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Review Article

Anatomy and Generalities of the Pelvic Nerves, Neuropelveology, A Discipline for the Management and Approach of Chronic Pelvic Pain: Review of the Literature

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Abstract

Neuropelveology (NP) is a new discipline focused on common pelvic pathologies, meaning the diagnosis and treatment of pelvic nerve injuries associated with chronic pelvic pain (CPP), which is the main symptom for which patients seek gynecology services. CPP affects multiple organs due to the connection of the intrapelvic organs and their innervation with the autonomic and somatic nerve plexuses. Therefore, NP involves a multidisciplinary approach, primarily neurological, gynecological, neurosurgical, urological, and colorectal. Objective: To understand the general aspects of NP and its application in CPP. Methods: A systematic search was conducted in Pubmed using the following keywords: Neuropelveology, chronic pelvic pain, and pelvic nerves. The inclusion criteria were as follows: availability of the text and original and review articles with publication dates from 2008 to 2023, excluding articles that were not in English and not indexed. Results: We described the most important endpoints of NP found in the literature and made a table to understand the importance of NP in CPP.

Keywords: Pathology; Urology; Etiology

Introduction

CPP is one of the main reasons for gynecological consultations. It is defined as pain associated with the lower abdomen and pelvis, which may or may not be related to a specific pathology. CPP has a global prevalence of approximately 12%; it affects thousands of women both physically and psychologically [1]. The management and treatment of CPP require the contribution and analysis of multiple disciplines due to its location, which can involve various anatomical structures. Furthermore, it is characterized by a considerable variation of symptoms in each patient, including their severity, making its approach difficult [2,3].

NP is a discipline focused on managing pathologies associated with the nerves of the pelvis, aiming to locate the pain and its etiology. Among the most common etiologies are sacral radiculopathy due to vascular or fibrotic entrapment, compression of the sacral

plexus by hypertrophy or atypical insertion of the piriformis muscle, deep infiltrating endometriosis of the sacral plexus, the sciatic nerve and sacral plexus tumors, as well as post-surgical pelvic neuropathies. This discipline seeks to use resources for the correct diagnosis and approach to the disease [4].

The diagnosis of CPP requires neurofunctional knowledge of pelvic anatomy, through which an improved approach is sought. NP primarily aims to find new possible diagnostic and treatment strategies. It focuses on the study of the nerves of the pelvis based on these main disciplines: urology, gynecology, gastrology, coloproctology, and neurology [1]. Classifying and localizing pain are crucial steps in addressing the disease, given its highly variable nature. It should be specifically addressed for each patient. Pelvic pain can be categorized as either visceral or somatic. Somatic pain is characterized by its superficiality and localization, often accompanied by caudal irradiation. On the other hand, visceral pain is diffuse, predominantly radiating to the back, and often accompanied by vegetative symptoms such as irritability, fatigue, and general malaise, among others [2,5].

NP employs a systematic approach for the management of the pathology, encompassing key steps. This involves identifying the implicated nerve pathways by pinpointing the location of pain, following a sequential algorithm: 1) distinguishing between somatic or visceral, 2) identifying specific nerve pathways, 3) understanding the etiology, and 4) formulating an appropriate treatment plan. Subsequently, the location of the neurological lesion and the type of lesion must be determined. With this information, the diagnosis is confirmed, the etiology is identified, and the corresponding treatment is suggested [4,6].

It is crucial to know which nerves are involved and the cause of the pain, as this will be the basis of the treatment and chosen intervention. The diagnostic suspicion is confirmed through a detailed clinical examination, which may include transvaginal or transrectal palpation of the pelvic nerves and imaging studies looking for the site of the lesion, mainly magnetic resonance imaging [4,6]. Hence, it is crucial to employ the knowledge and methodology outlined by NP to address CPP and its associated implications.

