Pelvic-Floor Muscle Rehabilitation in Erectile Dysfunction and Premature Ejaculation

Pierre Lavoisier, Pascal Roy, Emmanuelle Dantony, Antoine Watrelot, Jean Ruggeri, Sébastien Dumoulin

Background. In men, involuntary or voluntary ischiocavernosus muscle contractions after erection lead to intracavernous blood pressures far higher than the systolic pressure, which builds and maintains penile rigidity. Thus, erectile dysfunction may be partly due to ischiocavernosus muscle atrophy and may be treated by rehabilitation interventions.

Objective. The purpose of this study was to determine whether pelvic-floor muscle strengthening interventions could be associated with increases in intracavernous pressure that would increase penile rigidity.

Design. An observational study was conducted.

Methods. One hundred twenty-two men with isolated erectile dysfunction and 108 men with isolated premature ejaculation participated (no neuromuscular diseases or previous perineal rehabilitation). Thirty-minute sessions of voluntary contractions coupled with electrical stimulation were designed to increase ischiocavernosus muscle strength (monitored through intracavernous pressure increase). A linear mixed-effects model per group analyzed separately, then jointly, the maximum change in pressure (ΔP) and the maximum baseline (ie, respectively, the average contraction-generated difference in intracavernous pressure and the intracavernous pressure plateau at full erection, both measured during the highest moving average of the best 2 minutes of each session).

Results. Over 20 sessions, the maximum ΔP increased in erectile dysfunction as well as in premature ejaculation (87% and 88%, respectively, in men with positive trends). The maximum baseline also increased (99% and 72%, respectively, in men with positive trends). The joint modeling indicated that the mean expected progressions of the intracavernous pressure after 5 sessions in erectile dysfunction and premature ejaculation were 62.85 and 64.15 cm H_2O, respectively.

Limitations. Indirect measurements were obtained of intracavernous pressure and ischiocavernosus muscle force.

Conclusions. Pelvic-floor muscle rehabilitation was found to be beneficial in erectile dysfunction. However, its effects on symptoms of premature ejaculation, despite intracavernous pressure gains, were much more difficult to assess. The definitive proof of its benefits requires rather difficult-to-design clinical trials.

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The physiology of erection includes a vascular phase[1–3] and a muscular phase.[4–22] Additionally, physiological data strongly suggest an additional intercourse rigidity process.

During the vascular phase, there is an increase in cavernous arterial blood flow together with a venous compression under the tunica albuginea (TA) that decreases the venous outflow; the 2 processes result in an increase in intracavernous pressure (ICP) and a stretching of the TA.[1–3] At full erection, the ICP plateaus at nearly 150 cm H_2O (110 mm Hg),[2,3] which is the mean arterial pressure.[3,23] At this point, there is no evidence for a physiological role of the ischiocavernosus muscle (ICM).[1–3]

During the muscular phase (or rigidity phase), ICM contractions induce a suprasystolic (SS) ICP[2–7] that allows intercourse. In several mammals (horse, bull, goat, dog, and rat),[8–14] concomitant ICP measurements and ICM electromyography (EMG) during coitus have shown that ICM contractions concur with SS ICP peaks and that anesthesia of the ICM prevents penetration by lack of rigidity.[8,12]

In addition, concurrent ICM contractions and coitus movements suggest a triggering of the ischiocavernosus reflex (ICR).[8,10,12] Indeed, authors have observed very important increases in the ICP (ie, up to 10 times the systolic blood pressure).[8] These findings imply that, during SS ICP, the corpus cavernosum (CC) is a blood-filled closed system.[24]

In men, the physiology of the ICM was described by Poirier and Charpy.[4] The ICM surrounds the CC in a semi-cone shape. Contractions of the ICM compress the roots of the CC, leading to an increase in the ICP. At full erection, in absence of contraction, the pressure in the blood-filled CC cannot exceed the mean arterial pressure. The ICM contractions may then compress the CC, which increases the ICP beyond the systolic pressure.[4] The latter point is confirmed by the fluid compressibility equation: $dP = -K\,(dV/V)$ (ie, the pressure (P) increases when the volume (V) decreases, with K being the constant bulk modulus or coefficient of elasticity of blood). Available data in humans indicate that ICM contractions may induce important SS ICPs,[5,6,15–21] regardless of whether the ICM contractions are reflexive or voluntary.[5,16,22]

Therefore, coital penile rigidity is achieved according to the following sequence: coital movement → glans pressure variations → ICR triggering → ICM contractions → SS ICP → penile rigidity.

