Neurovascular Anatomy of the Penis and Pelvis in Thai Males: Applications to Male-to-Female and Pelvic Surgeries

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Objective: *To determine the neurovascular profiles in the pelvis and penis for applying to sex reassignment surgery.*
Material and Method: *Dissection of the pelvis and penile shaft was performed in 12 soft-preserved and 32 fresh adult male cadavers respectively. The neurovascular structures were located and documented, and the distances between anatomical landmarks were measured. Thirty-two specimens from the glans penis were obtained for immunohistochemical analysis to analyze its innervation and blood supply.*
Results: *Several anatomical variations of penile arterial supply were found. They are the presence of the accessory pudendal artery, multiple cavernous and bulbourethral arteries. The unilateral dorsal artery was observed in 10 of 32 cadavers, predominantly on the left. From the root to the neck of the penis, the dorsal nerves were divided into two groups. The first group of fibers innervating the glans coursed along the dorso-lateral surface of the shaft and pierced the entire area of the corona. The other group diverged to distribute throughout the lateral surface to innervate the lateral and ventral portions. The mean distance between the left and right medial main branches that terminated in the glans was 1.18 cm. Immunohistochemical analysis revealed that the main nerves, after entering the glans, divided into terminal branches that concentrated around urethra. A mean distance from the main nerves to the epithelium was 0.71 cm.*
Conclusion: *This detailed anatomy in the pelvis and along the penis should provide a valuable guide for sex reassignment surgery and intrapelvic operations.*

Keywords: *Neurovascular anatomy, Penis, Sex reassignment surgery, Pelvic surgery*

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Trans-sexualisms are considered as low class citizens, hiding in a dark corner and selling their services as prostitutes. These people seek doctors who have neither competency nor enough experience to do the sex reassignment surgery, leading to serious complications and sequenlaes. Corrective surgery, which may be more difficult than doing the original surgery, is needed[1]. Nobody could inhibit the desire of these people, who usually suffer from gender identity disorder, from strongly wishing to change their genital sex to the sex they want. For those who fail conservative treatment in adjusting the mind to the body, sex reassignment surgery is the best way to transform their body to their mind and gives the best result in properly selected patients[1-4].

A one-stage procedure of male-to-female sex reassignment surgery has been regularly performed in Chulalongkorn Hospital for managing male trans-sexuals. Though most patients are satisfied with the results after operation, some complications and sequenlaes might happen during the operations or post-operative periods. There may be partial necrosis of

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neoclitoris caused by inadequate blood supply from the pedicle, excessive blood loss during penectomy, and anesthetized neoclitoris, etc.

Herein, the neurovascular structures in the pelvis and penis using cadaveric dissection and immunohistochemical techniques were defined. The anatomical point of view in the present study was utilized in the strategic design of sex reassignment surgery to improve surgical techniques and excellent outcome.

Material and Method

Dissection of the pelvis. 12 soft-preserved adult male cadavers without formaldehyde were dissected to locate and document the neurovascular structures. Each cadaver was sectioned transversely at the level of anterior superior iliac spine and midthigh. Later, pelvic block from transverse section was divided sagittally into two halves. The pelvic visceral organs were retracted medially, and dissection of nerves and arteries was done carefully layer by layer. Moreover, the arterial supply in the hilum of the penis was followed.

Dissection of the penile shaft. In 32 fresh adult cadavers, the attachment of the prepuce around the neck of the penis including the frenulum was cut and the pliable tubular penile skin was retracted proximally to the root of the penis. Buck's fascia was opened longitudinally with scissors, exposing the deep vein and the dorsal arteries and nerves. The bleeding from the superficial vein was wiped out carefully. The topography of neurovascular structures was noted throughout the entire length of the penis. Also, the distances between the left and right dorsal nerves, and between the left and right dorsal arteries were measured. A 3-mm proximal transverse slice of specimens from the glans penis was obtained for immunohistochemical analysis.

Immunohistochemistry. All 32 specimens were fixed in formalin, embedded in paraffin and serially sectioned at 3 mm. Sections were stained with haematoxylin and eosin. Selected sections were stained immunohistochemically with S-100 antibody. Each specimen was analyzed for a distribution of nerves and vascular structures in the glans penis. The distance between the main nerves and epithelial surface was also measured. The distribution of the dorsal nerves was reconstructed and rendered into three-dimensional images.

