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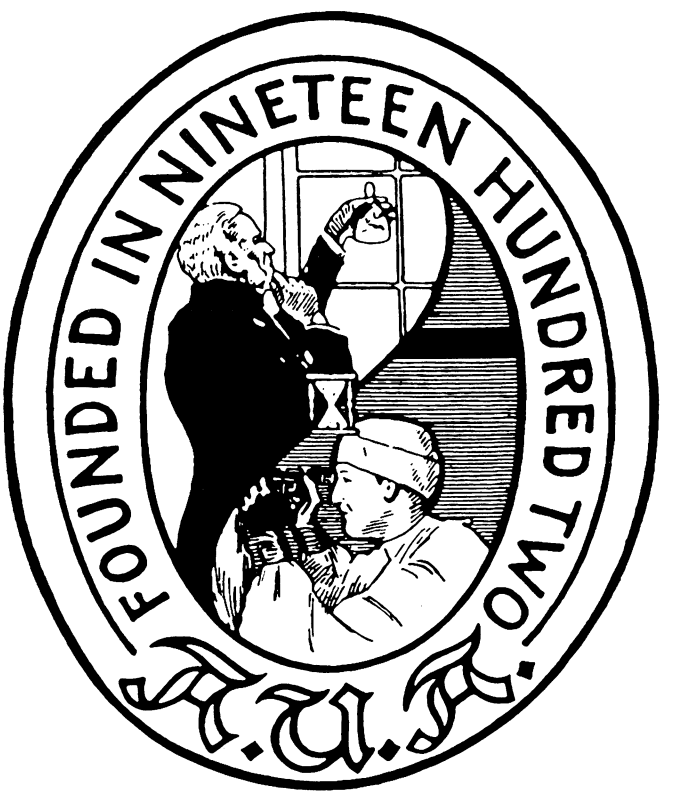

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TRANSCUTANEOUS REGISTRATION OF CAVERNOUS SMOOTH MUSCLE ELECTRICAL ACTIVITY: NONINVASIVE DIAGNOSIS OF NEUROGENIC AUTONOMIC IMPOTENCE

CHRISTIAN G. STIEF, WALTER F. THON, MOHAMAD DJAMILIAN, ERNST P. ALLHOFF AND UDO JONAS

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ABSTRACT

Registration of cavernous electrical activity was shown to be a possible method for the evaluation of cavernous autonomic innervation. Recent studies in patients with normal erectile function showed that cavernous electrical activity is synchronous throughout the entire cavernous bodies. Therefore, we examined the feasibility of transcutaneous registration of cavernous electrical activity in 8 normal and 62 impotent patients. In the sitting patient cavernous electrical activity was recorded with a 2-channel electrophysiological unit. Recording was done with a coaxial needle electrode in the proximal left cavernous body and with surface electrodes bilaterally on the penile shaft.

In 7 of 8 normal patients registration was similar regarding shape, amplitude and length of the potentials. In 1 of 8 normal patients swelling of the penile shaft after circumcision resulted in a dramatically decreased amplitude of the potentials. In 41 of 62 impotent patients recordings were similar. In 10 of 62 patients no recording or markedly decreased amplitudes were noted with the surface electrodes and in these patients a small penis or penile retraction with consecutive electrode displacement was found. Careful repositioning of the surface electrodes with the patient in the supine position resulted in similar recordings in 9 (inconsistently in 4). In 11 of the 62 patients more information was obtained with the surface than with the needle electrode. Our results show that recording of cavernous electrical activity can be done in a completely noninvasive manner using surface electrodes with similar or even better information obtained than with needle electrodes.