Whereas studies of penile rigidity have led to the above-stated sequence, studies of premature ejaculation (PE) did not lead yet to a consensual sequence; most authors consider that the etiology and the pathophysiology of PE are still nebulous. Regarding etiology, there is a complex contribution of several factors (genetic, neurobiological, pharmacological, psychological, urological, and endocrine),[25] most of which are still not—or are poorly or contradictorily—evidence-based. Regarding pathophysiology, there is some consensus on the "disturbances of the serotonergic neurotransmission and certain serotonin (5-HT) receptors and, to a lesser extent, oxytocinergic neurotransmission in the CNS [central nervous system],"[26] which partly founds or explains the successful treatments with some selective serotonin reuptake inhibitors (SSRIs). However, a few reviews published after 2000 have mentioned "pelvic floor alteration"[27] and "a neurobiological phenomenon,"[28,29] or suggested "pubococcygeal muscle training" within a multiple strategy treatment.[30]

In humans, the male pelvic-floor muscles, specifically the ischiocavernosus and bulbospongiosus, are

The Bottom Line

What do we already know about this topic?

In humans, the male pelvic floor muscles are active during sexual intercourse and play a role in penile erection. There are two phases in penile erection: the vascular phase (which allows tumescence) and the muscular phase (which induces rigidity). Rigidity is achieved by the contraction of the ischiocavernosus muscle.

What new information does this study offer?

This study demonstrated that rehabilitation interventions increased ischiocavernosus muscle force in 87% of the men studied.

If you're a patient or a caregiver, what might these findings mean for you?

Men with erectile dysfunction may benefit from interventions to strengthen the ischiocavernosus muscle, potentially enhancing the muscular phase of the erection.

active during sexual intercourse and play a role in penile erection and ejaculation. A number of authors hypothesized that weak pelvic-floor muscles would lead to erectile dysfunction (ED) and that exercising these muscles would significantly improve or restore erectile function secondary to venous leakage or post-prostatectomy.[31–33] Dorey found that pelvic-floor muscle exercises (ischiocavernosus and bulbocavernosus muscles) appear to have merit as a treatment for ED (they increase penile rigidity in the tumescent penis[34]) and that they are a realistic and noninvasive first-line approach for the prevention and treatment of ED.[35]

Furthermore, some authors supported the idea that contraction of pelvic-floor muscles is involved in the control of the ejaculatory reflex and evaluated pelvic-floor rehabilitation as a possible treatment for PE.[36–38] In one study,[36] after 15 to 20 sessions, 11 out of 18 patients were considered cured. In a more recent study,[37] after 12 weeks, 11 out of 19 patients were able to control the ejaculatory reflex. These authors concluded that physical treatment may be a viable therapeutic option for the treatment of PE.

The above physiological considerations suggest that coital penile rigidity dysfunction and possibly PE may be partly due to ICM atrophy and that they may be treated by rehabilitation intervention (RI). Despite the above-cited and other positive reports on the effect of pelvic-floor rehabilitation in ED,[39–44] no reports have provided measurements of ICM force or the ICP.

The aim of the present study was to determine whether pelvic-floor muscle strengthening interventions could be associated with increases in ICP that would increase penile rigidity.

Method

Participants

This study (historical cohort) considered as potential participants all men with ED or PE who were seen at the Centre d'Etudes des Dysfonctions Sexuelles (CEDS, Lyon, France) from August 2007 to July 2010 (Fig. 1).

Symptoms of ED ranged from simple difficulty to maintain a rigid erection to impossibility to achieve penetration. Symptoms of PE ranged from simple difficulty to maintain penetration for more than 5 minutes before ejaculation to ejaculation before penetration. Whatever the disorder, the inclusion criteria did not consider ED-specific causes, PE levels, or age ranges. However, all patients with neuromuscular diseases and those who had practiced perineal rehabilitation were excluded.