Neuropelveology, an Overview

Anatomy of the female pelvis

Understanding the structure and relationships of reproductive and urinary organs in women relies heavily on the anatomy of the female pelvis. The key anatomical structures of the female pelvis include:

- **Pelvic Bones**: The pelvis is composed of iliac bones, located on each side and joining at the front at the pubic symphysis and the back at the sacrum, forming the sacroiliac joints. These bones consist of the ilium (the upper prominence), the ischium (the curved anterior prominence), and the pubis, and they enclose the acetabulum, the point of connection with the head of the femur [7].
- **Pelvic Cavity:** This is a cavity housing internal organs. It is divided into the greater pelvis (above an imaginary line connecting the sacral spines) and the lesser pelvis (below the imaginary line) [8].

Reproductive organs

- **Uterus:** The uterus varies in size depending on whether a woman has had children. It comprises a robust muscular tissue called myometrium and an inner layer, the endometrium, whose composition fluctuates with the menstrual cycle. Additionally, three pairs of ligaments, including the broad, round, and uterosacral, anchor the uterus to the pelvis, ensuring its position against changes in abdominal pressure [8,9].
- **Fallopian Tubes:** Two anatomical structures projecting from the uterus to the vicinity of the ovaries, terminating in an infundibulum adorned with fimbrial projections. The transport of the oocyte through the uterine tube, spanning a length of 7 to 12 centimeters and comprising the isthmus, ampulla, and interstitial segment, is facilitated by ciliary activity and smooth muscle peristalsis. This journey, taking about a week, is the preferred site for fertilization [7,8].
- **Ovaries:** Primary organs of the female reproductive system; they produce sex hormones and release ovules. They are two organs located in the pelvis, in the ovarian fossae, suspended by ligaments that connect them to the uterus and the pelvic wall (the ovarian suspensory ligament, proper ligament of the ovary, and round ligament of the uterus). They are covered by the ovarian cortex and ovarian medulla [10].
- **Vagina:** A strong fibromuscular hollow conduit. It measures approximately between 7-9 cm. It extends from the uterus to the vestibule of the external genitals, opening to the exterior. The fornix is the circular folded area formed around the cervix. It is divided into an anterior fornix, a posterior fornix, and two lateral fornices. At its lower end, it passes through

the urogenital diaphragm, where it is surrounded by two muscles and bulbocavernosus bodies (vaginal sphincter) [11].

Urinary system

- **Urinary bladder:** Located in the lower portion of the pelvis, the urinary bladder, a muscular organ lined with mucosa, serves as a reservoir for urine and changes shape depending on whether it is full or empty. It is attached to the pelvic region through the pubovesical ligaments and connects to the umbilical area through the urachus. Additionally, it is situated behind the pubis and in front of the uterus, with the ability to contract due to its smooth muscle tissue, and it opens into the urethra [12].
- **Ureters:** Tube-shaped organs. They extend from the termination of the renal pelvis to the lower external corner of the base of the bladder. As they approach the bladder, they pass behind the common iliac and uterine arteries, crossing in front of the uterosacral ligament. They measure approximately between 26 and 28 cm, with a 4-6 mm diameter. There are two ureters (one for each kidney) [13].
- **Urethra:** The adult female urethra, approximately 3 to 4 cm in length, originates in the vesical neck and extends to the external urethral meatus, situated posteriorly to the pubic symphysis. Histologically, it is characterized by four layers: an internal epithelial lining, a vascularized spongy submucosa, a thin fascial layer, and two layers of smooth muscle, an internal longitudinal and an external circular layer. The proximal segment has transitional epithelial cells that transition to squamous cells, which predominate in the urethra. Functionally, the conjunction of the vesical neck and the proximal urethra forms the internal sphincter, while more distally, the external sphincter is located, both essential for urinary continence [14].
- **Pelvic floor muscles:** These muscles are located in the lower part of the pelvis, helping to maintain pelvic organs in place. Their function is the control of urination and defecation [15].
- **Superficial pelvic floor muscles**: These include the bulbocavernosus, ischiocavernosus, and superficial and deep transverse perineal muscles, essential for sexual and urinary functions [15,16].
- **Rectum:** The rectum is the terminal section of the large intestine, located in the concavity of the sacrum within the pelvis and extending between the sigmoid loop and the anus for about 12 to 18 cm. It is distinguished from the colon by its 2 or 3 internal curves originated by the Houston valves. This organ is divided into two parts: the upper rectum, wide and covered anteriorly by the peritoneum up to the Retterer septum, and the lower rectum, narrow, located between the perineal areas and lacking peritoneum. The peritoneum reflects, in women, towards the back of the uterus and in men towards part of the bladder, creating the Douglas pouch. The lower rectum is related to Denonvilliers' fascia and anchored to the sacral bone by the endopelvic fascia, specifically at Waldeyer's ring [17].

