

INNERVATION OF THE HUMAN GLANS PENIS

CLAIRE C. YANG AND WILLIAM E. BRADLEY*

From the Departments of Urology and Neurology, University of Washington, Seattle, Washington

ABSTRACT

Purpose: We demonstrate the innervation of the glans penis through nerve blockade and electrophysiological tests.

Materials and Methods: The study was conducted in 14 healthy, sexually potent volunteers. The dorsal nerves of the penis were anesthetized bilaterally with lidocaine. Electrophysiological testing was performed by stimulating the dorsal nerve of the penis at the penile base distal to the block and recording action potentials at the glans.

Results: Dorsal nerve of the penis block resulted in anesthesia of the dorsal, lateral and glanular aspects of the penis. The ventral surface, including the frenulum, was intact to pinprick sensation. Dorsal nerve of the penis stimulation resulted in responses from the corona, dorsal and ventral mid glans, and penile shaft. Frenular responses were less consistently obtained. The most common recorded pattern was a monophasic waveform representing the arrival of a standing potential at a nerve terminal. Latencies were progressively longer with increasing distance from the point of stimulation with the longest latencies measured at the frenulum. Amplitudes of the responses decreased with increasing distance from the point of stimulation.

Conclusions: The dorsal nerve of the penis innervates the glans, including the frenulum which is also innervated by a branch of the perineal nerve. Branches of the dorsal nerve of the penis extend through the glans ventrolaterally. Electrical representation of glanular innervation reveals the glans to be filled with nerve endings supporting its function as a sensory structure.

KEY WORDS: penis, electrodiagnosis

Recent dissections of the human penile dorsal nerve indicate that it is the principal sensory nerve supply to the penile shaft, glans and anterior urethra.¹ Prior studies demonstrated the importance of the penile dorsal nerve in erection and ejaculation in animals^{2,3} and humans.⁴ Whereas innervation of the penile shaft and glans has been the subject of anatomical dissection and electrophysiological techniques have been applied to the penile shaft, to our knowledge similar studies have not been applied to the glans. Neuro-anatomical studies of the glans have confirmed the presence of terminal sprouting of the penile dorsal nerve within the glans. Electrophysiological studies would indicate the nature of the terminal sprouts. It is anticipated that these data would support the idea of the glans as the principal source of afferent information for the induction and maintenance of sexual responses. In addition, anesthetizing the penile dorsal nerve would determine the extent to which the nerve subserves glanular sensation.

METHODS

A total of 14 healthy, sexually potent men 20 to 43 years old with no history of neurological or urological disease were enrolled in the study following approval from our hospital human subjects review committee. A physical examination confirmed intact innervation to the genitalia. We used 10 ml. lidocaine 1% to anesthetize the dorsal nerves of the penis bilaterally at the base of the penis and to document the distribution of penile dorsal nerve while also making needle electrode placement on the penis more tolerable. The stimulating and recording electrodes were placed on the penis distal to the block after preliminary studies performed without lidocaine revealed that this methodology did not change the latencies or character of the recorded responses. To facilitate the recording of penile dorsal nerve potentials a phar-

macological erection was induced by injecting the corpus cavernosum with 0.3 to 0.4 ml. alprostadil. The resultant erection increased the distance between the stimulating and recording electrodes to avoid stimulus block. Pinprick sensation was tested along the penis 10 minutes after anesthesia, and results were recorded. Only 1 side of the penis was examined per test session.

