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Role of penile electrodermal activity in the evaluation of autonomic innervation of corpus cavernosum

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Electrodiagnostic tests measuring the activities of cavernous smooth muscle and sudomotor structures of penile skin are used in order to evaluate autonomic innervation of the penis. Owing to closeness of these tissues, the interference of sympathetic activity during recording is a possibility. In this study, we investigated this possibility in 10 patients whose cavernosal tissues were destroyed during penile prosthesis implantation by comparing the pre- and postoperative penile skin electrodermal activities. Penile electrodermal activities were recorded with surface electrodes before and after the operation. All of the patients had spontaneous and evoked penile electrodermal activity (EDA). The mean amplitude of evoked EDA decreased from 2159 ± 700 to 1413 ± 515 μV following penile prosthesis surgery ($P = 0.017$). The decrease in the amplitude of penile-evoked EDA following penile prosthesis implantation suggests the contribution of cavernous smooth muscle activity to the sudomotor responses prior to operation. Although corpus cavernosum sympathetic activity contributes to the penile skin recordings, these recordings are mostly the result of penile skin sudomotor sympathetic activity. Therefore, surface potentials recorded from penile skin should not be used for the evaluation of autonomic innervation of corpus cavernosum.
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Introduction

Tests measuring sympathetic nervous system activity are sometimes used for the evaluation of penile autonomic innervation in patients with erectile dysfunction.[1] Sympathetic activity is carried to the perineal skin by sudomotor sympathetic nerve fibers and to the corpus cavernosum and other vascular structures by vasomotor sympathetic fibers.[2] Sudomotor sympathetic activity is classically recorded by surface electrodes placed over the penile skin or mons pubis.[3,4] On the other hand, sympathetic activity of corpus cavernosum is evaluated by needle electrodes placed within the cavernous bodies.[5–7]

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Some authors claimed that surface potentials recorded from penile skin could reflect corpus cavernosum electromyography and they proposed to utilize surface electrode recordings instead of needle electrode recordings.[8] However, the possibility of interference of sympathetic activity recorded with surface electrode from one of the two nearby structures as penile skin and corpus cavernosum may hinder accurate evaluation. We tried to evaluate the possibility of discrepancy between the sympathetic innervation of corpus cavernosum and penile skin in a model of penile prosthesis implantation in which bougie dilatation of corpus cavernosum up to tunica albuginea was performed, destructing the sinusoidal smooth muscles. Previous studies demonstrated added tumescence by pharmacological stimulation in some of the patients with penile prosthesis.[9,10] However, this added tumescence was reported to be due to the engorgement of glans and corpus spongiosum by the same authors.

In this way, we tried to determine the contribution of these two potential generators, that is, penile skin and corpus cavernosum by turning off one of the generators, that is, corpus cavernosum. We named the activity that we have recorded from penile skin by surface electrode as electrodermal activity (EDA), and pre- and post-operative EDA values were compared.

Materials and methods

We recruited 10 men who had penile prosthesis implantation following bougie dilatation of corpus cavernosum up to tunica albuginea that disrupted the sinusoidal smooth muscles. Patients were informed about all the stages of evaluation and neurophysiologic tests, and written informed consents were obtained. None of the subjects were under the treatment of anticholinergics or any other autonomic nervous system drugs, and all neurophysiologic testing were performed at the same time of the day. Tests were performed in a silent room with a temperature between 20 and 22°C. Two-channel Medelec Synergy EMG/EP machine (Oxford, London) was used for all the neurophysiologic tests. Penile prosthesis implantation was performed in these patients due to arteriogenic, neurogenic and veno-occlusive erectile dysfunction. The type of the prosthesis was malleable (AMS 650™) in all cases. All the patients had partial erections preoperatively, which were not sufficient to allow sexual intercourse. In order to determine the absence or presence of spontaneous electrical activity in corpus cavernosum (CC-EMG) preoperatively, all patients were evaluated with a concentric needle electrode (TECA disposable Concentric Needles, length, 37 mm; needle diameter, 0.46 mm (26 G); recording area (mm^3), 0.07 mm; Part Number: X53156) that was placed into the right corpus cavernosum on the mid-shaft with the tip in the mid-corpus, and the activity was recorded for 30 min. Spontaneous corpus cavernosum activity was present in all patients preoperatively. After the implantation, all the patients were questioned specifically for the presence of extra penile enlargement and/or rigidity during sexual stimulation and intercourse. For the preoperative CC-EMG recordings, frequency filters were set between 0.1 and 50 Hz for needle electrodes.