KEY WORDS: autonomic nervous system; impotence; penile erection; muscle, smooth; transcutaneous electric nerve stimulation

Whereas vasculogenic impotence can be assessed rather precisely,[1,2] the diagnosis of possible neurogenic factors was limited to the evaluation of somatosensory penile innervation.[3-5] The autonomic cavernous supply, responsible for erection, could not be examined. This major deficit in the diagnosis of impotence was first approached by Gerstenberg[6] and Wagner[7,8] et al with their suggestion for registration of cavernous electrical activity. However, only analysis of the single potentials of the cavernous electrical activity possibly allows for the diagnosis of cavernous autonomic dysfunction.[9]

Simultaneous recording of cavernous electrical activity in the normal subject at different areas of the cavernous bodies showed synchronization of the electrical activity (fig. 1). This synchronous contraction of the cavernous smooth muscle cells results in a potential with an amplitude of approximately 450 μv.[9] This relatively large potential prompted us to attempt recording of cavernous electrical activity with surface electrodes. We describe the results of synchronous recording of cavernous electrical activity with needle and surface electrodes in 8 normal and 62 impotent patients.

PATIENTS AND METHOD

Eight patients with normal erectile function from our urological ward were extensively informed about the procedure as well as possible side effects. All 8 patients consented to undergo simultaneous recording of cavernous electrical activity. Patient age was 17 to 60 years. Furthermore, cavernous electrical activity was recorded simultaneously in 62 consecutive patients from our impotence clinic who were 34 to 71 years old. In 29 of the 62 patients with erectile dysfunction a history revealed possible underlying diseases, including multiple sclerosis in 4, insulin-dependent diabetes in 5 (in 4 for more than 20 years), primary erectile dysfunction in 5 and aorto-occlusive disease (stage IIb) in 2. Pelvic trauma was found in 2 patients, radical prostatectomy in 3, chronic renal failure for more than 5 years in 2 (1 of these experienced a 14-day episode of priapism 15 years previously), radical cystoprostatectomy in 1 and acute cerebral ischemia in 1. A total of 4 patients had a complete spinal cord lesion above the T12 level.

The examination was done with the patient in the sitting position. After appropriate disinfection of the penile skin a coaxial needle electrode (Dantec 9013 L, 4 cm. long, surface of the tip 0.07 mm.^{2}) was inserted into the proximal lateral left cavernous body and advanced until the needle tip was in the center of the proximal left cavernous body. The surface electrodes (Dantec 13 L 20) were placed bilaterally on the proximal cavernous bodies with the positive electrode over the left cavernous body. The grounding electrode was placed around the right thigh. Since audiovisual sexual stimulation was not necessary for interpretation of the recordings,[9] it was omitted for

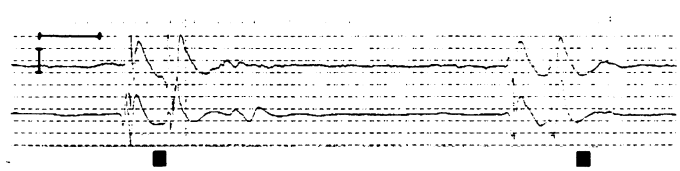

FIG. 1. Simultaneous recording in both cavernous bodies with needle electrodes showed synchronization of cavernous electric activity in 53-year-old patient with normal erectile function. Horizontal bar is 5 seconds. Vertical bar is 100 μv.

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routine diagnostic tests. Because sympathetic activation, for example by stress, induces cavernous smooth muscle contraction[10] with consecutive changes in cavernous electrical activity, great importance was attributed to decreasing possible stress factors. The examination was performed in a quiet room during the second or third visit. Patients were advised to relax during the examination and to close their eyes. Examination was begun approximately 20 minutes after the electrodes were placed with the examiner leaving the room. The signals were processed by an electrophysiological unit (Spacerecorder* and modified Neuromatic†). For control or for specific scientific purposes a Hugo Sachs Electronic electrophysiological unit‡ with a wider range of low cutoff frequencies (down to 0.1 Hz.), combined with a Graphtec Thermowriter (model 3310) was used.