All solicited patients were informed about the treatment process, the functioning of the apparatus, and the analysis of the data. Only voluntary patients who gave their consent to the treatment were further instructed and could use the apparatus, and any volunteer could withdraw at any time without specific justification. There was no randomization of study participants either before or during the study period. The data collection was a natural part of the treatment, and only anonymized observational data were analyzed.

The present study included 230 men (mean age=47.9 years, SD=13.0) (Fig. 1). All participants had reached or completed high school level. The study considered 2 groups: (1) 122 men with ED but without PE (ED group; mean age=51.8 years, SD=12.7) and (2) 108 men with PE but without ED (PE group; mean age=41.8 years, SD=10.8). As the latter group had no penile rigidity dysfunction, they were not deemed to have ICM atrophy (which is backed by the study results). The length of dysfunction in both groups was more than 6 months.

According to the current French Legislation (Loi Huriet-Sérusclat 88-1138, December 20, 1988, and its subsequent amendments), an observational study that does not change routine management of patients does not need to be declared or submitted to the opinion of a research ethics board.

Baseline Tests and Drug Treatments

The usual tests included: a blood test for androgen level (free and bioavailable testosterone), glucose and glycosylated hemoglobin, lipid profile, penile echo-Doppler ultrasonography, and perineal EMG.

Men with ED were prescribed phosphodiesterase type 5 inhibitors (PDE5-Is): either tadalafil 5 mg once daily or tadalafil 20 mg, vardenafil 20 mg, or sildenafil 50 mg 2 or 3 times weekly. The dosage was adapted to each participant according to the drug effect. Participants with ED with low free testosterone or low bioavailable testosterone, or both, received injectable testosterone enanthate 250 mg twice monthly for 3 months.

Men with PE were prescribed paroxetine 10 to 40 mg once daily. Those who experienced side effects or insufficient efficacy, or both, were prescribed clomipramine 12.5 to 50 mg once daily. The dosage of paroxetine or clomipramine was adapted to each participant according to the efficacy and the side effects. Table 1 summarizes the conditions and the drug treatments given to the participants of each group.

ICM-RI Principle

The ICM-RI was proposed to all participants. This treatment was designed to increase the strength of

