Neurophysiology of Erection and Ejaculation

Francois Giuliano, MD, PhD
Neuro-Uro-Andrology, Department of Physical Medicine and Rehabilitation, Raymond Poincaré Academic Hospital, Garches, Versailles Saint Quentin en Yvelines University, Garches, France

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ABSTRACT

Introduction. Penile erection and ejaculation are closely associated during sexual intercourse. Erection is a central psychoneuroendocrine and peripheral neuro-vasculo-tissular event, resulting in blood filling the sinusoidal spaces of the corpora cavernosa and corpus spongiosum. Ejaculation represents the climax of the sexual cycle and comprises emission (secretion of semen) and expulsion (propulsion of semen) phases.

Aim. This article provides an overview of the proposed neurophysiology of erection and ejaculation.

Methods. Review of the literature.

Main Outcome Measures. Current data on the neurophysiology of erection and ejaculation.

Results. In terms of peripheral innervation, the pelvic plexus represents a junction for efferent nerves to the structures involved in erection and ejaculation. At the spinal level, the spinal cord contains three sets of neurons (thoracolumbar sympathetic, sacral parasympathetic, and somatic) innervating the sexual organs involved in erection and ejaculation. The presence of cerebral descending pathways to spinal erection and ejaculation centers indicates that the brain has an excitatory or inhibitory effect on these processes. Brain structures that modulate spinal command of erection and ejaculation are part of a larger network that is dedicated to regulating sexual responses. Neurophysiological and pharmacological research has elucidated that dopamine and serotonin have central roles in modulating erection and ejaculation. Interestingly, erection is not a prerequisite for ejaculation, and each of these sexual responses can exist without the other.

Conclusion. Despite the association between erection and ejaculation during intercourse, these two processes can be considered distinct events from an anatomical, physiological, and pharmacological perspective. Giuliano F. Neurophysiology of erection and ejaculation. J Sex Med 2011;8(suppl 4):310–315.

Key Words. Dopamine; Serotonin; Peripheral Innervation; Spinal Centers; Brain Network

Introduction

First defined in humans by Masters and Johnson [1] in the 1960s and then subsequently revised by Kaplan [2] and Levin [3], the human sexual cycle consists of four interactive phases: desire, arousal (or excitement), orgasm, and resolution [4]. Each phase is characterized by specific physiological and behavioral responses that, more notably, include penile erection and ejaculation in the man [5]. Erection is associated with the arousal phase and continues until the resolution phase, whereas ejaculation corresponds to the orgasm phase [5]. Despite this, ejaculation and orgasm are neurophysiologically distinct and should not be regarded as equivalent [6].

Under normal circumstances and in absence of any dysfunction, erection and ejaculation occur during sexual intercourse, or in response to masturbation, according to a temporal pattern that optimizes the capacity of the male to impregnate the female partner. Such a coordinated activity requires an intimate link between the two neurophysiological processes that reside within the central nervous system [7,8].

Physiology

Penile erection is a central psychoneuroendocrine as well as a peripheral neuro-vasculo-tissular event caused by sexual/erotic stimulation with subsequent blood filling the sinusoidal spaces of the
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Ejaculation consists of two distinct successive phases: emission phase (i.e., secretion of the various components of sperm by seminal vesicles, prostate, and ampullary vas deferentia contents into the prostatic urethra) and expulsion phase (i.e., forceful propulsion of sperm from the prostatic urethra to the urethral meatus caused by rhythmic contractions of perineal striated muscles) [6]. The major component of the perineal muscles involved is the bulbospongiosus muscle, which plays the role of a pump contracting intensively and rhythmically according to a specific pattern [6]. During the expulsion phase, the bladder neck contracts to prevent the backflow of sperm into the bladder [16]. Both sympathetic and parasympathetic tones act in a synergistic manner to initiate seminal emission by activating, respectively, smooth muscle contraction and epithelial secretion in accessory sex glands [6]. The sympathetic system also commands bladder neck contraction at the appropriate time [6]. Pre-established rhythmic contractions of bulbospongiosus muscle depend on the somatomotor system. The organic feeling associated with ejaculation is concomitant with the expulsion phase [16]. Ejaculation represents the climax of the male sexual cycle and lasts only several seconds [16].