RESULTS

In 7 of 8 normal patients similar potentials (regarding shape, amplitude and length of the potentials) were recorded with the needle and surface electrodes, respectively (fig. 2, *A*). In 4 of these 7 patients audiovisual sexual stimulation was applied at the end of the examination. Before audiovisual sexual stimulation the needle electrode was removed because many patients previously complained that the needle electrode caused some pain that decreased the full erectile response to audiovisual sexual stimulation. All 4 patients had a full erection to audiovisual sexual stimulation with surface electrodes on the penile shaft. With increasing tumescence and rigidity the amplitude and length of the potentials decreased, whereas the frequency increased. During full erection small potentials of high amplitude were observed (fig. 2, *B*). In 1 of the 8 normal patients the examination was done 1 day after circumcision with consecutive edema of the penile skin. In this patient recording with the surface electrodes showed a dramatically decreased amplitude of the potentials (fig. 2, *C*). In 2 of the 8 normal patients with constant potentials different cutoff frequencies were applied to the recording of cavernous electrical activity. The recording showed that narrowing of the frequency range from 0.1 to 20 Hz. to 1 to 20 Hz. resulted in a significant loss of amplitude of the potentials, whereas narrowing to 5 to 20 Hz. resulted in an almost complete loss of the potential (fig. 3).

In 41 of 62 impotent patients similar recordings were found with the needle and surface electrodes. In these patients information on each of the recordings was comparable to the other and did not contain more diagnostic information than did the other. In 10 impotent patients no recordings or only recordings of a decreased quality were obtained by the surface electrodes, whereas the needle electrode enabled normal (or pathological) recordings. In 9 of these 10 patients dislocation of the surface electrodes was induced by a small penis or by penile retraction (especially in obese patients in the sitting position with the

* Wiest, Unterhaching, Germany.
† Dantec, Copenhagen, Denmark.
‡ HSE, March Hugstetten, Germany.

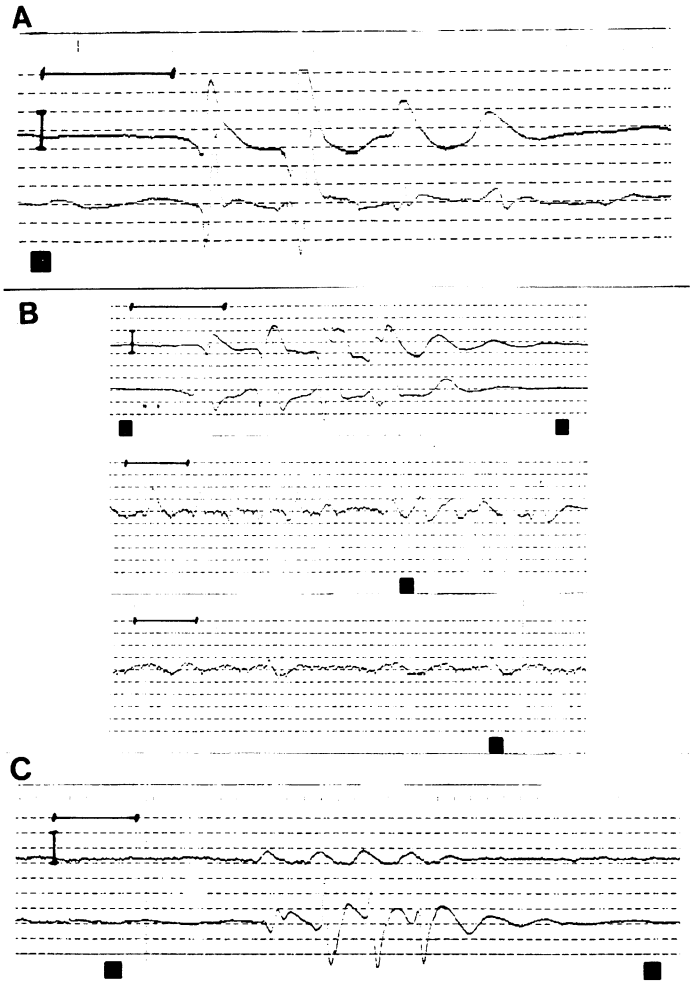

FIG. 2. *A*, recordings with surface electrodes (upper tracing) and with needle electrode (lower tracing) were comparable in 17-year-old man with normal erectile function. *B*, upper tracing from same patient shows cavernous electrical activity during flaccidity, medium tracing during tumescence and lower tracing during full erection. *C*, 1 day after circumcision with consecutive penile swelling, surface electrodes (upper tracing) showed dramatically decreased amplitude of potentials compared to needle electrode (lower tracing). Horizontal bars are 5 seconds. Vertical bars are 100 μv.