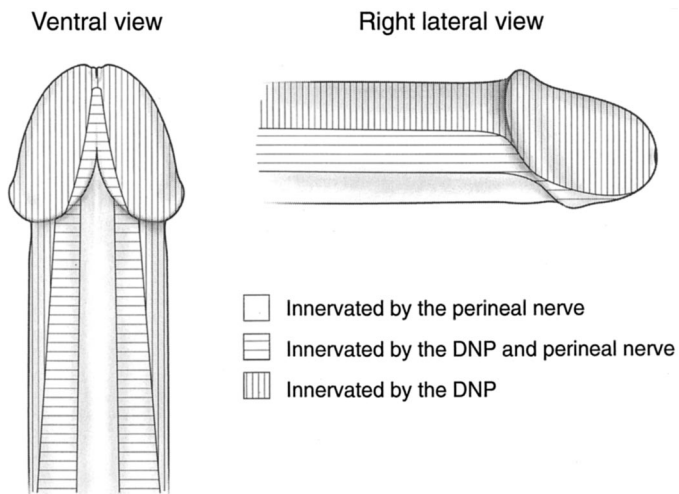
Subdermal monopolar needle electrodes were placed beneath the penile shaft skin along the dorsum with needle tips positioned lateral to the main trunk of the penile dorsal nerve at the penile base. The cathode was positioned 5 mm. distal to the anode and electrodes were secured to the skin. The subdermal arrangement was used to stimulate selectively 1 dorsal nerve, confirmed by stimulating the nerve and observing the absence of a response in the opposite glans. Anatomical dissections have demonstrated that innervation of the glans is shared by both dorsal nerves but there is no crossover of nerve fibers from 1 side of the midline to the other.¹

Subdermal monopolar recording electrodes were placed in the glans ipsilateral to the stimulating electrodes at varying intervals along the corona, and in the dorsal and ventral mid glans and frenulum. Positions on the corona were designated by clock face position. The electrode tip was positioned just beneath the dermis and the electrode was secured to the skin. A separate electrode was placed beneath the penile skin 10 mm. proximal to the corona to serve as a representative recording site on the penile shaft. A small reference disk electrode was placed on the ipsilateral glans 2 cm. from the active electrode. When possible, the reference electrode was positioned more distal on the glans than the active electrode. However, references for the frenular and ventral mid glans were positioned proximal to the active electrode. A ground was placed on the penile shaft between the stimulating and recording electrodes.

Stimuli were applied to the penile dorsal nerve through the electrodes at the penile base at a frequency of 1 Hz., duration

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* Deceased.



0.1 millisecond, bandpass 5 to 5,000 Hz. and intensity 7 to 10 mA. Twenty responses were averaged at each recording site with the latency and amplitude measured at the peak of the initial negative (upward) deflection. Each test was repeated to ensure reproducibility. Temperature corrected nerve conduction velocities were calculated from the responses on the shaft, corona and dorsal mid glans. Nerve lengths to other portions of the glans could not be reliably measured. To confirm the validity of the response the recording and stimulating electrodes were then reversed so that the electrodes at the base of the penile shaft became the recording electrodes, with the active electrode in the more distal position. Orthodromic stimulation was applied to the penile dorsal nerve through electrodes on the glans and shaft using the same parameters described previously.

FIG. 1. Sensory distribution of dorsal nerve of penis. Hatched area on ventrolateral aspect of penis represents transition zone where pinprick sensation was appreciated but dulled compared to ventral aspect. This area is innervated by dorsal nerve of penis and perineal nerve. Area not anesthetized is innervated solely by perineal nerve.

RESULTS

Following bilateral anesthesia of the penile dorsal nerve pinprick sensation was abolished along the dorsal aspect of the penile shaft and most of the glans. Some sensation of touch or pressure was intact in several subjects, particularly

