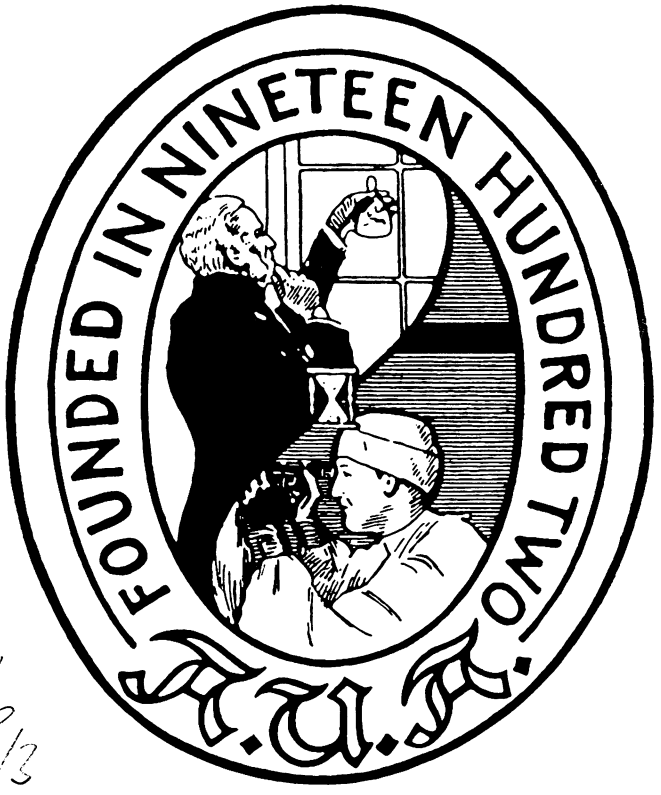
Volume 146 July 1991 Number 1

The Journal of UROLOGY®

Official Journal of the American Urological Association, Inc.
Founded In 1917 By Hugh Hampton Young



Annual Meeting, American Urological Association, Inc., Washington, D. C., May 10–14, 1992

Vol. 146, Decembe
Printed in U. S. A

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0022-5347/91/1463-0867$03.00/0
THE JOURNAL OF UROLOGY
Vol. 146, 867-871, September 1991
Printed in U.S.A.

PENILE DETUMESCENCE: CHARACTERIZATION OF THREE PHASES

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ABSTRACT

In 22 dogs in which erection was induced by cavernous nerve stimulation, we analyzed the intracavernous pressure changes during detumescence without and with acute clamping of the aorta or electrostimulation of the lumbar sympathetic chains. Additionally, the degree of venous outflow obstruction was assessed by saline perfusion of the cavernous body during aortic occlusion.

Detumescence had three distinct phases: an initial phase exhibiting a small pressure increase; a second phase showing a slow pressure decrease; and a third phase in which a fast decrease occurred. The first phase was abolished by aortic clamping, whereas the other phases were not significantly affected. Sympathetic stimulation abolished or prevented the second phase. Perfusion of the cavernous body during the second phase resulted in a pressure rise to off-scale values; however, when initiated during the terminal phase or in the nonstimulated penis, the pressure increase was slight.

Our study indicates that the arterial flow rate influences the duration of the first phase of detumescence and that venous drainage is completely restored in the third phase. Furthermore, sympathetic stimulation causes an almost immediate full restoration of venous drainage, as cavernous perfusion initiated with an intracavernous pressure about twice as high as without sympathetic stimulation failed to increase pressure to off-scale values.

KEY WORDS: penile erection, arterial flow rate, dog, sympathetic nerve, venous drainage, detumescence

The hemodynamics[1-3] and neurophysiology[4] of erection have been studied extensively, but detumescence has received less detailed attention. Studies of the neural mechanisms by Langley and Anderson[5] and Semans and Langworthy[6] verified sympathetic nervous system involvement. The latter authors demonstrated various pathways by which the sympathetic effect could be mediated: in erection induced by sacral root stimulation, neurostimulation of the lumbar sympathetic chains, the hypogastric nerves, or the pudendal nerve resulted in subsidence.[6] Sympathetic stimulation has also been shown to cause subsidence of erection induced by cavernous nerve stimulation in the dog[7] and monkey.[8] The fact that alpha-adrenergic blockade can induce erection suggests that the sympathetic nervous system has a role in detumescence.[9] However, because patients who have undergone extensive retroperitoneal lymph node dissection do not suffer from changes in their erectile mechanism,[10] some doubt is cast on the active role of the sympathetic system during physiologic detumescence.