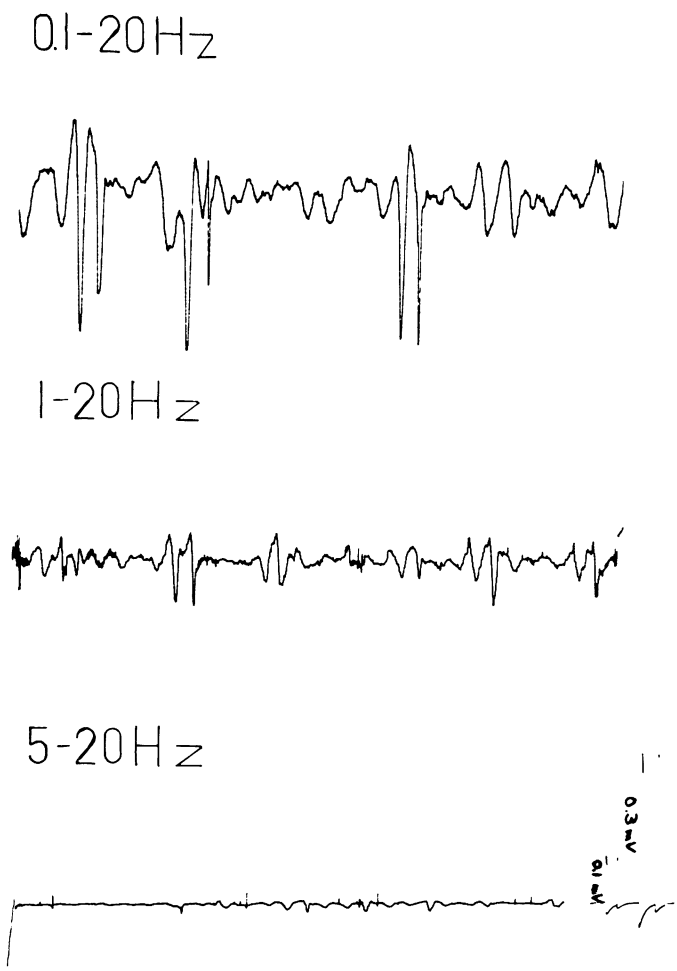

FIG. 3. Changing of frequency range in 31-year-old normal patient with stable potentials resulted in dramatic changes of recording.

penis retracting into the pubic fat). Therefore, at the end of the examination the patient was placed in the supine position, the surface electrodes were carefully replaced and the examination was repeated. In all 9 patients similar recordings to those with the needle electrode subsequently were obtained (in 4 the similarity of the potentials was not consistent during the entire recorded time, fig. 4, *A*). In 1 of the 10 patients recording with the surface electrodes again showed a markedly decreased amplitude after repositioning, whereas recording with the needle electrode showed normal potentials (fig. 4, *B*).

In 11 of the 62 impotent patients recordings with the surface electrodes resulted in more diagnostic information than recordings with the needle electrode. In 1 of these patients recording with the needle electrode showed an unspecific wave-like pattern, whereas recordings with the surface electrode showed normal potentials (fig. 4, *C*). In 1 patient with insulin-dependent diabetes 25 years in duration clinical evaluation[11] was suggestive for intact cavernous smooth muscles (full erectile response to 3 mg. papaverine plus 0.1 mg. phentolamine) and not for cavernous smooth muscle degeneration.[12] In this patient recording of the needle electrode showed potentials suggestive of cavernous smooth muscle degeneration, whereas recording of the surface electrode suggested autonomic failure without smooth muscle impairment (fig. 4, *D*). In 9 of these 11 patients (all with pathological recordings) recordings with the surface electrode showed significantly more pathological findings, especially positive or negative whips,[9] than recordings with the needle electrode. Nonetheless, in 6 of these 9 patients an identical diagnosis (abnormal findings) would have been made with an independent intrepretation of the recordings of the needle or surface electrodes, respectively. In only 3 of the 9 patients were the abnormal potentials recorded by the surface electrodes.

