16**, 179–182.

KUO DC, HISAMITSU T, DE GROAT WC (1984) A sympathetic projection from sacral paravertebral ganglia to the pelvic nerve and to postganglionic nerves on the surface of the urinary bladder and large intestine in the cat. *Journal of Comparative Neurology* **226**, 76.

LANGLEY JN, ANDERSON HK (1805–1806) The innervation of the pelvic viscera and adjoining viscera. The external generative organs. *Journal of Physiology* **19**, 85–121.

LATARJET P, BONNET P (1913) Le plexus hypogastrique chez l'homme. *Lyon Chirurgical* **9**, 221–244.

LAUX G, COURTY A (1938) Étude anatomique des branches efférentes viscérales de la chaine sympathique sacrée. *Annales d'Anatomie Pathologique* **15**, 546–552.

LAVOISIER P, PROULX J, COURTOIS F, DE CARUFEL F, DURAND LG (1988) Relationship between perineal muscle contractions, penile tumescence and penile rigidity during nocturnal erections. *Journal of Urology* **139**, 176–181.

LEARMONTH JR (1931) A contribution to the neurophysiology of the urinary bladder in man. *Brain* **54**, 147–176.

LEPOR H, GREGERMAN M, CROSBY R, MOSTOFI FK, WALSH PC (1985) Precise localization of the autonomic nerves from the pelvic plexus to the corpora cavernosa: a detailed anatomical study of the adult male pelvis. *Journal of Urology* **133**, 207–212.

LEVI G (1900) Morfologia delle arterie iliache. *Archivio Italiano di Anatomia e di Embriologia*; I, II, III.

LUE TF, TAKAMURA T, SCHMIDT RA, TANAGHO EA (1983) Potential preservation of potency after radical prostatectomy. *Urology* **13**, 165–167.

LUE TF, ZEINEH SJ, SCHMIDT RA, TANAGHO EA (1984) Neuroanatomy of penile erection: Its relevance to iatrogenic impotence. *Journal of Urology* **131**, 273–280.

McKAY JY (1889) *The Arterial System of the Vertebrates Homologically Considered. Memoirs and Memoranda in Anatomy*, vol. I. London, Edinburgh: Baillière, Tindall.

McKENNA KE, NADELHAFT I (1986) The organization of the pudendal nerve in the male and female rat. *Journal of Comparative Neurology* **248**, 532–540.

MONTORSI F, GUAZZONI G, STRAMBI LF, DA POZZO LF, NAVA L, BARBIERI L (1997) A recovery of spontaneous erectile function after nerve-sparing radical retropubic prostatectomy with and without early intracavernous injections of alprostadil: results of a prospective, randomized trial. *Journal of Urology* **158**, 1408–1410.

MULLER J (1836) *Über die organischenn Nerven der erectilen männlichen Geschleshtorgane des Menschen und der Saugethiere*. Berlin: F. Dumeerlor.

NARAYAN P, KONETY B, ASLAM K, ABOSEIF S, BLUMENFELD W, TANAGHO E (1995) Neuroanatomy of the external urethral sphincter: implication for urinary continence preservation during radical prostate surgery. *Journal of Urology* **153**, 337–343.

PADMA-NATHAN H, PETERSON GH, TAM PY, GESUNDHEIT N (1996) Transurethral Alprostadil treatment of erectile dysfunction: clinical and pharmacokinetic correlations. *International Journal on Impotence Research* **8**, 146.

PARSON FG (1902) The blood vessels of mammals in relation with those of man. *Lancet* **i**, 851–653.

PICK J, SHEEHAN D (1946) Sympathetic rami in man. *Journal of Anatomy* **80**, 12–20.

POIRIER P, CHARPY A (1912) *Traité d'Anatomie Humaine*, tome II, fasc. 2, pp. 55–133. Paris: Masson.

POLASCIK TJ, WALSH PC (1995) Radical retropubic prostatectomy: the influence of accessory pudendal arteries on the recovery of sexual function. *Journal of Urology* **154**, 150–152.

QUAIN R (1882) *Quain's Elements of Anatomy*, 9th edn, pp. 450–461. London: Longmans, Green.

REINER WG, WALSH PC (1979) An anatomical approach to the surgical management of the dorsal vein and Santorini's plexus during radical retropubic surgery. *Journal of Urology* **121**, 198–200.

SACHS BD (1982) Role of striated penile muscles in penile reflexes, copulation, and induction of pregnancy in the rat. *Journal of Reproduction and Fertilization* **66**, 433–437.

SANTORINI GD (1739) *Observationes Anatomicae*. Lughuni Batavorum.

SOEMMERRING S TH (1800) *De Corporis Humani Fabrica*, vol. 5, pp. 261–285. *De Angiologia Traiecti ad Moenum*. Varrentrapp and Wenner.

WAGNER G, BRO RASMUSSEN F, WILLIW EA, NIELSEN MG (1982) New theory on the mechanism of erection involving hitherto undescribed vessels. *Lancet* **20**, 416–417.

WAGNER HE, ANDRESSEN R, KNISPEL HH, BANZER D, MILLER K (1995) Evaluation of penile arteries with color-coded duplex sonography: prevalence and possible therapeutic implications of connections between dorsal and cavernous arteries in impotent men. *Journal of Urology* **153**, 1469–1471.

WALSH PC, DONKER PJ (1982) Impotence following radical prostatectomy: Insight into etiology and prevention. *Journal of Urology* **128**, 492–497.

WALSH PC, LEPOR H, EGGLESTON JC (1983) Radical prostatectomy with preservation of sexual function: Anatomical and pathological considerations. *The Prostate* **4**, 473–485.

WEISS JP, SCHLECKER BA, WEIN AJ, HANNO PM (1985) Preservation of periprostatic autonomic nerves during total perineal prostatectomy by infrafascial dissection. *Urology* **26**, 160–163.

ZUCKERKANDL (1990) *Zur morphologie der Art. pudenda interna*, Bd. CIX, Abath III. Sitzungsbericht der kaiserlich akademie in Wien.