The hemodynamic changes during detumescence represent a reversal of those occurring during erection: contraction of the cavernous smooth muscles, decrease of the arterial flow, and full restoration of venous outflow, either passively (owing to intrinsic smooth muscle tone) or actively (increased sympathetic activity) or both. In human volunteers, the electrical activity of the cavernous smooth muscle tissue has been shown to decrease during erection and to resume during detumescence.[11] The arterial flow to the penis decreases from a maintenance level to baseline after terminating cavernous nerve stimulation in monkeys[1] and dogs,[2] and venous drainage has been shown radiographically to resume in monkeys after about 40 sec.[1] In dogs, Carati et al. noticed a biphasic decrease in intracavernous pressure after electrostimulation (a slow phase followed by a more rapid phase).[7]

We undertook this study to analyze further the detumescence induced by electrostimulation and the sequence of changes in hemodynamic events in the canine model and to correlate the different phases with the hemodynamic changes.

MATERIALS AND METHODS

Animal preparation. Twenty-two male dogs of various breeds, weighing 22 to 54 kg., were premedicated with acepromazine (0.1 mg./kg. BW) and ketamine (5 mg./kg. BW). The dogs were then placed supine on a heating pad to maintain body temperature. Sodium pentobarbital was administered intravenously in 45 to 60-mg. boluses as needed to maintain adequate anesthesia and spontaneous respiration. Fluid maintenance consisted of intravenous normal saline (two ml./kg./hr.). Blood pressure was monitored through an 18-gauge angiocath placed in the right femoral artery and connected to a Statham transducer (Model 23 BC).

Surgical procedure. A midline abdominal incision was made from the xyphoid process to the pubic symphysis; at the level of the penis, the incision skirted slightly laterally to the right. Either the left or right cavernous nerve was exposed posterolaterally to the prostate and a platinum cuff electrode (Avery Laboratories; Farmingdale, NY) was placed around the nerve for electrical stimulation. In the animals in which sympathetic stimulation was planned, both sympathetic chains were isolated posterolaterally to the aorta at the level of L_5 and platinum cuff electrodes placed. The aorta was freed circumferentially above the level of the aortic trifurcation to facilitate placement of a Satinsky clamp. An ultrasonic blood flow probe (Transonics Systems, Inc.) designed specifically to measure flow in arteries with a diameter of three mm. or less was placed around the internal pudendal artery on the same side as the isolated cavernous nerve. The probe can measure flow as low as 0.5 ml./min. (maximum error of the probe [absolute volume of flow] = ±15% of the reading); linearity [relative accuracy] = ±1%).

Accepted for publication March 14, 1991.
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Supported by a Grant from the Sophia Foundation for Medical Research, The Netherlands.

The penile shaft was partially denuded for placement of one or two 21-gauge butterfly needles in the ipsilateral cavernous body. One needle was connected to a Statham transducer for measurement of the intracavernous pressure; in the dogs slated to undergo cavernous perfusion, the second needle served for saline infusion via a Harvard perfusion pump.

The electrodes were connected to radiofrequency receivers and stimulated with a battery-operated neural stimulator via an antenna (Avery Laboratories; Farmingdale, NY). Amplitudes for cavernous nerve stimulation ranged from 0.6 to 4V (mean, 2 V), for sympathetic chain stimulation from 0.6 to 8 V (mean, 2.8 V). Higher voltages did not lead to a better response. A frequency of 20 Hz and a pulse width of 200 μsec were used for all stimulations. The duration of stimulation of the cavernous nerve was 1 min per trial, for sympathetic stimulation 40 seconds. (The latter began after cavernous nerve stimulation was terminated.) Pressure and flow tracings were recorded on a Grass polygraph (model 7).