Data were presented as number, mean, standard deviation (SD) and range to describe the result.

Results

Pelvis (Table 1, 2)

Vascular system. Internal pudendal artery entered the gluteal region through the greater sciatic foramen. It then entered the perineum after crossing posteriorly to the ischial spine through the lesser sciatic foramen and lied in the pudendal canal. After giving off its perineal branches to the scrotum, muscles and skin of perineum, the internal pudendal artery continued as the penile artery. The latter pierced the urogenital diaphragm and ran along the medial margin of the inferior ramus of the pubis. Near the urethral bulb and deep in the perineal pouch, it divided into terminal branches, being the bulbourethral, cavernous and dorsal arteries. This was seen in eleven cadavers. However, in one cadaver, the internal pudendal artery terminated as the bulbourethral artery. Then, the accessory pudendal artery divided into the cavernous and dorsal arteries.

The accessory pudendal artery was observed in two of 12 cadavers, traveling along the lower part of the bladder and the anterolateral surface of the prostate to the root of the penis. In one cadaver, it was seen unilaterally on the left side and originated from the inferior vesical artery to anastomose with the penile artery proximal to the origin of the cavernous

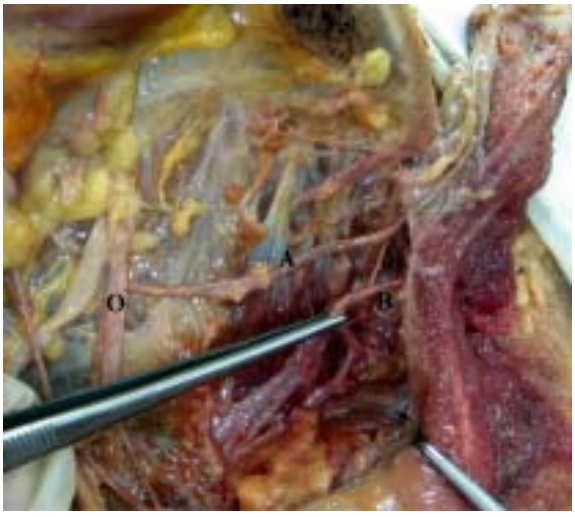

Fig. 1 The accessory pudendal artery (A) arising from the obturator artery (O). It ends as cavernous and dorsal arteries. Bulbourethral artery (B) as end artery of internal pudendal artery

Table 1. Mean distances (in cm) between anatomical landmarks in the pelvis

	Left				Right			
	n	Mean	SD	Range	n	Mean	SD	Range
Bulbourethral a. to perineal body	11	1.96	0.36	2.56-1.22	13	2.04	0.56	3.25-1.26
CA* to corporeal junction	13	0.31	0.84	1.24-(-1.72)	12	0.22	0.81	1.11-(-1.38)
CA* to ischial attachment	13	4.46	1.29	6.59-2.64	12	4.19	1.00	5.66-2.25
Ischial tuberosity to pudendal canal	9	3.51	0.28	3.80-3.06	9	3.52	0.27	4.01-3.18

* CA, cavernous artery, measured from the site on the penis where the cavernous artery perforates the albuginea
+ CA perforates the albuginea proximal to the corporeal junction
- CA perforates the albuginea distal to the corporeal junction

Table 2. Variations of penile arterial systems in 24 cases of 12 cadavers

Variations	No. of cases
Bulbourethral artery and perineal branch arise from a common trunk	3
Bulbourethral artery and cavernous artery arise from a common trunk	4
> 1 bulbourethral artery	8
> 1 cavernous artery	4
Accessory pudendal artery anastomosed with main penile artery	1
Cavernous artery as a branch of accessory pudendal artery	2
Dorsal artery as a branch of accessory pudendal artery	2
Bulbourethral artery as end artery of internal pudendal artery	2
One or more anatomical variations	16/24

artery. In the other cadaver with bilateral arteries, they originated from the inferior vesical artery on the right and the obturator artery on the left (Fig. 1).

The first branch of the penile artery was the bulbourethral artery. It was a short artery with large caliber that passed medially to the crus, piercing the inferior fascia of the urogenital diaphragm to enter the dorsolateral aspect of the bulb. It arose from the main penile artery, or a common branch with the cavernous artery or with the perineal artery. Two bulbourethral arteries were identified on one side in six cadavers and on both sides in one cadaver.