Pelvic nerves

We divide them into somatic and visceral.

Somatic

- **Genitofemoral Nerve:** The genitofemoral nerve arises from the lumbar plexus. It provides sensation to the skin of the mons pubis in women, the anterior scrotal area in men, and the upper segment of the anterior thigh in both men and women. The nerve continues inferiorly, dividing into femoral and genital branches. Once the genitofemoral nerve reaches the groin area, it crosses the deep inguinal ring that traverses the inguinal canal [18].
- **Ilioinguinal Nerve:** The ilioinguinal nerve, a mixed nerve, arises from the anterior branches of T12 and L1. It emerges adjacent to the outer edge of the major psoas muscle. It descends inferiorly through the anterior abdominal wall, located beneath the peritoneum and anterior to the quadratus lumborum muscle until it reaches the iliac crest. From there, the ilioinguinal nerve traverses the transverse abdominis and internal oblique muscles [19].
- **Femoral Nerve:** The longest nerve within the lumbar plexus originates from the dorsal divisions of L2-L4. It initiates its pathway in the abdominal region, traversing through the psoas major muscle. Moving posteriorly, it extends laterally within the distal section of the psoas major muscle [20].
- **Obturator Nerve:** It comes from the nerve roots from L2 to L4 and will be found in the obturator fossa, deep and lateral to the iliac vessels. It descends through the psoas muscle fibers, emerging from the medial border of the psoas muscle near the pelvic brim. During laparoscopic surgery, dissection is performed in the space called the "obturator fossa" between

the psoas and the iliac vessels. After lymphadenectomy, the obturator nerve will be found, descending towards the obturator canal, where it branches anteriorly and posteriorly, thus reaching the paravesical fossa, being lateral to the obliterated umbilical artery [21].

- **Sciatic Nerve:** For some authors, the sciatic nerve is considered the continuation of the lumbosacral trunk by joining with the S1-S2-S3 roots. Its origin can be found in the obturator fossa. Its laparoscopic approach consists of locating the lumbosacral trunk and exposing the sciatic nerve leaving the pelvis through the suprapiriformis canal [22].
- **Pudendal Nerve:** It emerges from the ventral roots of the sacral plexus's S2, S3, and S4 segments. It carries motor, sensory, and autonomic fibers. It passes through the piriformis and the coccygeal muscles, exiting the pelvic cavity through the greater sciatic foramen, ventral to the sacrospinous ligament. It passes below the sacrospinous ligament to re-enter the pelvic cavity through the greater sciatic foramen. It runs in the Alcock canal. Its last three branches (inferior rectal, perineal, and dorsal sensory nerve of the clitoris) terminate in the ischioanal fossa [23].