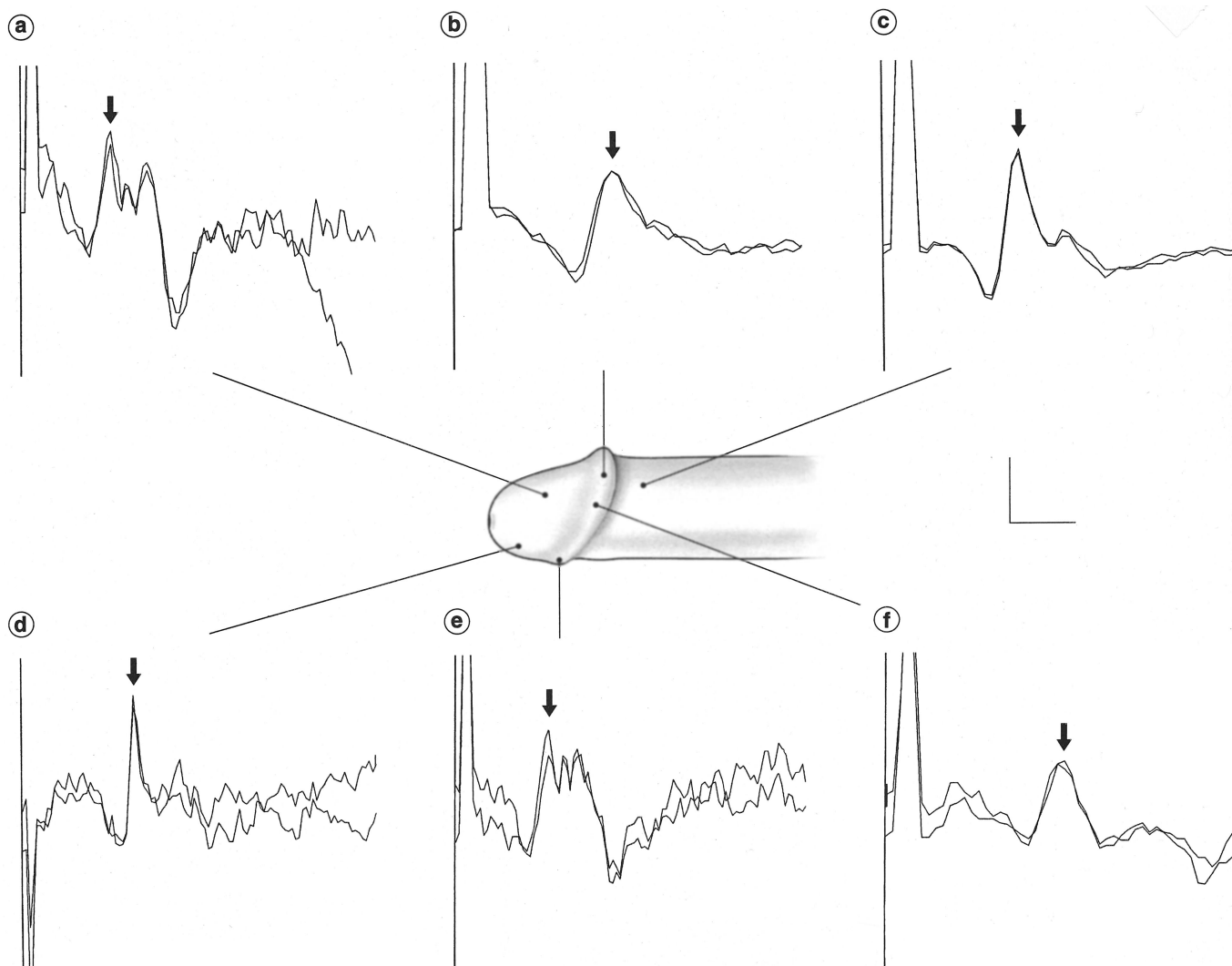


FIG. 2. Representative responses from single subject recorded from dorsal mid glans (a) corona 1:00 (b), penile shaft (c), ventral mid glans (d), frenulum (e) and corona 3:00 (f) following antidromic stimulation of dorsal nerve of penis. Coronal responses are designated by clock face position when looking at glans en face. Arrows designate response at peak of initial negative deflection. Time base a, d, e 2 milliseconds/div., b, c, f 1 milliseconds/div. Amplitude a, d, e 1 μ V./div., b, f 2 μ V./div., c 4 μ V./div.

on the distal aspect of the penis. Occasionally, subjects would report small patches of sensation within the anesthetized areas. Pinprick sensation was intact in a narrow, triangular strip along the ventral surface of the penis corresponding to the width of the corpus spongiosum with the apex at the frenulum (fig. 1). There was a transition zone between the insensate dorsum and sensate ventral aspect in most subjects, in which they experienced a gradual appreciation of pinprick sensation in the skin starting from the lateral penile shaft and approaching the ventral surface. The sensate area is innervated by a branch of the perineal nerve, and the transition zone is innervated by the penile dorsal nerve and a branch of the perineal nerve.