The cavernous artery usually arises distally to the bulbourethral artery. It traveled along the dorsomedial surface of the corpus cavernosum and medially to the dorsal artery. It perforated the albuginea of the corpus cavernosum adjacent to the junction of both cavernous bodies, about 4 cm from the ischial attachment of the crus. The cavernous artery then continued distally in the center of the corpus cavernosum and disappeared before reaching to its tip. More than one artery was identified on one side in four cadavers.

In five cadavers, small crural arteries were found, arising from the penile artery or accessory pudendal artery and passed laterally to enter the dorsomedial surface of the crus.

The dorsal artery was the terminal branch of the penile artery and had characteristically tortuous shape. Its origin was almost consistent, arising commonly from the penile artery, excepting in one cadaver in which the dorsal artery arose from the accessory pudendal artery. It then passed dorsally to the crus and courses distally along the dorsum of the penis.

Nervous system. The main trunks of the ventral rami from S-2, S-3 and S-4 combined to form the pudendal nerve, which continued in the striped covering fascia of the pudendal canal on the lateral pelvic wall. The pudendal canal was approximately 3.5 cm above the ischial tuberosity. The pudendal nerve gave rise to the inferior rectal nerve, which emerged from the medial wall of the pudendal canal, innervating the external anal sphincter and perianal skin. After the pudendal nerve left the pudendal canal, it extended into its two terminal branches of the perineal and dorsal nerve of the penis. The perineal nerve sent the posterior scrotal branches into scrotal septum and the spermatic and scrotal fascia, but also gave several branches that coursed through the posterior edge of the urogenital diaphragm to perineal skin and urethral mucosa. The dorsal nerve, after branching from the pudendal nerve, traveled forward along the margin of the inferior pubic ramus into the urogenital diaphragm.

It then coursed through the suspensory ligament of the penis anterior to the pubic symphysis and turned acutely downward to the dorsum of the penis, where it ran distally along the dorsolateral surface of the penis.

The cavernous nerves were identified as a thick network of strong fibers accompanied by thin arteries and veins. They passed along the posterolateral aspect of the seminal vesicle and the prostate, and then ran between the prostatic capsule and endopelvic fascia. These nerves were traced back to the inferior hypogastric plexus, which was located at the rectal mesocolon above the ampulla. The inferior hypogastric plexus seemed to be an integrating center that acted as a relay between fibers arising from the hypogastric and pelvic splanchnic nerves, and plexuses in pelvic viscera such as prostatic, vesical and rectal plexuses (Fig. 2).

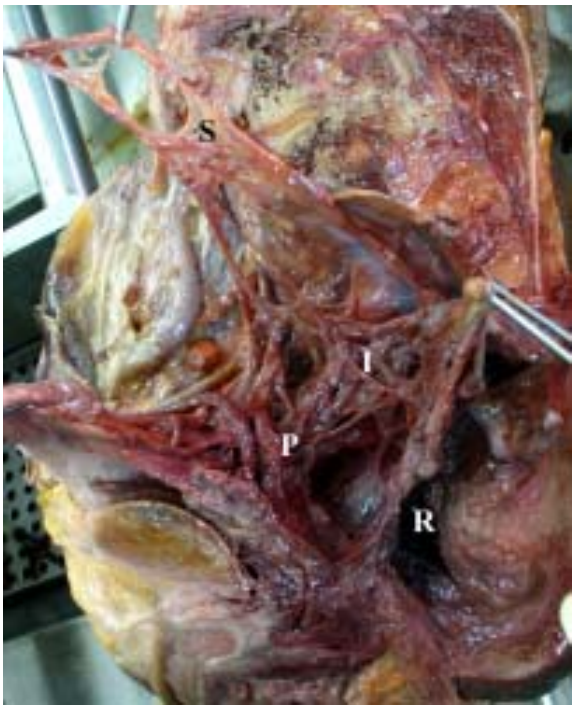

Fig. 2 Nerve plexuses. S, superior hypogastric plexus; I, inferior hypogastric plexus; P, prostatic plexus; R, rectum