Visceral

- **Superior Hypogastric Plexus**: It is a network of nerves in the pelvis, specifically in the hypogastric region. It extends towards the middle hypogastric plexus, located anteriorly to the vertebral column. This plexus is responsible for innervating the pelvic organs (bladder, uterus, female reproductive organs, and part of the large intestine). It divides into several main branches that extend to specific organs in the pelvis, providing them with innervation for sensitivity, muscular control, and the autonomous functions of pelvic organs [24].
- **Hypogastric Nerve**: It consists of ganglia and nerve branches. The hypogastric ganglion comprises a group of neurons forming a nervous cluster. These neurons receive nerve signals from splanchnic nerves and project towards pelvic organs such as the bladder, reproductive organs, and rectum through nerve branches. It communicates with other ganglia and nerve plexuses in the pelvis, such as the upper and lower hypogastric plexus and pelvic splanchnic nerves. It is responsible for the contraction and relaxation of smooth muscles in pelvic organs, blood circulation control, and visceral sensitivity modulation. It contributes to urinary, reproductive, and fecal function and regulates blood flow in pelvic organs [25].
- **Pelvic Splanchnic Nerves:** These are primarily visceral sensory components in pelvic splanchnic nerves. They originate in the sacral region of the spinal cord, heading towards the pelvis through the sacral plexus. They control the bladder, reproductive organs, and visceral sensitivity [15].
- **Inferior Hypogastric Plexus:** Located in the hypogastric region, the lower part of the abdomen and pelvis, anterior to the vertebral column. It is formed by the fusion of sympathetic, parasympathetic, and sensory nerve fibers from the sacral spinal nerves. It is responsible for the innervation of pelvic organs, transmitting sensory and motor signals between these organs and the central nervous system [26] (table 1).

Somatic nerves	Anatomy.	Reference
Genitofemoral nerve.	It arises from the lumbar plexus. It provides sensation to the skin of the mons pubis in females and the anterior scrotal region in males. The nerve continues downward and divides into femoral and genital branches.	[18]
Ilioinguinal nerve.	It is known as a mixed nerve originating from the anterior branches of T12 and L1. It emerges adjacent to the outer edge of the psoas major muscle and descends inferiorly through the anterior abdominal wall.	[19]
Femoral nerve.	The longest nerve within the lumbar plexus, originates from the dorsal divisions of L2-L4.	(20]
Obturator nerve.	It comes from the nerve roots from L2 to L4, it will be found in the obturator fossa, deep and lateral to the iliac vessels.	[21]
Sciatic nerve.	It comes from the nerve roots from L2 to L4, it will be found in the obturator fossa, deep and lateral to the iliac vessels.	[22]
Pudendal Nerve.	It emerges from the ventral roots of the S2, S3, and S4 segments of the sacral plexus. It carries motor, sensory, and autonomic fibers.	[23]
Visceral nerves.	Anatomy.	References
Superior hypogastric plexus	This plexus is responsible for the innervation of pelvic organs (bladder, uterus, female reproductive organs, and part of the large intestine).	[24]

Hypogastric nerve.	It is responsible for the contraction and relaxation of smooth muscles in pelvic organs, the control of blood circulation, and the modulation of visceral sensitivity. It contributes to urinary, reproductive, and fecal function, as well as the regulation of blood flow in pelvic organs.	[25]
Pelvic Splanchnic Nerves.	It originates in the sacral region of the spinal cord, extending towards the pelvis through the sacral plexus.	[15]
Inferior Hypogastric Plexus.	It is formed through the fusion of sympathetic, parasympathetic, and sensory nerve fibers from sacral spinal nerves.	[26]

Table 1

Sexual and bladder dysfunction

Spinal cord injury (SCI) is a debilitating condition resulting in sensory-motor loss and dysfunction of multiple organs. Although motor loss is the most evident consequence of SCI, urinary and fecal incontinence, genital desensitization, loss of tactile sensitivity, and even cognitive deficits have an even worse impact on the social, psychological, and physical well-being of individuals with this condition [27]. While non-paraplegic patients prioritize the recovery of movement, individuals affected by SCI consider disorders in the functioning of the autonomic nervous system to be even more devastating than the loss of motor and sensory function [28]. Consequently, it is essential to devise new solutions to address these dysfunctions. With the purpose of achieving this goal, various efforts have been undertaken to improve the rehabilitation process through assistive technologies, the application of neuroprosthetic devices, and the introduction of innovative therapies.