Peripheral Innervation

Preganglionic parasympathetic neurons innervating the sexual organs arise from sacral segments of the spinal cord and join the sympathetic neurons, via the pelvic nerve, to form the pelvic (inferior hypogastric) plexus [16]. Preganglionic sympathetic fibers destined to the sexual organs emerge from the lower thoracic and upper lumbar spinal segments [16]. After passing via different pathways, these fibers reach the pelvic plexus via the hypogastric nerves [6,16]. The pelvic plexus represents a peripheral crossroad that gives rise to different sets of nerves reaching the anatomical structures participating in erection and ejaculation [6,16]. One branch of the most caudal portion of the pelvic plexus, the cavernous nerve, innervates cavernosal smooth muscle cells. Other branches provide autonomic innervation to the pelvic viscera, including the seminal tract. Sacral motorneurons send direct projections, via the pudendal nerve, to the striated pelvi-perineal muscles, including the ischiocavernous and bulbospongiosus (Figure 1) [6].

Two main pathways conduct somatosensory information from pelvi-perineal area to the spinal cord, where sensory signals are integrated and relayed toward the brain [6,16]. The dorsal nerve of the penis, a sensory branch of the pudendal nerve, carries impulses from sensory receptors harbored in the penis to the sacral segments of the spinal cord [6,16]. Few sensory fibers originating in the vas deferens, prostate, and urethra have also been identified in the pudendal nerve. A second afferent pathway is constituted by fibers travelling along the hypogastric nerve and entering the spinal cord via thoracolumbar dorsal roots [6,16]. All of the sensory afferents terminate in the medial dorsal horn and the dorsal gray column (DGC) of the spinal cord [16].

Spinal Centers

The spinal cord contains the three sets of neurons (thoracolumbar sympathetic, sacral parasympathetic, and somatic) that are anatomically linked with sexual organs and functionally involved in erection and ejaculation [16]. The cell bodies of sympathetic preganglionic neurons are located in the intermediolateral cell column (IML) and DGC of thoracolumbar segments [6,16]. The cell bodies
of the parasympathetic preganglionic neurons are found in the IML of sacral segments in an area referred to as the sacral parasympathetic nucleus [19]. Somatic motoneuron cell bodies are located in the ventral horn of sacral segments in the Onuf’s nucleus [6,16]. Neurons that send the ultimate command to peripheral structures involved in erection and ejaculation are located in the same spinal areas. Although it is obvious that distinct populations of neurons participate in either erection or ejaculation, no discriminative marker has been identified yet.

More recently, another group of spinal neurons, known as the lumbar spinothalamic cells (LSt), has been demonstrated to play a role of generator for ejaculation in the male rat [20,21]. These interneurons, located around the central canal in lumbar segments, orchestrate the coordinated activation of autonomic and somatic spinal centers leading to normal anterograde ejaculation [6]. Moreover, LSt integrate and relay sex-related somatosensory information and may be the key in the occurrence of orgasm. Several cerebral descending pathways to spinal erection and ejaculation centers have been found, suggesting that the brain can positively or negatively influence spinal mechanisms of both of these physiological processes [8].

Brain Network
Brain structures regulating erection and ejaculation belong to a larger network dedicated to the control of sexual responses [6,16]. Animal studies and brain imaging in humans have led to the identification of cerebral circuits more particularly involved in the regulation of one process. The medial preoptic area (MPOA) of the hypothalamus occupies a pivotal position, since it is a region where sexually related stimuli are summated and coherent outputs relevant to sexual responses are generated [22,23]. In the rat, the MPOA projects...
to hypothalamic (paraventricular nucleus) [24], midbrain (ventral tegmental area) [25], and brainstem nuclei (raphe and gigantocellular) [26] that, in turn, send projections to autonomic and somatic spinal centers commanding the peripheral events that impact on erection and ejaculation [27]. Within the MPOA, several mechanisms involving various neurotransmitters and receptor subtypes have been studied in animals and are suggested to be committed specifically in the control of one sexual response [28–30].

Brain descending pathways are both excitatory and inhibitory [16]. From a sexual context, a state of inhibition exists on both erectile and ejaculatory functions, while the excitatory component is silent. When sexual stimulation (peripheral and/or central) reaches a sufficient level, proerectile and proejaculatory descending outputs, comprising increased excitatory and reduced inhibitory signals, activate the spinal centers that result in the characteristic peripheral events [16]. Positron emission tomography imaging, coupled with well-designed experimental paradigm in male volunteers, provided insight on brain areas functionally related with sexual responses [31]. Although data from animal results were largely confirmed (i.e., activation of midbrain structures), some discrepancies appeared (i.e., no neuronal activation was found in MPOA) [31].