Penile shaft

Vascular system. At the proximal penile shaft, the dorsal artery coursed on the dorsal surface of the penis between the deep dorsal vein medially and dorsal nerve of the penis laterally. It then traveled divergently along the shaft to the lateral surface of the corpus cavernosum toward the glans penis. In 10 of 32 fresh cadavers, the dorsal artery was present unilaterally, nine on the left side and one on the right (Fig. 3), whereas in the others it occurred bilaterally. Special patterns were observed in two cadavers: the artery on the left curved immediately to the ventral aspect of the corpus cavernosum at the level of midshaft and the artery on the right terminated as small branches at distal one-third of the shaft. The mean distance between the left and right dorsal arteries at the neck of the penis was 1.77 cm (Table 3). Multiple small veins were seen emerging from the glans penis to drain into the deep dorsal vein. The circumflex veins, identified around the lateral surface of the penis superficial to the tunica albuginea, also opened into this

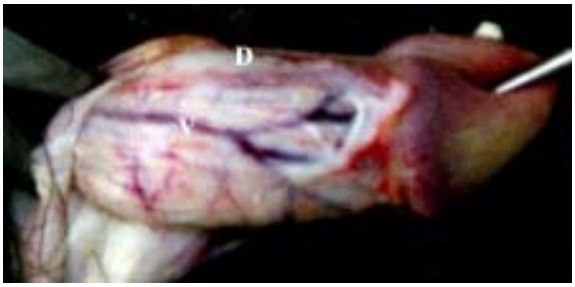

Fig. 3 Dorsal artery (D) presenting unilaterally on the penile shaft, deep dorsal vein (V)

Table 3. Mean distances (in cm) between two structures at the penis

	n	Mean	SD	Range
Left and right dorsal a*	20	1.77	0.37	2.50-1.20
Left and right main dorsal n*	32	1.18	0.17	1.50-0.75
Main dorsal n. to epithelial surface	21	0.71	0.11	0.94-0.54

* Measured at the neck of the penis
Measured at proximal glans penis

vein. The deep dorsal vein coursed along the groove between the two corpora cavernosa and entered the pelvis through the suspensory ligament to drain into the periprostatic venous plexus.

Nervous system. The dorsal nerve of the penis was identified bilaterally in all cadavers dissected, lateral to the dorsal artery. This nerve as well as the dorsal artery has a characteristically crooked shape along its course. From the root to the neck of the penis, the dorsal nerve fanned out into small parallel branches that could be divided into two groups. The first group was composed of fibers traveling along the dorsolateral surface of the penile shaft and piercing the entire area of the corona of the glans penis posteriorly (Fig. 4). The other group of fibers diverged to distribute throughout the lateral aspect of the shaft. The mean distance between the left and right medial main branches of the dorsal nerves, which terminated in the glans, was 1.18 cm.

Immunohistochemistry

At the proximal end of the glans penis, the inner core consisted of two tips of the corpora cavernosa and the single corpus spongiosum with the horizontal star-shaped urethral slit in the center. The collagen fibers of the tunica albuginea, coverings of the corpora cavernosa, were densely regularly-arranged especially at the midline septum. The thin tunica albuginea of the corpus spongiosum blended with the dermis of the glans penis. About three large branches of the dorsal nerves lay dorsolaterally to the tips of the corpora cavernosa on either side. Small nerve branches were observed among these main branches (Fig. 5). A mean distance from the main nerves to the

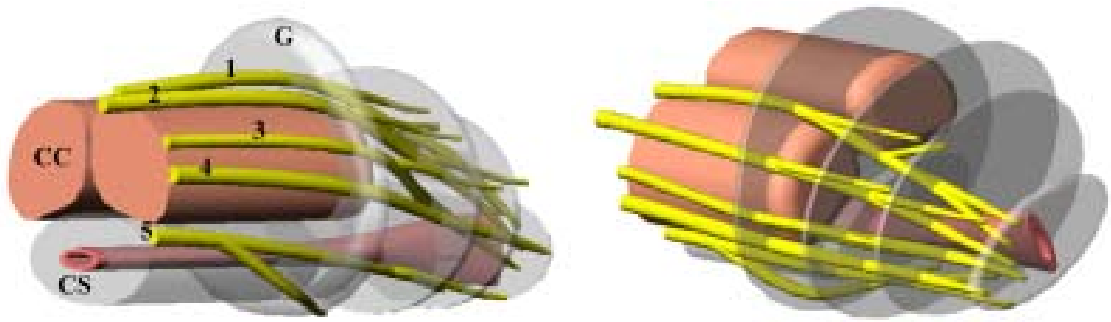

Fig. 4 3-D reconstruction images showing the distribution of nerves on one side at distal penile shaft. Dorsal nerves (1-4) surrounding on dorsolateral surface of corpora cavernosa (CC) and piercing the glans penis (G) posteriorly. Perineal nerves (5) coursing on the lateral surface of corpus spongiosum (CS)