Antidromic stimulation of the penile dorsal nerve resulted in consistent responses in the shaft, corona, and dorsal and ventral mid glans (fig. 2). Responses at the frenulum were obtained in 11 of 14 subjects. Mean latencies are recorded in the table. The progressive increase of latencies from the shaft to the frenulum outlines the path of penile dorsal nerve branches through the glans. This finding corroborates those noted in neuroanatomical dissections of the glanular penile dorsal nerve, whereby penile dorsal nerve branches enter the glans and radiate ventrolateral.¹

Distinct morphological patterns were evident in the responses. The most common response was a monophasic wave, which was often followed by 1 or more smaller monophasic waves (fig. 3). Monophasic waves were recorded from the corona and mid glans, and represent the arrival of a standing potential at a nerve terminal. When the initial wave is followed by subsequent waves, the latter responses indicate the arrival of standing potentials at the terminals of slower conducting penile dorsal nerve fibers. Most responses from the distal shaft and some from the corona were biphasic waves with an initial positive deflection. The responses from the frenulum were less consistently obtained. In the 11 responders the morphologies varied (fig. 4) in part due to the position of the reference electrode which was more proximal on the glans than the active electrode. In 3 subjects frenular responses were not measurable, and so frenular innervation is derived exclusively from a branch of the perineal nerve. Triphasic waves were recorded in the penile dorsal nerve trunk following stimulation of the nerve from the glans (fig. 5). This result was anticipated as it represents a traveling wave moving orthodromically along the penile dorsal nerve.

Amplitudes of the responses from different recording sites were compared (fig. 6). In general the more distal recording sites (ventral mid glans and frenulum) had smaller amplitude responses than those proximal attributed to smaller caliber nerve fibers in these regions of the glans. The largest responses were obtained from the shaft where the nerve branches are larger. Statistical comparisons were not made because of the variability of reference electrode placement and overlapping ranges of amplitudes from subject to subject.

Temperature corrected nerve conduction velocities for each subject remained constant at each of the recording sites (shaft, dorsal mid glans, corona). Mean nerve conduction velocity of the penile dorsal nerve was 36 milliseconds (range 31 to 40). These data were consistent with previously reported nerve conduction velocity of the penile dorsal nerve measurements in the presence of a pharmacological erection.⁵

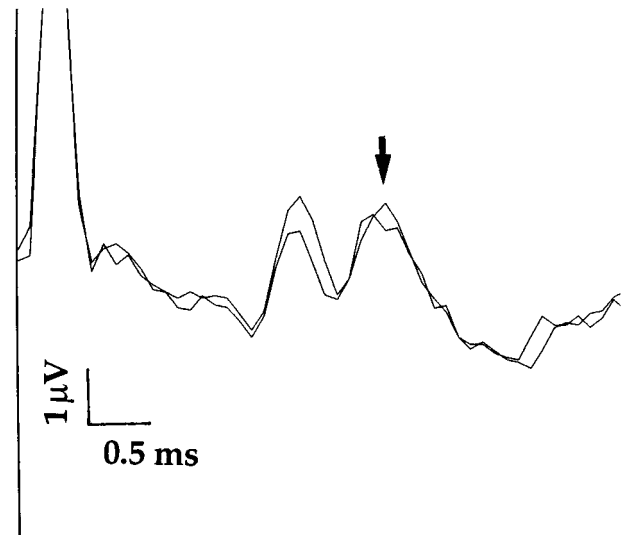


FIG. 3. Monophasic wave pattern characteristic of glanular responses. Secondary wave (arrow) represents population of slower conducting fibers.

DISCUSSION

Many studies illustrate the significance of somatosensory input to male sexual function which is mediated through the penile dorsal nerve. The glans penis, which is densely innervated by the terminal branches of the penile dorsal nerve, is a structure that appears to be the primary source of sensory information to the central nervous system for the induction of sexual reflexes. Clinical and structural studies of animals and humans have supported this idea. Rats² and cats⁶ display severely impaired erectile and almost completely abolished ejaculatory ability after desensitization of the glans. In humans induction of ejaculation in spinal injury patients can be achieved by applying vibratory stimuli to the glans penis, particularly on the corona.⁷ Histological studies of the human glans reveal receptors unique to the penis, distinct from any found in other areas of glabrous skin.⁸