Experimental procedure. Three sets of experiments were performed:

Aortic occlusion. In 10 dogs, we studied the influence of aortic occlusion on detumescence. First, the cavernous nerve was stimulated three times, each stimulation lasting one minute with a ten-minute interval between. This procedure was repeated, but at the termination of each of the three stimulations the aorta was clamped to occlude the arterial flow to the penis.

The following parameters were noted with each stimulation: intracavernous pressure at the end of cavernous nerve stimulation; pressure increases occurring just after termination of the stimulation, and the time necessary for the pressure to return to the value at the end of stimulation; any subsequent change in intracavernous pressure, which was subdivided into time sections showing an equal rate of change (the pressure was recorded at a point in the pressure curve where a variation in the rate occurred and the interval between two rate changes was noted); the baseline to which the pressure eventually returned; the maintenance flow rate in the internal pudendal artery just before termination of cavernous nerve stimulation; the rate of flow decrease after termination of stimulation and the baseline to which the flow rate eventually returned.

Means of the values obtained in the three stimulations were calculated for each individual dog, and the detumescence events in the experiments without aortic occlusion were compared with those during occlusion.

Sympathetic stimulation. In seven dogs the influence of sympathetic chain stimulation on detumescence was studied. The cavernous nerve was stimulated three times as described above. When this procedure was repeated, the sympathetic chains were stimulated for 40 sec. at the termination of each of the three stimulations. The above-described parameters were noted and the values compared for cavernous nerve stimulation alone and in combination with sympathetic chain stimulation.

Cavernous perfusion. In five dogs, an attempt was made to determine when the venous channels open during detumescence. For this purpose, cavernous nerve stimulation was performed as described. After termination of the stimulation, the aorta was clamped to circumvent any possible influence of changes in arterial supply. During the subsequent detumescence phase, the cavernous body was perfused once after every stimulation at the rate of 15.6 ml./min. In the non-stimulated dog penis, this rate results in a plateau of moderate pressure; however, under these experimental conditions it causes a rapid increase in intracavernous pressure to off-scale values and allows detection of relatively rapid changes in penile compliance during detumescence. Perfusions were repeated during subsequent stimulations, but the interval between the termination of cavernous nerve stimulation and the initiation of perfusion was gradually increased until the intracavernous pressure values during perfusion remained within the scale.

The duration of detumescence was defined as the interval between termination of cavernous nerve stimulation and the moment at which intracavernous pressure returned to a value within 10 cm. H_2O above the prestimulation baseline.

Data were analyzed with Student's *t* test. Results are expressed as the mean ± S.E.

RESULTS

The duration of detumescence varied considerably among the 17 dogs in the first two sets of experiments, ranging from 42 to 255 sec. (mean, 101 sec.).

Analysis of the pressure changes during detumescence showed an initial phase in all 17 dogs lasting 21 ± 4 sec., during which the intracavernous pressure rose slightly above the level at the termination of stimulation in 15 dogs (an increase of 9.7 ± 1.8 cm. H_2O) and remained stable in two. This phase was followed in 14 dogs by a second phase lasting 35 ± 9.8 sec., during which intracavernous pressure decreased slowly. In the remaining three dogs, the initial phase was followed immediately by the third phase, during which the intracavernous pressure decrease accelerated. These three dogs had all shown the slight increase in pressure in the initial phase. The third phase was seen in all dogs and led to a decrease in pressure to prestimulation values. It lasted 45 ± 4.3 sec., and the pressure fell by 79.8 ± 3.8% of the difference between the level at the end of cavernous nerve stimulation and 10 cm. H_2O above the prestimulation baseline pressure.

After cavernous nerve stimulation was terminated the flow rate gradually decreased at a constant rate of 0.9 ± 0.2 ml./sec. per second to a baseline level of 9.7 ± 1.6 ml./sec. in 21.4 ± 3.1 sec. The time required for the flow rate to return to baseline levels equalled the duration of the initial phase. After reaching baseline, the flow rate remained constant at that level throughout the rest of detumescence.