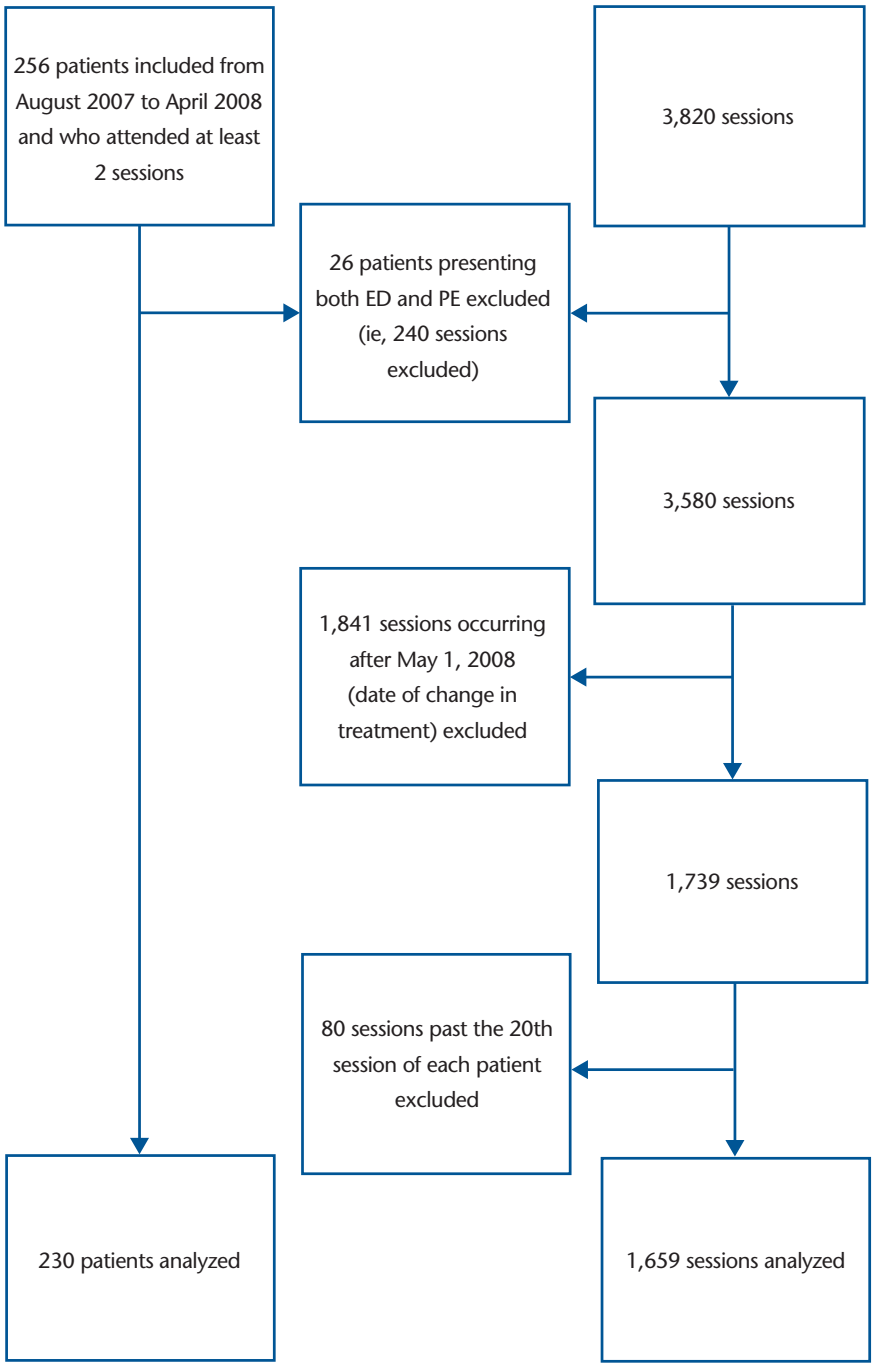

Figure 1.
Flow diagram of study participants and number of analyzed sessions. ED=erectile deficiency, PE=premature ejaculation.

the ICM, avoid the involvement of other muscles because only the ICM is able to induce large increases in ICP,[4–7,15,44] and control fatigue.

Increasing the strength of a striated muscle implies a work of this muscle against a resistance.[23,45] Regarding the ICM, the only resistance is the pressure in the CC.[4] The treatment, therefore, should be carried out in full erection when the CC is filled and the ICP is close to the mean arterial pressure. For this treatment, all participants received intracavernous prostaglandin E1 (PGE1) injections at doses expected to cause full erection for nearly 30 minutes.

For ICM work, voluntary contraction and electrical stimulation could be separately used, but the exercise is more efficient when both are associated.[45] In addition, a vibratory system was used to stimulate erection through activation of the mechanoreceptors of the glans penis and increase the effect of the exercise on the muscular strength.[46,47]

Devices, Electronics, Computer, and Software

Three devices were connected to an electronic box and then to a computer: (1) a penile cuff to measure the ICP, (2) 2 electrodes for electrostimulation, and (3) a vibrator device.

The validated penile cuff device[48] that recorded ICP variations (MedaSonics, Cooper-Surgical Inc, Trumbull, Connecticut, or Koven Technology Inc, St Louis, Missouri) has an inner surface lined with a plastic reservoir filled with water. The cuff was wrapped around the penile shaft and connected via a pressure line (Vygon, Ecouen, France) to a pressure transducer (Smiths Medical MX 950, Smiths Medical, Dublin, Ohio) able to record pressures from 0 to 1,000 mm Hg (1,359.51 cm H_2O). Before each session, the pressure signal was calibrated with a water manometer. During a session, the signal from the pressure transducer was amplified and recorded on a computer. Electrostimulation was triggered by the participant and applied to the skin by 2 self-adhesive electrodes attached to the electronic box. The vibrator device had an eccentric axis motor with variable speed (Precision Microdrives, London, United Kingdom).

The electronic box contained a pressure signal amplifier, an analog-digital converter, a microprocessor for signal analysis, an electrostimulation system, and a power supply. This box was connected to a personal computer through a USB port. The software and the electronic box were designed and built in our laboratory specifically for this study. They allow a screen display of ICM-RI indications and curves (Fig. 2). The signals were recorded in real time at all ICM-RI sessions.