Possover., *et al*. reported effective sacral nerve stimulation to address CPP and neurogenic bladder dysfunction in female patients undergoing or having undergone prior treatment for deeply infiltrating endometriosis. This approach allows for assessing the underlying cause of pain and, ultimately, offers the possibility of performing neurolysis and neuroelectrode implantation, known as laparoscopic implantation of neuroprostheses [29,30]. The laparoscopic implantation of neuromodulation electrodes using the Possover-LION technique has been adapted to restore gait and improve bladder, bowel, and sexual function in patients with SCI [27,31].

The Finetech-Brindley bladder controller also exists, which activates the bladder by stimulating the ventral sacral nerve roots. At the same time, dorsal rhizotomy is employed to reduce detrusor muscle hyperactivity and address external detrusor sphincter dysfunction. However, many paralysis patients reject this procedure due to the loss of the ability to have erections and evacuate, in addition to concerns associated with nerve intervention [32]. For the assessment of the Possover-Lion procedure and to ensure improvement in mobility and sexual, urinary, and anorectal functions with LME, patients underwent an intensive rehabilitation protocol, which included neurofunctional physiotherapy, aquatic therapy, cardiorespiratory physiotherapy, occupational therapy, and pelvic physiotherapy [27,33]. Regarding outcomes, the most significant impact was observed in mobility measures [34]. Regarding bladder function, a notable decrease was noted in the weekly incontinence episodes and the severity of nocturnal enuresis. However, changes in the quality of life-related to urination, as assessed by the Qualiveen questionnaire, and urodynamic parameters did not reach statistical significance. In the case of female patients, a temporary decline in sexual function was observed in the short term, followed by recovery to pre-intervention levels. Conversely, male patients showed a trend towards improvement, possibly reflecting a beneficial effect of stimulation on erectile function. Additionally, approximately 70% of patients reported an improvement in genital sensitivity [35].

Pelvic floor dysfunction

Pelvic floor dysfunction (PFD) is associated with CPP, as well as dyspareunia and urinary and fecal incontinence (symptoms vary depending on the specific disorder) [36]. PFD is caused by abnormal changes in the function and anatomy of the muscles within the pelvic cavity, such as hypertonicity, hypotonicity, and poor coordination of pelvic muscles. These muscles play a supportive role for organs in both men (prostate, urethra, bladder, rectum, anus) and women (urethra, bladder, vagina, uterus, rectum, and anus) [37].

The most common symptom of PFD is dyspareunia and, generally, pelvic pain, affecting approximately 65.8% of women over 40 years who report some form of sexual dysfunction [38]. Dyspareunia can be caused by various factors: damage to the spinal nerve NC XI, inflammatory disease, infection, pelvic floor condition during childbirth, sexual abuse, posture or body movement, neuromuscular diseases, interstitial cystitis, and endometriosis [39]. Treatment and rehabilitation for dyspareunia encompass various approaches, including functional electrical stimulation with heat and cold (FES), transcutaneous electrical nerve stimulation

(TENS), intravaginal massages, and myofascial release techniques (physiotherapy) [40].

The most common case in women is pelvic organ prolapse (POP), affecting 50% of multiparous women undergoing gynecological examination, with 11% requiring some form of surgical treatment [41]. Certain risk factors increase the likelihood of developing POP, such as advanced age, collagen deficiency or abnormalities, overweight or obesity, chronic constipation, parity, and family history [42]. Significant improvement has been observed in patients who have undergone some form of treatment involving genital nerve stimulation (GNS) for urinary and/or fecal incontinence. This treatment helps prevent detrusor contraction in the bladder, reducing symptoms of overactive bladder and improving idiopathic fecal incontinence. Treatments such as pudendal nerve stimulation, sacral nerve stimulation (SNS), dorsal penile/clitoral nerve stimulation (DPN), and the implementation of the LION procedure have shown positive outcomes [43].