The recordings of cavernous electrical activity with the needle electrode were compared among the different patient groups with particular etiologies. Similar recordings as those described previously were made. Specific patterns of cavernous electrical activity were found in patients with lesions of the peripheral nerve, complete spinal cord injury or cavernous smooth muscle degeneration.[9]

DISCUSSION

The potentials recorded in the normal men are similar to smooth muscle potential recorded with needle electrodes in other species and in other organs.[13] Furthermore, the frequency range of the potential recorded in man is comparable to the findings of the uterus smooth muscle in the rabbit.[13] These similarities support the assumption that our recordings are electrical potentials of the cavernous smooth muscles and not artifacts. Our results show that cavernous electrical activity can be recorded with surface electrodes. Given appropriate placement of the surface electrodes over the cavernous bodies, the diagnostic information seems to be similar or even greater than that obtained with an intracavernously placed needle electrode. The tunica albuginea, although entirely covering the cavernous body, seems not to be an electrical shield for intracavernous electrical activity. This fact most probably is due to the sparse vascularization of the tunica albuginea. However, amplification of the distance between cavernous tissue and the surface of the penile skin seems to interfere dramatically with the quality of recording of the cavernous electrical activity, as seen in the patient with edema of the penile skin.

A prerequisite for recording of cavernous electrical activity is the synchronization of a larger group of cavernous smooth muscle cells, resulting in an electrical potential larger than the background noise (especially in a clinical setting without a Faraday cage). Our previous studies showed that in the normal man cavernous electrical activity is synchronized within the entire cavernous bodies in the flaccid state, suggesting the synchronization of all cavernous smooth muscle cells in the flaccid state. An anatomical base for this electrophysiological finding is the detection of gap junctions between human cavernous smooth muscle cells by Moreno et al.[14] Similar to the studies of cavernous electrical activity recorded with needle electrodes,[9] recording with surface electrodes showed a desynchronization of cavernous smooth muscle electrical activity with increasing tumescence and rigidity during physiological