Aortic occlusion. After termination of cavernous nerve stimulation, an initial phase lasting 20.7 ± 4.4 sec. occurred in all 10 dogs. After clamping the aorta, the initial phase was present in only one dog; it lasted 10 sec. and showed an increase in intracavernous pressure of six cm. H_2O. The second phase occurred in seven of 10 dogs; in the remaining three dogs, the termination of cavernous nerve stimulation initiated the terminal phase. The second and terminal phases lasted 28.4 ± 8.3 and 38.3 ± 4 sec, respectively, with the aorta clamped and were 21.5 ± 7.2 and 46.8 ± 6.8 sec, respectively, without clamping—a difference that was not significant. Figure 1 depicts the

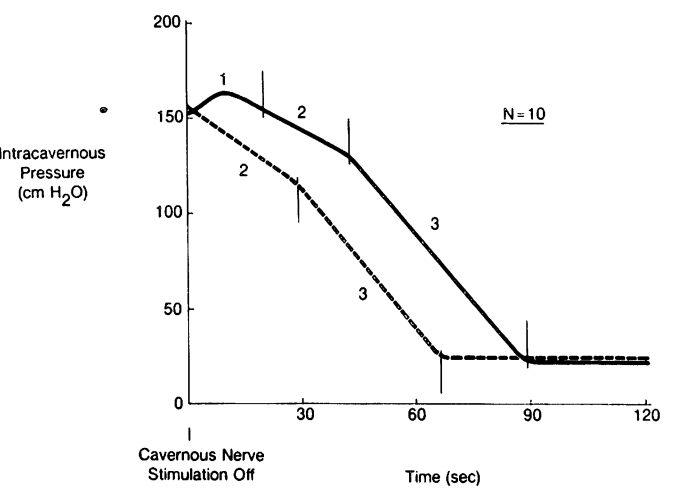

FIG. 1. Averaged pressure-time curves of three detumescence phases in 10 dogs, with (broken line) and without (solid line) aortic clamping. Initial phase is omitted under influence of aortic occlusion. Pressure in slow (2) and fast (3) phases decreases under both conditions in almost parallel fashion.

pressure-time curves of the 10 dogs under both conditions and shows the omission of the initial phase during arterial occlusion and the parallel nature of the second and third phases.

The flow rate in the internal pudendal artery with and without aortic occlusion decreased gradually and by a constant rate of 4 ± 1.1 and 1.2 ± 0.4 ml./sec. per second, respectively, p = 0.007. The baseline flow rate was likewise significantly different: 0.4 ± 0.3 vs. 11.6 ± 2.2 ml./sec. with and without occlusion, p = 0.001. The blood pressures and flow rates in the internal pudendal artery before and during erection did not vary significantly in these trials.

Sympathetic stimulation. Six of the seven dogs receiving sympathetic stimulation underwent the initial phase. This lasted 6.2 ± 1.8 sec. and, although it was shorter than without sympathetic stimulation (20 ± 7.8 sec.), the difference was not statistically significant. (The seventh dog experienced an immediate slow decrease in intracavernous pressure.) The difference in pressure rise, although greater, was likewise statistically insignificant: 40.7 ± 18 and 9.8 ± 2.6 cm. H_2O with and without sympathetic stimulation, respectively (fig. 2). In the second phase, the duration was significantly different: 5.6 ± 4 and 53.7 ± 20.3 sec. with and without sympathetic stimulation (p = 0.05). In the terminal phase, the duration again became similar (34 ± 5 and 42.8 ± 4.5 sec. with and without sympathetic stimulation, respectively), and this parallel nature of the third phase and omission of the second are evident in the pressure-time curves in fig. 2.

The flow rate decreases in the internal pudendal artery were not significantly different, although a significantly lower baseline flow rate was attained with sympathetic stimulation: 3 ± 1.3 vs. 7 ± 2.2 ml./sec., p = 0.019. The blood pressures and flow rates in the internal pudendal artery before and during erection did not vary significantly in these trials.