Chronic pelvic pain

CPP is a non-malignant pain manifested in pelvic structures. When this pain persists for more than six months or is not associated with any pathology, it is termed Chronic Pelvic Pain Syndrome (CPPS), with a prevalence ranging from 4% to 15%. However, limited information is available regarding this condition due to its unknown etiology. It is more common in women and is often linked with other pelvic organ pathologies such as endometriosis, pudendal neuropathy, sacral spinal cord pathology, pelvic congestion syndrome, and May-Thurner syndrome, among others [3]. As a form of idiopathic pain, its precise etiology, classifications, severity, and optimal treatment remain uncertain. Consequently, patients often resort to frequent hospital visits in pursuit of relief from pain [1,44,45]. Possover., *et al*. suggest that pathologies of both visceral and somatic pelvic neural plexuses could explain nonspecific pelvic pain, such as in the case of endometriosis, indicating a need for a deep understanding of autonomic neuronal function in CPPS to comprehend it better [3,44,45].

Another mentioned cause is pelvic congestion, known as visceral pain due to pelvic varices. Often, these varices occur in multiparous women and remain asymptomatic. However, when symptoms such as visceral pain emerge, they are referred to as pelvic congestion. Possover suggests that treating varices could decrease or even eliminate pain; however, in 95% of patients, the pain reappears after eight months [46]. NP aims to diagnose and treat pelvic nerve-centered conditions, such as CPP, through an interdisciplinary approach. There are various neuropelveological steps to diagnose the site of the lesion. However, the treatment aspect is affected due to the lack of minimally invasive surgical methods to access such a complex area as the pelvis [3,47].

Discussion

The management and treatment of CPP require the contribution and analysis of multiple disciplines, as it may involve various anatomical structures. NP is a discipline focused on its management, as it constitutes one of the main reasons for gynecological consultation, with a worldwide prevalence of approximately 12% of the population. This discipline aims to locate the pain and its etiology through the use of resources such as clinical examination, ultrasound, magnetic resonance imaging, and laparoscopic exploration for its proper approach and classification [2,47,48].

NP focuses on studying the nerves of the pelvis from an interdisciplinary perspective, aiming to determine the nerve pathways involved, ascertain whether the pain is related to the lumbar or sacral plexus, identify the location of the neurological lesion, and define the type of injury, either due to irritation, often secondary to compression, or if it involves axonal nerve damage with sensory-motor dysfunction [4].

The results of a systematic review on PubMed spanning fifteen years, from 2008 to the current date (2023), incorporating 50 articles published between April and July 2023, suggest that stimulating the genitopelvic nerves and performing specific surgical procedures aimed at nerve repair have enhanced the quality of life for patients experiencing various PFD, CPP, and urinary incontinence associated with neuro-pelvic issues. This has led to a reduction in the frequency of urinary and/or fecal incontinence episodes, along with an increase in pelvic floor muscle strength. Neuropelvological treatment typically revolves around laparoscopic decompression or neuromodulation of the involved nerves, intervention of the pelvic somatic nerves, or exploration of the retroperitoneal pelvic space with access to the lumbosacral plexus [4,5].

Lastly, patient follow-up post-treatment is essential to the approach due to potential complications, particularly pain-associated. One of the most common complications arises in laparoscopic nerve decompression, where patients initially experience a sub-

stantial increase in pain followed by improvement that typically becomes apparent only around eight months after the operation. Hence, patient follow-up is crucial, as is the appropriate management of CPP according to its etiology [4].

Conclusion

NP is a relatively new discipline and stands as one of the primary motives for gynecological consultations, with a prevalence exceeding 10% globally. This field investigates innovative methods to determine the etiology, diagnosis, and treatment of pelvic nerve lesions. Essentially, it focuses on identifying the involved nerve pathways through pain localization. Consequently, NP involves a multidisciplinary approach, primarily encompassing neurology, gynecology, neurosurgery, urology, and colorectal specialties.

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