Pre- and postoperative spontaneous and evoked EDA from penile skin were recorded with two Ag/AgCl surface electrodes (adult size, disc diameter 9 mm, Touchproof Part No. 19329T, TECA Accessories by Medelec), one of them was placed on the penile skin over left corpus cavernosum as an active recording electrode and the other one on the left anterior superior iliac spine as a reference electrode. A grounding connection was placed on the contralateral forearm. A bipolar nerve stimulator was placed on the flexor side of forearm over the median nerve. Impedances of electrodes were adjusted to be lower than 8 kΩ. Frequency filters were set between 0.1 and 100 Hz for the surface electrodes. After connecting the electrodes, we waited for 15 min before starting the tests in order to eliminate the possible effects of procedures on sympathetic nervous system. Pre- and postoperative penile spontaneous EDA recordings were obtained for 30 min. Following the spontaneous activity recordings, we recorded evoked activity by stimulating the median nerve at 15–19 mA. The sweep of evoked activity was 10 s and the tests were repeated six to 10 times with an interstimulus interval of minimum 1 min to eliminate habituation. The latencies of evoked activity were measured at the first positive or negative deflection from the baseline, and the amplitudes were measured between peak-to-peak distances. The earliest latency and the highest amplitude values were taken into account for analyses. Pre- and postoperative penile-evoked EDA values were compared with Wilcoxon's test and a *P*-value of less than 0.05 was regarded as statistically significant.

Results

The mean age of the patients was 57.6±4.5 (25–72) y. The mean duration of the implantation was 7.4±1.3 (3–14) months. The etiologic factors were neurogenic in six, arteriogenic in two and cavernous in two cases (Table 1). Three patients had diabetes mellitus and one of them had autonomic neuropathy in accordance with the criteria used by Low *et al.*[11] None of the subjects with penile prosthesis reported the presence of extra enlargement or rigidity during sexual stimulation or intercourse. Penile spontaneous and evoked EDA were present in all patients both preoperatively (Figure 1a) and postoperatively (Figure 1b). In the penile spontaneous EDA recordings after implantation, synchronous and usually

Table 1 Demographic features and comorbidity profile of the patients

Patient	*Age (y)*	*Duration (months)*	*Etiology of erectile dysfunction*	*DM*	*AN*
HD	25	14	Neurogenic (DM)	+	+
HA	50	4	Neurogenic (RRP)	–	–
MO	55	9	Neurogenic (SP)	–	–
RU	48	3	Arteriogenic	+	–
MK	70	10	Cavernous (VOD)	–	–
MA	71	6	Cavernous (VOD)	–	–
NO	60	6	Arteriogenic	+	–
HG	58	5	Neurogenic (trauma)	–	–
MK	72	14	Neurogenic (TURP)	–	–
SA	67	3	Neurogenic (RCP)	–	–

DM: diabetes mellitus; AN: autonomic neuropathy; VOD: veno-occlusive dysfunction; RRP: radical retropubic prostatectomy; SP: suprapubic prostatectomy; TURP: transuretral resection of the prostate; RCP: radical cystoprostatectomy.

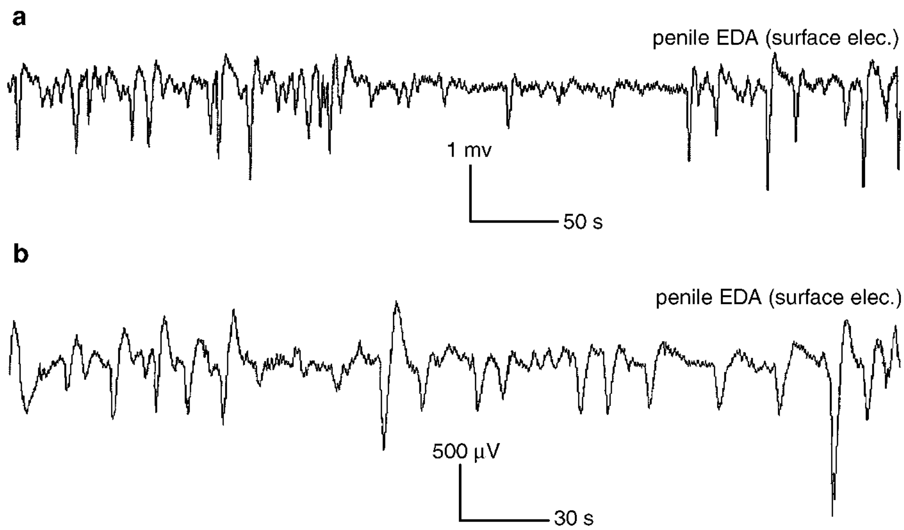

Figure 1 (a) Penile spontaneous EDA recording from penile skin with surface electrode before penile prosthesis implantation. (b) Penile spontaneous EDA recording after penile prosthesis implantation.