A critical stimulus threshold must be reached within the central nervous system before ejaculation and orgasm can occur. During erection the glans penis may act as a source of sensory information which is transmitted through the penile dorsal nerve to the central nervous system. With erection the glans distends with the corpora cavernosa resulting in an increase of glanular surface area. The increase in surface area stretches the glanular epithelium, exposing more sensory receptors which were buried in the ridges of the rete papilla during the flaccid state. This mechanism enhances exposure of the genital corpuscles, receptors specific to the glans and presumably related to sexual function, to mechanical stimulation. The path from the glans to the central nervous system via the penile dorsal nerve is the neural substrate by which ejaculation and orgasm can occur. This path can be demonstrated electrophysiologically by stimulating the penile dorsal nerve and recording the resultant bulbocavernosus muscle contraction,⁹ which is the primary motor event of ejaculation.

Mean response latencies

	Msec.					
	Shaft	Corona 1:00	Dorsal Mid Glans	Corona 3:00	Ventral Mid Glans	Frenulum
Lt. hemipenis	2.0	2.2	2.7	3.0	3.2	3.6
Rt. hemipenis	2.0	2.1	2.3	2.4	2.7	3.6

Shaft and frenulum data were obtained from the midline.

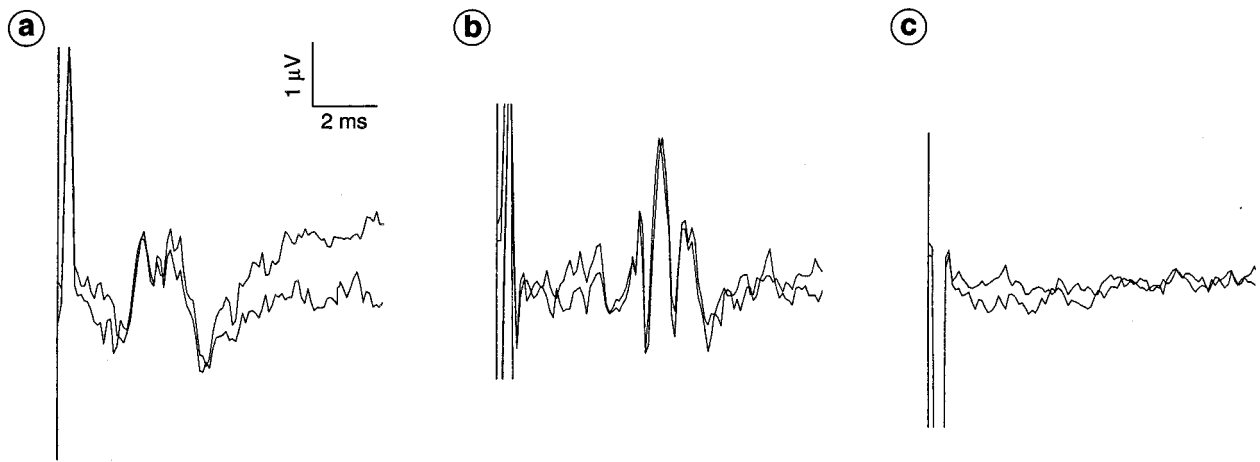


FIG. 4. Variability of frenulum responses between subjects. *c*, absence of penile dorsal nerve response suggests that frenulum is innervated solely by branch of perineal nerve.

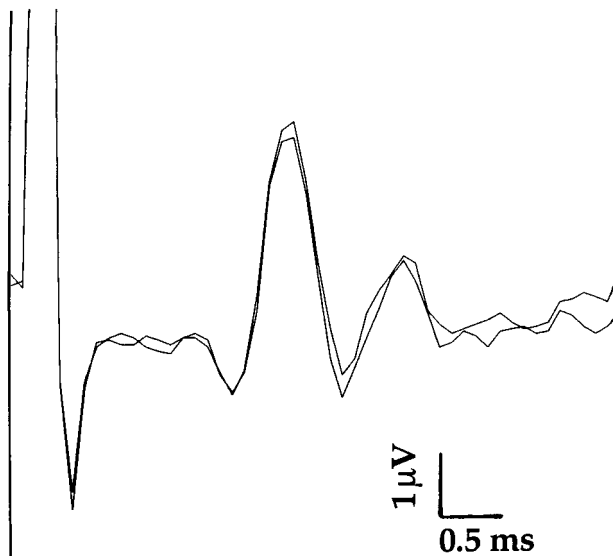


FIG. 5. Response recorded from penile dorsal nerve trunk following orthodromic stimulation of terminal branches of same nerve in glans. Response is triphasic wave denoting passage of traveling wave past recording electrodes. Compare to monophasic waves recorded in glans which denote arrival of action potential in terminal portion of nerve.