Cavernous perfusion. In the five dogs, cavernous nerve stimulation was administered for one minute, the aorta was clamped, and detumescence observed. In all dogs a phase of slow pressure decrease occurred, followed by a terminal phase of rapid decrease. Perfusion of the cavernous body at the rate of 15.6 ml./sec. in the non-stimulated state but during aortic occlusion elicited a stable plateau pressure of 55.4 ± 3.8 cm. H_2O (fig. 3A). Perfusion at the same rate during both aortic occlusion and cavernous nerve stimulation led to a rapid rise to off-scale levels (fig. 3B), indicating that the cavernous stimulation, not the perfusion, was the cause of the increase. When sympathetic stimulation was combined with aortic occlusion, perfusion led to an increase in plateau pressure in four of the five dogs of 13 ± 3.8 cm. H_2O; in one dog the increase was followed by a decrease to a level lower than before sympathetic stimulation (fig. 3C). When cavernous nerve and sympathetic stimulations were initiated simultaneously during perfusion, the intracavernous pressure either did not rise to off-scale values or did so only after a considerable delay (fig. 3D).

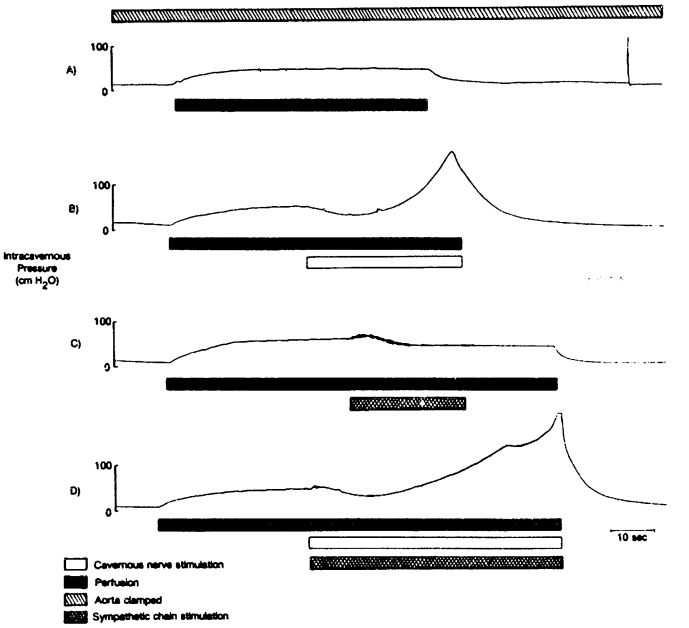

FIG. 3. With aorta clamped, saline perfusion of cavernous body at rate of 15.6 ml./min. is performed. A, with no additional stimulation, stable plateau pressure is reached. B, with cavernous nerve stimulation, pressure rises to off-scale values. C, with sympathetic stimulation, pressure first rises, probably owing to smooth muscle contraction, and then decreases to below prestimulation levels (this might be due to widening of outflow channels). Note that lower pressure level persists after termination of sympathetic stimulation. D, with both cavernous nerve and sympathetic stimulation initiated at same time, pressure rises to off-scale values, but effect is delayed (when compared with B).