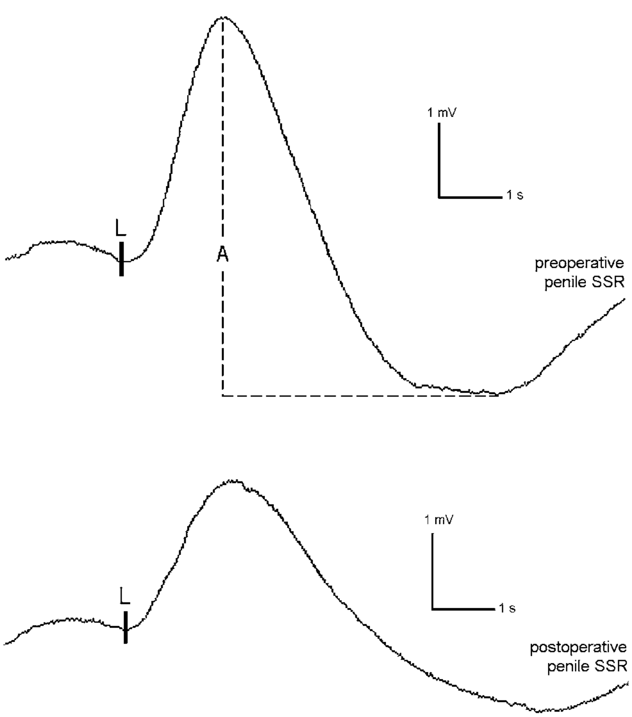

Figure 2 Penile-evoked EDA (SSRs) before and after penile prosthesis implantation (A: amplitude, L: latency).

mono- or biphasic waves with a frequency of 1–8/min were observed. Postoperative penile spontaneous EDA showed lower amplitude oscillations when compared to the preoperative recordings (Figures 1a and b). Although there was no significant difference in the evoked EDA latency in the postoperative period, when compared to the preoperative value, a statistically significant decrease in amplitude was detected ($P<0.05$) (Figure 2, Table 2).

Table 2 Mean latency and amplitude values (±s.e.m.; minimum–maximum) of penile SSR in patients before and after penile prosthesis implantation

	Latency (ms)	*Amplitude (µV)*
Penile SSR before prosthesis	1665±98 (1320–2410)	2159±700 (289–7277)
Penile SSR after prosthesis	1754±90 (1330–2350)	1413±515 (255–4808)
P-value	0.203	0.017

Discussion

The evaluation of autonomic innervation of corpus cavernosum is frequently performed by needle electrodes. However, some of the authors prefer surface electrodes. Both of the tests has its own advantages and disadvantages.[7] The possibility of recording the activity originating from penile skin in addition to corpus cavernosum is the main disadvantage of surface electrodes.[7] The main objective of this study was to find out the origin of the activity recorded from penile skin with surface electrodes. We named this penile skin recording as EDA. Hence, the activity that appears without sympathetic nervous system activation on the surface recordings was named as spontaneous EDA, which some of the authors named it as penile sudomotor oscillations or surface recorded CC-EMG.[8,12–16] We named the activity that was recorded from electrode region by the median nerve stimulation as evoked EDA, which some of the authors named it as penile sympathetic skin response (SSR).[4,17] We have used the CC-EMG term only for recordings obtained from corpus cavernosum by needle electrode. In this study, we obtained both spontaneous and evoked EDA from penile skin with surface electrodes in all patients who had disrupted smooth musculature following penile prosthesis implantation. Furthermore, we recorded lower amplitude waveforms in the postoperative period compared to the preoperative recordings. This finding suggests the contribution of cavernous body activity to the skin potentials recorded in the preoperative period, and skin recordings should not represent the autonomic innervation of corpus cavernosum.