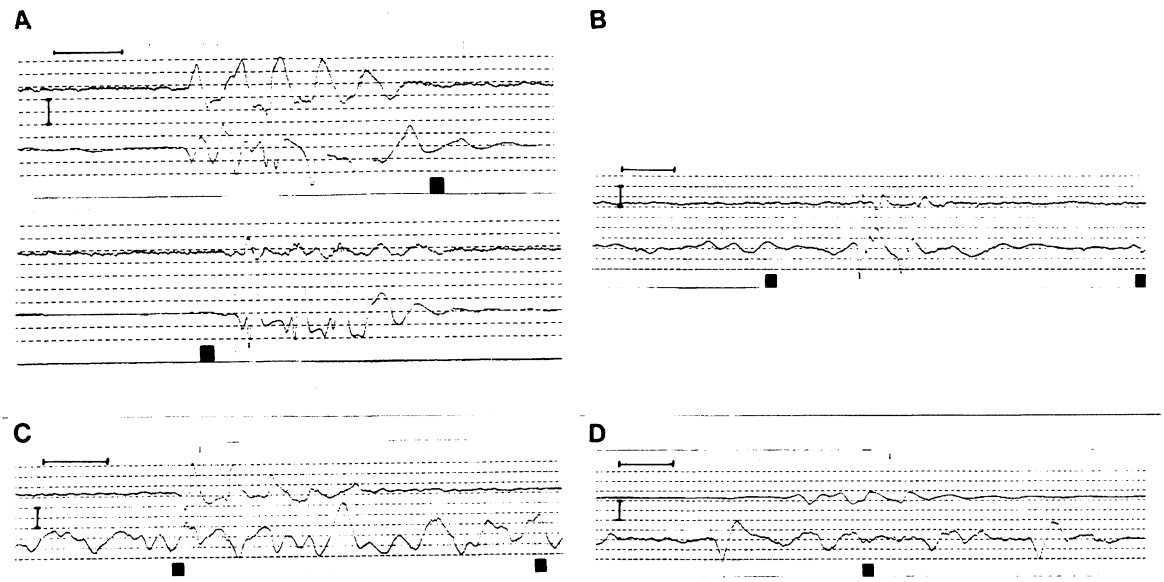

FIG. 4. *A*, in 4 of 9 patients with no surface electrode recordings, repositioning of surface electrodes showed inconsistent similarities comparing recordings with needle or surface electrodes. Upper recording shows good correlation of 2 tracings, whereas lower recording shows normal potential with needle electrode (lower tracing in both recordings) and abnormal potential with surface electrodes (upper tracing). *B*, in 49-year-old patient recording with surface electrodes (upper tracing) shows marked decrease in amplitude compared to needle electrode (lower tracing). *C*, in 62-year-old impotent patient surface electrodes (upper tracing) show normal potentials, whereas needle electrode (lower tracing) shows unspecific wave-like recording. *D*, in impotent patient with diabetes surface electrodes (lower tracing) show potentials suggestive of neurogenic impotence, whereas needle electrode shows potentials suggestive of a myogenic etiology. Horizontal bars are 5 seconds. Vertical bars are 100 μv.

erection. This desynchronization results in potentials of low amplitude and high frequency. The general belief about erection is that it is consistent with complete cavernous smooth muscle relaxation.[15,16] During full erection cavernous electrical activity, although small, high frequent potentials, could still be recorded. Further studies must examine if this electrical activity is associated with complete smooth muscle relaxation or if at least some groups or parts of the cavernous smooth muscles contract during full erection.

Recent ultrastructural studies of the cavernous tissue showed that at least some of the morphological cavernous lesions are only of focal nature.[17] This explains the finding of the patient with an onset of diabetes for 25 years in whom the recordings with the needle electrode suggested myogenic lesions but the surface electrode findings (and the clinical findings with a good erectile response to intracavernous pharmacotherapy) strongly suggested neurogenic lesions with intact smooth muscles. The needle electrode may have been placed into an area with smooth muscle degeneration, whereas most of the cavernous tissue underwent no smooth muscle degeneration. The neurogenic autonomic lesion was detected by the surface electrode, since it picks up the electrical activity of a wider tissue area than the needle electrode. Thus, interpretation of the recording of cavernous smooth muscle electrical activity should be more accurate with surface electrodes than with needle electrodes because a greater area of tissue is recorded and, therefore, pathological potentials are more readily discovered. This assumption is supported by the findings that in 9 patients with pathological potentials more pathological potentials were noted during recording with the surface electrode than with the needle electrode. Especially in patients with focal lesions of the autonomic nerve supply, for example after radical prostatectomy with unilateral partial excision of the neurovascular bundle, small areas of abnormally innervated smooth muscles should be detected more easily. This explanation may also be applicable to the 4 of 9 patients with inconsistent recordings after repositioning of the surface electrodes.

We believe that the noninvasive recording of cavernous electrical activity offers attractive possibilities in the diagnosis of autonomic impotence. Most diagnostic methods for impotence depend upon the complete cavernous smooth muscle relaxation, such as cavernosometry and cavernosography.[2] In case of incomplete relaxation positive results (venous leak) are found. The combination of pharmacocavernosometry with recording of cavernous electrical activity with surface electrodes should provide information about the degree of cavernous smooth muscle relaxation. Furthermore, biofeedback therapy in patients with erectile dysfunction due to performance anxiety may be possible.

Our study shows that cavernous electrical activity can be recorded with surface electrodes bilaterally on the penile shaft with similar information compared to the needle electrode. Further studies by other groups are necessary to reproduce our findings and their interpretations. Furthermore, comparative studies of the single potential analysis of cavernous electric activity with electron microscopic findings of cavernous morphology are necessary to validate the method.

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