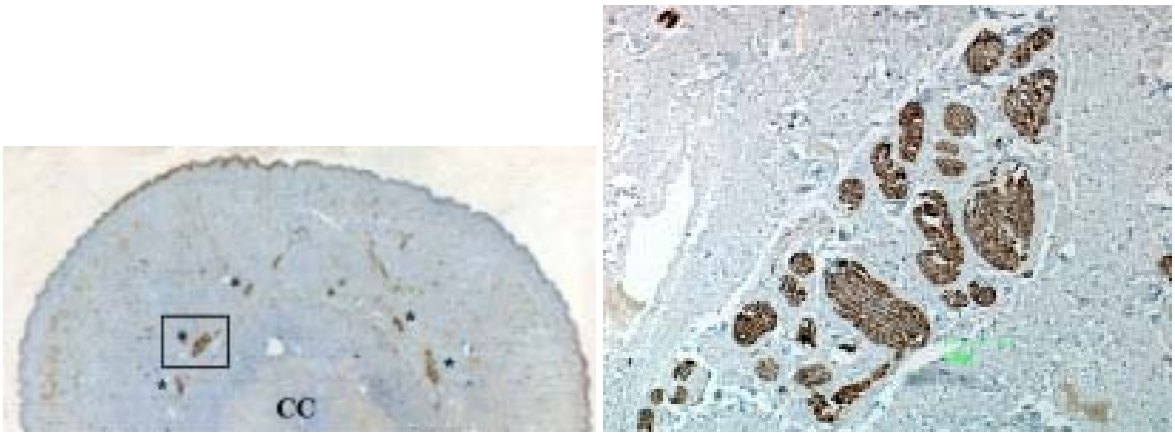

Fig. 5 The dorsal nerve of the penis stained with S-100 antibody at the proximal glans penis. A, nerves (*) lie dorsolaterally to the tips of corpora cavernosa (CC) on either side. B, high power view of A inset shows bundles of the dorsal nerves

epithelial surface was 0.71 cm. These main branches then descended to both sides of the urethral slit in the middle part of the glans penis, where they divided into small multiple branches distributing anteriorly to the surface of the tip of the glans. All terminal branches were concentrated around the dorsal half of the vertical slit-liked urethral meatus (Fig. 4).

The dorsal artery was identified laterally to the dorsal nerves and could be found variably from the 9 o'clock to 10 o'clock position. Multiple dorsal veins lied between the superior branches of the dorsal nerves to form the deep dorsal vein, which was proximal to the neck of the penis. In addition, some apocrine glands and small blood-filled venous sinuses were seen lying close to the urethral epithelium.

Discussion

The present study revealed anatomical variations of the penile arterial supply, most of which were bulborethral arteries in forms of multiple arteries and a trunk giving rise to the bulbourethral and cavernous arteries. The present study also described a common trunk of the perineal and bulbourethral arteries. The reported incidences of accessory pudendal artery varied from 4% to 70% in surgical and cadaveric dissections[5-9]. Some previous reports did not clearly show the origin and end of the artery. Moreover, their results varied depending on whether small arteries located beneath the prostatic fascia were included. In the present study, the accessory pudendal artery was identified in two of 12 cadavers (17%) to originate from the inferior vesical or the obturator artery, as previously described[5,7]. The artery ended at the cavernous artery, dorsal artery, or anastomosing with the main penile artery.