The association of electrical oscillations in the skin related to the secretions of sweat glands with sympathetic system has been known since 1890s.[18] After the demonstration of the possibility of recording potential changes as a result of a certain stimulus by Shahani *et al*[19] in 1984, evoked EDA (SSR) has been used for the evaluation of autonomic involvement in neurological patients. In 1987, Ertekin *et al*[20] reported that SSR could be recorded with surface electrodes from the genital region in addition to hand and foot. In the following years, various studies evaluating the diagnostic value of genital-evoked EDA in neurourologic diseases were published.[3,4,21,22] Genital-evoked EDA is usually seen as a biphasic wave with an amplitude value of 0.2–1 mV and a latency of 1.5 s. Ertekin *et al*[20] reported that the recording could be obtained through a pair of surface electrodes placed on the penile shaft or dorsum of the penis and mons pubis or anterior superior iliac spine. They also reported that responses with higher amplitude and less habituation could be recorded from dorsum of the penis and mons pubis. The recording could also be obtained from the perineum–pubis and dorsal–ventral sides of the penis.[3]

Wagner *et al*[5] reported the first electromyographic activity recording from corpus cavernosum in 1989. Since then, CC-EMG has been widely investigated and the nature of the recorded waves and their role in demonstrating autonomic dysfunction and smooth muscle degeneration has been evaluated.[12,13,23] It was reported that in addition to spontaneous activity, evoked cavernous activity (with electrical and other stimuli) was recorded from the corpus cavernosum.[6,24] Sympathetic fibers regulating sudomotor activity of penile skin and smooth muscle activity of corpus cavernosum originate from lumbar spinal cord and they travel in close proximity to the lumbar postganglia and then to the genital area through hypogastric nerve.[20] Owing to this close proximity in the peripheral neural tracts, it was reported that genital-evoked EDA in patients with erectile dysfunction could reveal sympathetic involvement; however, as the clinical validity of CC-EMG was established, the value of genital-evoked EDA has been decreased.[1,3]

Corpus cavernosum electromyography was usually performed with needle electrodes. Stief *et al*[8] first reported the possibility of activity recording by the use of surface electrodes placed on the penile skin, and surface recording yielded better results compared to needle electrodes. They reported that potentials recorded by surface electrodes had lower amplitudes and they related this to distant area recording. However, in the following studies, they reported that they did not prefer surface recording method due to concerns about the interference of skin potentials.[25] However, after this report, most of the investigators preferred surface electrodes for CC-EMG recording for its noninvasive nature.[12–16] Our study shows that the potentials recorded with surface electrodes could not be reflections of CC-EMG, but they are sudomotor sympathetic skin activities; however, there seems to be some potential interference and amplification of skin potentials by the intact smooth muscle tissue as we compare the pre- and postoperative amplitudes of evoked responses. Similarly, Yarnitsky *et al*[24] reported the absence of a correlation between spontaneous cavernous activity and spontaneous EDA, but due to similarity of latency and configuration of evoked activities, they proposed a relationship between EDA and activity recorded from the cavernous bodies. Although they were not able to obtain spontaneous EDA recording in any of the subjects, this was probably due to their attempt to obtain EDA recording from subcutaneous tissue and nonpalmar, nonplantar regions with needle electrodes. It is also known that EDA in nonpalmar, nonplantar region could only be recorded after changes in body heat.[26]

In a study involving simultaneous penile-evoked EDA and CC-EMG recordings, during erection following intracavernous prostaglandin E1 injection, CC-EMG could not be recorded while it was possible to record evoked EDA.[4] However, the difference in the penile-evoked EDA amplitudes before and after prostaglandin E1 injection was not reported in that study. In another study, it was reported that CC-EMG and penile EDA were different activities due to spatial difference of waves observed during simultaneous spontaneous activity recordings and their different responses at various physiological conditions.[23] However, during recording from corpus cavernosum with a concentric needle and from penile skin with a surface electrode, although they appear in different time periods, both the oscillations due to smooth muscle activity of cavernous body and EDA are expected to occur simultaneously. In addition, the contribution of electrical changes in both tissues to the potentials recorded from penile skin after a certain stimulus is expected.

In our opinion, both electromyographic activity of cavernous smooth muscle and sudomotor EDA originating from the sweat glands contribute to the spontaneous or evoked activities recorded from penile skin with surface electrodes that records activity from a larger area compared to needle electrodes.[7] Although they have similar peripheral tracts but different central neural structures and effectors, we believe that the surface recording method is not an appropriate way for the evaluation of autonomic innervation and smooth muscle functions of the corpus cavernosum due to interference of activities derived from these two structures. In spite of progressed degeneration in cavernous smooth muscles, the waveforms in EDA obtained with surface electrodes could be interpreted as smooth muscle activity and the results could be erroneously evaluated as normal.

Conclusion

The significant decrease in the amplitude of penile spontaneous and evoked EDA following prosthesis implantation suggests the contribution of cavernous smooth muscle activity to the activity recorded from the penile skin in cases with undisrupted cavernous smooth muscle structure. Since the recordings from penile skin with the surface electrodes represent mostly sudomotor sympathetic activity, surface recordings for CC-EMG is not suitable for the evaluation of autonomic innervation of cavernous tissues.

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