The data from our study demonstrate the electrical characteristics of the penile dorsal nerve within the glans. There are many nerve endings compared to nerve trunks within the glans, in contrast to the shaft where the relative number of nerve endings is small compared to the size and number of nerve trunks and branches. The monophasic wave forms are an electrical representation of the nerve endings proliferating within the glans, confirming its function as a sensory structure. This structure is in keeping with the anatomical dissections in which innervation of the shaft by the penile dorsal nerve demonstrated a 2-dimensional, arborizing pattern but innervation of the glans was an effusive 3-dimensional array.¹

The glans appears to have areas that are neurologically distinct. Kuhn found the corona and frenulum to be particularly responsive to inducing erection and ejaculation in spinal cord injured patients.¹⁰ Halata and Munger corroborated this observation with the identification of higher numbers of genital receptors in these 2 areas compared to the remainder of the penis.⁸ However, data from our study does not provide any electrophysiological evidence for particular areas of the

glans to be of lower threshold than others in the induction of sexual reflexes. There is no significant difference in amplitude, morphology or latency of the responses to explain the previously noted findings. The threshold of sexual reflex induction may be due to the type and density of receptors rather than the pattern of nerve fiber distribution within the glans.

Latencies of the responses within the glans corresponded to a pattern of innervation whereby the branches of the penile dorsal nerve enter the glans close to the dorsal midline and then radiate ventrolaterally while traveling distally. The progression of the nerve fibers through the glans can be traced by following the progression of latencies at various points (see table). The latencies of the frenular responses when present were typically the longest, indicating that the fibers to innervate this structure are the most distal reaching penile dorsal nerve fibers within the glans.

In 3 of the 14 subjects frenular responses were not obtained. Frenular sensation remained intact in these men indicating that this area is innervated solely by a branch of the perineal nerve without a contribution by the penile dorsal nerve. This is not an unexpected finding as Kaneko and Bradley electrophysiologically demonstrated that the ventral aspect of the penis in 22% of their subjects was innervated by the penile dorsal nerve and perineal nerve.¹¹ A sensory examination performed in all subjects following anesthetization of the penile dorsal nerve revealed a triangular area on the ventral aspect of the penile shaft that was intact to pinprick sensation with the frenulum at the apex. There was also a surrounding area (transition zone) in which pinprick sensation was impaired but not abolished. This area is innervated by the penile dorsal nerve and perineal nerves, whereas the ventral aspect is solely innervated by the perineal nerve. These data suggest that the percentage of men with perineal innervation of the penis is much higher than 22% and that the penis receives dual innervation from both nerves in most men. Urologists acknowledge that a penile block for circumcision requires a circumferential block to anesthetize the perineal nerve contribution as well as anesthetization of the penile dorsal nerve trunks.¹² Future electrophysiological studies on the perineal innervation of the penis are needed to clarify the role of this nerve in sexual responses.

Application of a penile dorsal nerve block allowed us to define clinically the sensory distribution of the penile dorsal nerve within the glans as well as along the shaft. In addition, blocking the penile dorsal nerve facilitated the study by allowing the subjects to be more comfortable during electrode placement. Preliminary studies were performed without