In the past, erectile dysfunction was a common complication occurring after radical pelvic surgery of all types. More evidence supported that impotence after pelvic surgery could be from vascular causes[10-12]. The corpora cavernosa normally received their primary arterial supply from the internal pudendal artery; however, the present study showed in one case that the accessory artery was the main blood supply, coinciding with many previous reports[5-7]. Because it is adjacent to the bladder and prostate, the artery may be inevitably compromised during radical pelvic surgery. This might contribute to vasculogenic impotence especially in patients with atherosclerosis of penile vasculature or with the main blood supply existing above the pelvic diaphragm. Recent studies[8,12] demonstrated that preservation of the accessory artery was important and favorably influenced the potency rates and the time to regain potency after surgery. For this reason, special care should be taken not to injure this artery during surgery.

Constructing a neovagina is one of the crucial procedures in male-to-female surgery. It is usually done by either inversion of the penile skin[2,13] or use of a combination of skin flaps from the penis and scrotum[14-16]. Psychologically, erotic tactile sensation around perineum is the crucial role for sexual arousing. From the authors' anatomical point of view, the superficial perineal nerve was the essential sensory nerve of this area including the posterior scrotum. Using posterior-based pedicle scrotal skin flap for the construction of most of the vaginal wall may add some sexual pleasurable sensation compensating the less sensitive neoclitoris. However, hair on the scrotal flap in the neovagina seemed to be a problem that was found in some of patients[14,15]. This problem can be alleviated by using a de-epithelial scrotal flap with the penile skin tube flap for surface lining or using a hair depilating cream. This method may guide construction of an endurable sensate neovagina.

To create the neovaginal space, the rectourethral muscle is divided ventrally to the central tendon of perineum to allow sharp and blunt dissection between the urethra and rectum up to the peritoneal reflection. Extensive dissection in lateral space of rectum including using electrocautery to increase the transverse diameter of the neovaginal space[2] may endanger the pelvic plexuses on either side, including cavernous and other pelvic autonomic nerves. These pelvic hypogastric plexuses play a role in the sphincteric and erectile controls. Urinary incontinence was reported as a common complication in patients after sex reassignment operations[17,18]. Injury to these plexuses can cause various degrees of incontinence but not of impotence in male-to-female sex reassignment surgery.

In the step of penectomy, the crura of the corpora cavernosa are separated and amputated from their attachment to the bone. The present study showed that the cavernous artery entered the dorsomedial aspect of the corpus cavernosum adjacent to the junction of both cavernous bodies. Consequently, the authors suggest that cutting the crura should be done close to the pubic rami and cauterization be effective for bleeding control. It is not necessary to place a continuous or interrupted suture around this area.

Because of the deep and wide separated position, both of the main branches of the dorsal nerves

on either side were inevitably removed from the glans penis during the trimming process. The lateral position of the dorsal arteries at the neck of the penis results in their absence in the distal part of the neurovascular pedicle of the clitoroplasty flap to some extent. From this point of view, the sensate neoclitoris of the patient may be less sensitive than the original glans penis. A physiologic experiment is required to clarify this question. Most patients still have the sensation of orgasm because this achievable wonderful sensation is a combination between psychological and physical stimulation.

To improve the sensate neoclitoris in clitoroplasty, the authors offer two methods for preserving the neurovascular bundle. First, Buck's fascia of the penis should be incised laterally, starting from the base of the penis. Then, the long neurovascular pedicle is raised deep to the tunica albuginea of both corpora cavernosa. This procedure can ensure an intact and adequate blood supply of the flap but the pedicle may be very wide and thick, resulting in much prominence of mons pubis. In another method based on the authors' data, after the penile skin flap is elevated, two longitudinal incisions about 1.2 cm in width are made laterally along Buck's fascia to free the neurovascular pedicle. An adequate dorsal portion of the glans penis is preserved with a depth of at least 0.7 cm, incorporating in the pedicle. This method can preserve the main branches of the dorsal nerves and a neoclitoris may be partially embedded by a hood of skin fold to camouflage its size but it may not preserve the dorsal arteries. Blood supply to the constructed clitoris is obtained from the small branches of the dorsal arteries. These methods have their pros and cons; selection depends on the opinion of the surgeons.