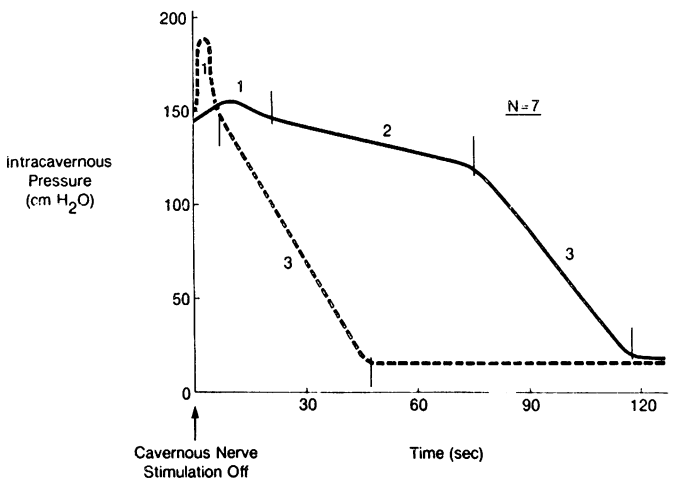

FIG. 2. Averaged pressure-time curves of three detumescence phases in 7 dogs, with (broken line) and without (solid line) sympathetic stimulation. Phase of slow pressure decrease (2) is omitted under influence of sympathetic stimulation. Pressure in fast phase (3) decreases in almost parallel fashion under both conditions. Sympathetic stimulation leads to higher pressure increase in initial (1) phase, although difference after termination of cavernous nerve stimulation without sympathetic stimulation is insignificant.

Next, we perfused during every phase of detumescence after cavernous stimulation followed by aortic occlusion; the interval between the termination of stimulation and initiation of perfusion was gradually increased in subsequent experiments. If perfusion was started during the second, slow, phase of pressure decrease, the intracavernous pressure always rapidly rose to off-scale values; if started during the terminal phase (fast pressure decrease), it never rose off the scale (figs. 4 and 5). It was impossible to time the perfusion exactly at the point of transition into the terminal phase, as this was detected only after it had begun. Nevertheless, the highest intracavernous pressure at which perfusion did not cause off-scale values was at approximately 38 ± 9.7% of the difference between intracavernous pressure at the termination of stimulation and 10 cm. H_2O above the pre-stimulation baseline.

The experiments were repeated with sympathetic stimulation initiated with aortic occlusion after cavernous nerve stimulation had been terminated. Again, the highest intracavernous pressure at which perfusion did not cause an off-scale increase was determined (fig. 5C). At approximately 71 ± 8.7%, this value was significantly higher than the 38% determination without sympathetic stimulation (p = 0.035). During detumescence after sympathetic stimulation, only a phase of fast pressure decrease was seen after the initial phase in these five dogs.

DISCUSSION

Our results indicate that, in the dog, the detumescence after cavernous nerve stimulation can be divided into three phases.

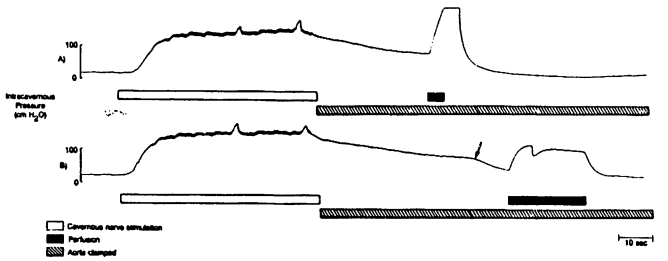

FIG. 4. Aorta clamped after termination of cavernous nerve stimulation. A, perfusion of the cavernous body initiated in slow phase of pressure decrease (2) shows pressure rise to off-scale values. B, perfusion initiated in fast phase (3) fails to increase pressure to off-scale values. Arrow indicates transition point from second phase to third phase.

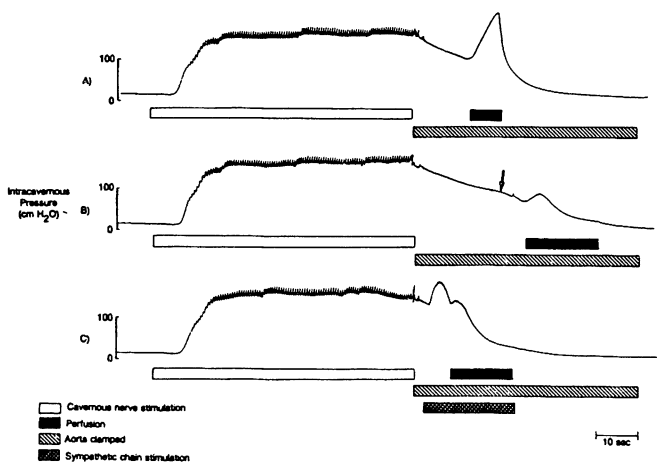

FIG. 5. Aorta clamped after termination of cavernous nerve stimulation. A, perfusion of cavernous body initiated in slow phase of pressure decrease (2) shows pressure rise to off-scale values. B, perfusion initiated in fast phase (3) results only in small rise in intracavernous pressure. Arrow indicates transition point from second to third phase. C, sympathetic stimulation initiated after termination of cavernous nerve stimulation. Perfusion initiated at intracavernous pressure level that is much higher than in A) and B) results in only slight increase in pressure.