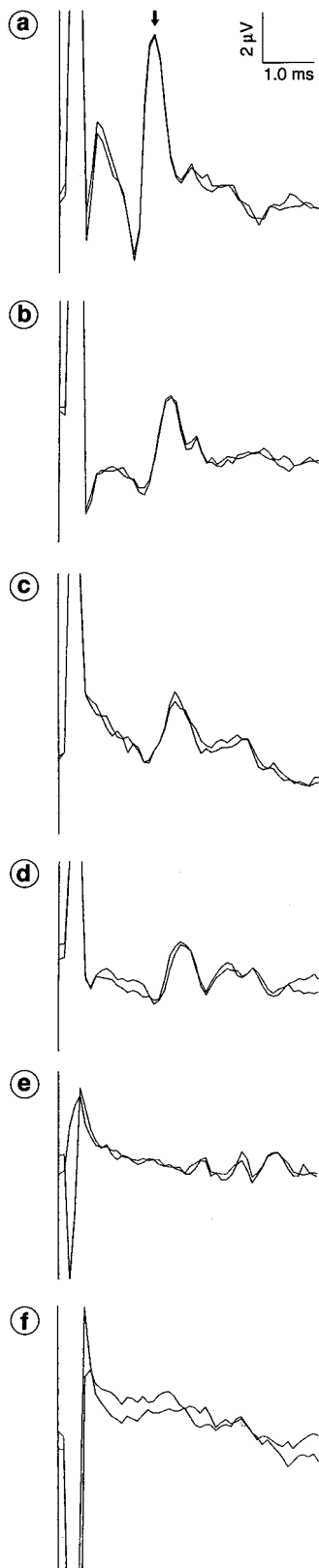


FIG. 6. Progressive diminution of response amplitude recorded in single subject proceeding from proximal to distal. Note initial negative deflection (arrow). *a*, penile shaft. *b*, corona 1:00. *c*, dorsal mid glans. *d*, corona 3:00. *e*, ventral mid glans. *f*, frenulum.

anesthetizing the penis and no significant difference in the results could be detected compared to the anesthetized penis. No aberration of the results was anticipated since the electrodiagnostic testing was performed distal to the nerve block.

Concentric needles were used instead of surface electrodes because of the increased specificity of needles for a particular area of the glans.

It is anticipated that this methodology will improve the detection of penile neuropathy, which is a demonstrated etiology of impotence.¹³ Current clinical assessment includes physical examination, biothesiometry and electrodiagnostic testing. As is common in other extremities, physical examination alone cannot detect subtle neuropathy in the penis as well as more objective methods. Biothesiometry provides a more objective evaluation of penile sensory capacity but it is not as precise as electrodiagnostic measurements of neural integrity.¹⁴

Electrodiagnostic testing for penile neuropathy includes measurement of the bulbocavernosus reflex latency⁹ and nerve conduction velocity of the penile dorsal nerve.^{13, 15, 16} Bulbocavernosus reflex latency measurements often are normal in impotent men with known neuropathy,¹⁷ in part because the range of normal latencies is so large. In the standard method of calculating the nerve conduction velocity of the dorsal nerve of the penis stimulating and recording electrodes are placed on the penile shaft.¹⁸ The glanular electrodes in our study recorded electrical responses in the terminal portions of the nerve rather than activity limited to the penile shaft. The pathology in peripheral neuropathy is known as a "dying back" neuropathy in which axonal degeneration occurs initially at the most distal portion of the neuron and proceeds proximally.¹⁹ In penile peripheral neuropathy the portions of the penile dorsal nerve most susceptible to degeneration are fibers innervating the glans. Thus, this modified technique of measuring nerve conduction velocity of the penile dorsal nerve may have an advantage over the standard method in detecting penile neuropathy. However, the usefulness of this method remains to be demonstrated in the clinical setting.

CONCLUSIONS

The penile dorsal nerve innervates the glans penis except for the area of the frenulum, which is innervated by the penile dorsal nerve and a branch of the perineal nerve. The electrical responses recorded from the penile dorsal nerve in the glans are consistent with the pattern of innervation described in neuro-anatomical studies, whereby the fibers enter the glans and radiate ventrolateral. The monophasic waves recorded through the glans represent terminal nerve endings supporting the concept of the glans as a sensory structure.