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กายวิภาคของระบบประสาทและหลอดเลือดขององคชาตและอุ้งเชิงกรานในชายไทย: ประยุกต์ใช้ในการผ่าตัดแปลงเพศจากชายเป็นหญิงและการผ่าตัดในเชิงกราน

ธันวา ตันสถิตย์, ศิรชัย จินดารักษ์, พิเชฐ สัมปทานุกูล, ธนะกูล วรรณประเสริฐ

วัตถุประสงค์: *เพื่อศึกษากายวิภาคของระบบประสาทและหลอดเลือดในเชิงกรานและองคชาต สำหรับนำไปประยุกต์ใช้ในการผ่าตัดแปลงเพศ*

วัสดุและวิธีการ: *ศึกษาบริเวณเชิงกรานและองคชาตในอาจารย์ใหญ่เพศชายที่เก็บรักษาสภาพโดยไม่ใช้ฟอร์มาลิน 12 ท่าน และในอาจารย์ที่เสียชีวิตใหม่ ๆ 32 ท่าน ตามลำดับ สังเกตและบันทึกข้อมูลของเส้นประสาทและหลอดเลือดแดงที่พบ นอกจากนี้ ชิ้นเนื้อเยื่อจากส่วนหัวองคชาตยังถูกนำมาใช้ในการวิเคราะห์ทางอิมมูโนฮิสโตเคมิสทรีเพื่อศึกษาการกระจายตัวของเส้นประสาทและหลอดเลือดที่ไปยังหัวองคชาต*

ผลการศึกษา: *จากการศึกษาพบว่า หลอดเลือดที่มาเลี้ยงองคชาตมีการผันแปรของรูปแบบค่อนข้างมาก ตัวอย่างเช่น การพบหลอดเลือดแดงแอคเซสซารีพูเดนดัล ซึ่งเป็นหลอดเลือดเสริมที่มาเลี้ยงองคชาต การพบว่าหลอดเลือดแดงคาร์เวอร์นัสและหลอดเลือดแดงบัลโบยูรีทัล มีหลายเส้น และมีจุดกำเนิดมาได้จากหลายที่ เป็นต้น ที่ส่วนลำขององคชาต พบว่า ในอาจารย์ใหญ่ 22 ท่าน จากทั้งหมด 32 ท่าน มีหลอดเลือดแดงดอร์ซัล ทั้ง 2 ข้าง (ซ้าย-ขวา) ขณะที่ในอาจารย์ใหญ่ 10 ท่านที่เหลือมีหลอดเลือดแดงดอร์ซัลเส้นเดียว มักเป็นข้างซ้าย จากส่วนฐานถึงส่วนคอขององคชาต เส้นประสาทดอร์ซัลแตกแขนงออกเป็นเส้นย่อยหลายเส้นในทิศทางขนานกัน สามารถแบ่งได้เป็น 2 กลุ่ม คือ กลุ่มที่ 1 เป็นกลุ่มที่ทอดตัวบริเวณระหว่างผิวด้านข้างและด้านหลังของลำองคชาต และแทงผ่านเข้าไปเลี้ยงในส่วนหัวขององคชาต ส่วนกลุ่มที่ 2 ทอดตัวแผ่ออกไปทางด้านข้างของลำองคชาต ไปเลี้ยงด้านข้างและด้านท้องของลำองคชาต ระยะทางเฉลี่ยระหว่างเส้นประสาทแขนงหลักใกล้แนวกลางทั้ง 2 ข้างที่ไปสู่ส่วนหัวขององคชาต เฉลี่ยเท่ากับ 1.18 เซนติเมตร สำหรับผลที่ได้จากการวิเคราะห์ทางอิมมูโนฮิสโตเคมิสทรี แสดงให้เห็นว่า เส้นประสาทดอร์ซัลที่เข้าสู่หัวองคชาตจะแตกแขนงย่อยลงเรื่อย ๆ และพบอยู่หนาแน่นรอบท่อปัสสาวะที่ตรงส่วนปลายของหัวองคชาต เส้นประสาทหลักในส่วนต้นของหัวองคชาตอยู่ลึกจากผิวหนังเฉลี่ย 0.71 เซนติเมตร*

สรุป: *ข้อมูลทางกายวิภาคของระบบประสาทและหลอดเลือดในองคชาตและอุ้งเชิงกราน ซึ่งได้จากงานวิจัยในครั้งนี้จะให้แนวทางที่มีประโยชน์สำหรับการนำไปใช้ในการผ่าตัดแปลงเพศ รวมทั้งการผ่าตัดที่เกี่ยวข้องกับองคชาต และการผ่าตัดในเชิงกรานอีกด้วย*