TABLE 1. *Correlation of the three phases of detumescence with hemodynamic events*

	Intracavernous Pressure	Arterial Flow	Sinusoidal Smooth Muscles	Venous Channels
1st phase	Slight increase (or stable)	Decreasing, but still above baseline	Contraction	Closed
2nd phase	Slow decrease	Baseline	Continued contraction	Begin to open
3rd phase	Rapid decrease	Baseline	Return to baseline tonus	Wide open

First, a pressure increase usually occurs (in a minority the pressure remained stable), most probably the result of cavernous smooth muscle contraction after the termination of stimulation.[7] The volume of the cavernous bodies at this point has not decreased much, as it takes time for the arterial flow to decrease from maintenance to baseline levels and for venous drainage to resume (table 1). The average duration of the initial phase (21 sec.) equalled the average time required for the arterial flow to return to baseline levels (21.4 sec.). The duration of phase 1 is therefore determined by two factors: A) the arterial inflow (which, although gradually and constantly decreasing in this phase, remains above baseline for some time); and B) cavernous smooth muscle contraction (which explains the initial increase in intracavernous pressure in the face of declining arterial inflow). Future studies combining pressure measurements with studies of the electrical activity of the cavernous smooth muscles are needed to prove this point directly.

Second, a period of slowly decreasing intracavernous pressure occurs, with an average duration of 35 ± 9.8 sec. When this phase begins, the arterial flow has already returned to baseline, and some venous drainage probably occurs during this phase.

Finally, a period of rapid pressure decrease follows (the terminal phase), with an average duration of 45 ± 4.3 sec. The pressure drop during this phase contributes to 79.8 ± 3.8% of the total pressure drop from the moment cavernous stimulation is terminated to the end of detumescence.

Aortic occlusion after cavernous stimulation abolished the initial phase. As this was accompanied by a faster decrease in arterial flow and a significantly lower baseline flow rate, we can conclude that arterial flow plays an important role in the duration of the initial phase.

During sympathetic chain stimulation without aortic occlusion, the second phase was omitted. Although sympathetic stimulation also caused a more rapid decrease in flow rate, the effect was statistically insignificant. Furthermore, the potential effect of the decreased flow rate on the duration of the initial phase was partially nullified by a more forceful contraction of the cavernous smooth muscles, evidenced by a higher increase in intracavernous pressure after cavernous nerve stimulation was terminated.

The perfusion studies show that at least a partial obstruction of venous outflow is still present during the second phase (slow decrease in intracavernous pressure). The outflow has been fully restored, however, during the terminal phase of fast pressure decrease, as evidenced by the fact that perfusion initiated during the second phase always resulted in an intracavernous pressure rise to off-scale values, whereas perfusion initiated during the terminal phase led to only a minor increase in intracavernous pressure. This suggests that a complete reopening of the venous channels occurs at the transition between the second and third phases.

Sympathetic stimulation abolished the second phase of detumescence and led to a rapid decrease in intracavernous pressure immediately after the initial phase. Furthermore, cavernous perfusion during sympathetic stimulation did not result in a pressure rise to off-scale values, even when initiated at the moment that the intracavernous pressure was, on average, still about twice as high as in the experiments without sympathetic stimulation. Therefore, sympathetic stimulation causes the venous outflow channels to open by inducing a strong contraction of the cavernous smooth muscles.

In summary, as can be seen in table 1, the hemodynamic events, so well elucidated for erection, are seen to reverse themselves during detumescence.

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