Pharmacology
Pharmacological investigations in male rats have demonstrated that either erection or ejaculation can be controlled by administrating selective ligands into the brain [27,32,33]. For example, selective agonists of dopamine receptor subtype-1 elicit erection, whereas activation of dopamine receptor subtypes-2 and -3 trigger ejaculation [27,32–34]—even in anesthetized rats and in absence of sexual stimuli [35]. Experimental data also suggest that a combination of a nonselective dopamine receptor agonist (apomorphine) and a serotonin (5-HT) receptor agonist (m-CPP) facilitates the ejaculatory response via dopamine subtype-2 and 5-HT3 receptors [36].

The development of medicines for treating men’s sexual dysfunctions clearly shows that one sexual response can be specifically affected. The targeting of peripheral mechanisms of erection using phosphodiesterase type-5 inhibitors facilitates erection without majorly impacting on other aspects of the sexual cycle (e.g., ejaculation and libido) [37]. The dopaminergic agonist apomorphine, acting at the brain level, exerts modest erectile effect and no effect on ejaculation [38]. The well-documented efficacy of chronic treatment with long-acting selective serotonin reuptake inhibitors (SSRIs) in increasing intravaginal ejaculatory latency time (IELT) in men with premature ejaculation (PE) supports the role of serotonergic inhibitory control of the ejaculatory process [39]. The short-acting SSRI dapoxetine has been recognized as an effective on-demand treatment of PE, with no unwanted side effects on other sexual responses [40,41].

Endogenous opioids have been shown to modulate the activity of the spinal generator for ejaculation in rats by exerting an inhibitory influence [42]. In men with PE, the centrally acting opioid tramadol was associated with a significant increase in IELT [43]. Pharmacological factors implicated in the pathophysiology of PE and the management of PE are discussed in detail elsewhere [44,45].

Clinical
The majority of findings on the mechanism(s) of ejaculation are derived from animal research. There is less, and mostly indirect, evidence in humans. In some pathophysiological conditions, ejaculation can be severely impaired or even absent, whereas other sexual responses are more or less unaffected. In the case of spinal cord injury that spares the sacral segments, reflexogenic erection is still possible and is usually sufficient for sexual intercourse [46,47]; however, ejaculation cannot be obtained during coitus in 90% of the patients [48,49]. Moreover, although most patients undergoing a surgical prostatectomy, during which seminal vesicles are also eliminated, regain erectile capacity following pharmacological treatment [50,51], the removal of accessory sex glands prevents the emission (but not expulsion) phase of ejaculation, resulting in a “dry” orgasm [50,51]. It is apparent that patients with “dry” orgasm can still experience orgasm concomitantly with the expulsion phase [50,51].

Erection impairment often has repercussions on ejaculatory response; although, in some conditions, ejaculation can be triggered in the absence of erection [52]. This is the case in spinal cord-injured men when intense (actually supraphysiologic) penile vibratory stimulation is applied using a penile vibrator [52,53]. Moreover, nocturnal emission of sperm during sleep, which is most frequent during adolescence, can occur without erection.
Conclusion

Preclinical research in animal models has led to considerable understanding of the physiological mechanisms underlying desire, arousal, genital, and other sexual responses and the understanding of mechanism of action of pharmacological treatments for certain sexual dysfunctions in the male and female [54]. Despite the fact that erection and ejaculation are closely associated during sexual intercourse, these two physiological events are totally different from an anatomical, physiological, and pharmacological perspective [6]. It is noteworthy that erection is not a prerequisite for ejaculation to occur and that each sexual response can exist without the other.

Corresponding Author: Francois Giuliano, MD, PhD, Neuro-Uro-Andrology, Department of Physical Medicine and Rehabilitation, 104 bdw, Raymond Poincaré Academic Hospital, Garches, Versailles Saint Quentin en Yvelines University, Garches 92280, France. Tel: (33) 147-107748; Fax: (33) 147-104443; E-mail: giuliano@cyber-sante.org

Conflict of Interest: Prof. Giuliano has acted as investigator to certain sexual dysfunctions in the male and female. He has received honoraria and travel expenses for his participation in meetings and symposia in France. He has received research grants from various pharmaceutical companies, and is an adviser for Janssen and Johnson.

References

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