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REFERENCES

1. Yang, C. and Bradley, W. E.: Peripheral distribution of the human penile dorsal nerve. *J. Urol.*, **159**: 1912, 1998.
2. Hart, B.: Sexual reflexes in the male rat after anesthetization of the glans penis. *Behav. Biol.*, **7**: 127, 1972.
3. Herbert, J.: The role of the dorsal nerves of the penis in the sexual behaviour of the male rhesus monkey. *Physiol. Behav.*, **10**: 293, 1973.
4. Seftel, A. D., Resnick, M. I. and Boswell, M. V.: Dorsal nerve block for management of intraoperative penile erection. *J. Urol.*, **151**: 394, 1994.
5. Yang, C., Bradley, W. E. and Berger, R. E.: The effect of pharmacologic erection on the penile dorsal nerve. *Muscle Nerve*, **20**: 1439, 1997.
6. Aronson, L. and Cooper, M. L.: Seasonal variation in mating behaviour in cats after desensitization of glans penis. *Science*, **152**: 226, 1966.
7. Sarkarati, M., Rossier, A. B. and Fam, B. A.: Experience in vibratory and electroejaculation techniques in spinal cord injury patients: a preliminary report. *J. Urol.*, **138**: 59, 1987.
8. Halata, Z. and Munger, B.: The neuroanatomical basis for the protopathic sensibility of the human glans penis. *Brain Res.*, **371**: 205, 1986.
9. Dick, H., Bradley, W., Scott, F. and Timm, G.: Pudendal sexual

- reflexes: electrophysiologic investigations. *Urology*, **3**: 376, 1973.
10. Kuhn, R. A.: Functional capacity of the isolated human spinal cord. *Brain*, **73**: 1, 1950.
 11. Kaneko, S. and Bradley, W.: Penile electrodiagnosis: penile peripheral innervation. *Urology*, **30**: 210, 1987.
 12. Serour, F., Mori, J. and Barr, J.: Optimal regional anesthesia for circumcision. *Anesth. Analg.*, **79**: 129, 1994.
 13. Lin, J. T. and Bradley, W. E.: Penile neuropathy in insulin-dependent diabetes mellitus. *J. Urol.*, **133**: 213, 1985.
 14. Bemelmans, B., Hendrikx, L. B., Koldewijn, E. L., Lemmens, W. A., Debruyne, F. M. and Meuleman, E. J.: Comparison of biothesiometry and neuro-physiological investigations for the clinical evaluation of patients with erectile dysfunction. *J. Urol.*, **153**: 1483, 1995.
 15. Benvenuti, F., Boncinelli, L. and Vignoli, G. C.: Male sexual impotence in diabetes mellitus: vasculogenic versus neurogenic factors. *Neurourol. Urodynam.*, **12**: 145, 1993.
 16. Daniels, J. S.: Abnormal nerve conduction in impotent patients with diabetes mellitus. *Diabetes Care*, **12**: 449, 1989.
 17. Buvat, J., Lemaire, A., Buvat-Herbaut, M., Guieu, J. D., Bailleul, J. P. and Fossati, P.: Comparative investigations in 26 impotent and 26 nonimpotent diabetic patients. *J. Urol.*, **133**: 34, 1985.
 18. Bradley, W. E., Lin, J. T. Y. and Johnson, B.: Measurement of the conduction velocity of the penile dorsal nerve. *J. Urol.*, **131**: 1127, 1984.
 19. Kimura, J.: Anatomy and physiology of the peripheral nerve. In:

Electrodiagnosis in Diseases of Nerve and Muscle: Principles and Practice, 2nd ed. Philadelphia: F. A. Davis Co., chapt. 4, pp. 55-77, 1989.

EDITORIAL COMMENT

This report, which is an extension of the work by this group on the innervation of the glans penis, further increases our understanding of the glanular innervations using electrophysiological techniques. Although the findings are as expected, the authors clearly demonstrate the overlap of the dorsal nerve and perineal nerve innervations to the frenular area, and confirm (no surprise) the glans as a sensory structure by documenting the presence of monophasic waves. The ventrolateral direction of the innervation of the dorsal nerve to the glans is of potential significance when one selectively measures conduction velocity of stimulus applied at the dorsal versus the ventral surface and from the corona versus the shaft. We will anticipate that the next phase of this study is documentation of the technique in detecting subtle neuropathy in men with erectile and those with ejaculatory dysfunction but even more in those with unexplained hypesthesia, hyperesthesia, anesthesia and pain of the glans penis.

Ananias C. Diokno
Department of Urology
William Beaumont Hospital
Royal Oak, Michigan