ICM-RI Session Course

Each weekly ICM-RI session consisted of controlled ICM exercises with ICP and fatigue measurements to control and quantify the progress of ICM work along the treatment.

Table 1.
Drug Treatments Given to the Participants[a]

Group, Condition, and Drug	n	%
ED group (n=122)		
Comorbidities		
Diabetes	5	4
Prostate cancer	3	2.5
Hyperlipidemia	25	20.5
Hypertension	12	9.8
Peyronie disease	4	3.3
Neuropathy	0	0
Smokers	34	27.9
Penile ultrasonography	39	32
Medication		
Tadalafil	73	60
Sildenafil	2	1.6
Vardenafil	4	3.2
Androgen	14	11.5
No PDE5-I	43	35.2
PE group (n=108)		
Smokers	32	29.6
Medication		
Statins (hyperlipidemia)	1	0.9
Paroxetine (SSRI)	79	73.1
Other SSRI	10	9.2
Clomipramine[b]	6	5.5
Nothing	13	12

[a] ED=erectile deficiency, PE=premature ejaculation, PDE5-I=phosphodiesterase type 5 inhibitor, SSRI=selective serotonin reuptake inhibitor.
[b] Tricyclic antidepressant.

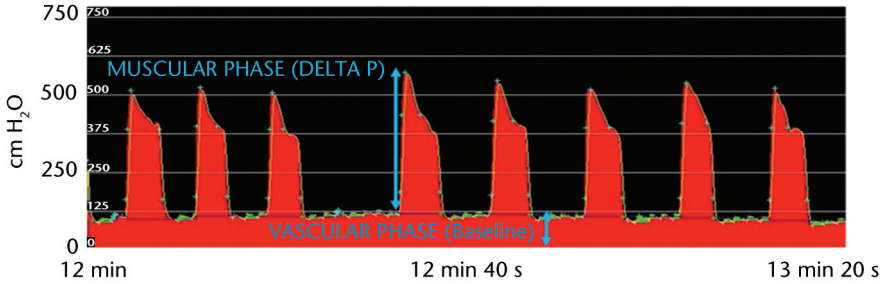

Figure 2.
Sample from the recordings made during a biofeedback session. The intracavernous pressure changes (the peaks) were provoked by voluntary contractions of the ischiocavernosus muscle starting from a baseline at about 100 mm Hg (135.95 cm H_2O).

The participant was placed in a quiet room, on a comfortable examination bed, in a supine position. A computer with a large screen was placed at the participant's head level at nearly 1-m distance. Electrostimulation electrodes were placed at the middle of the upper face of the penis shaft to stimulate the dorsal nerve responsible for ICR. This stimulation was applied at 80 Hz because this frequency is known to increase both the ICP and the EMG activity of the ICM and induce ICM contractions without fatigue.[49]

The participant was then given the PGE1 injection, and the penile cuff (previously filled with water without air bubbles) was wrapped by the physician around the penis shaft and closed over the electrostimulation electrodes and the vibrator. The physician used a virtual button on the computer screen to adjust value zero for water pressure.

The participant could start electrostimulation and adjust its intensity using a virtual button on the screen to obtain a maximum perception of stimulation below pain threshold. Electrostimulation lasted 30 minutes. The participant could initiate the vibrator and produce various frequencies also using a virtual button so as to have a good perception without discomfort. The participant then had to check that voluntary ICM contractions—and, to the extent possible, only these contractions—were displayed. The participant could check these contractions manually and check on the screen that his contractions easily produced large increases in ICP. The physician also could check the involvement of only ICM contractions.

After an increase in ICP from zero to about 150 cm H_2O (about 110.33 mm Hg) for a normal vascular phase, a baseline plateau corresponding to full erection appeared on the screen (Fig. 2). During ICP recordings, each participant was shown an ideal mask of voluntary muscle contractions he had to reproduce (Fig. 3). This mask showed the optimal duration and magnitude of voluntary contractions as well as the duration of the rest phase and was adjusted in real time according to an ICM fatigue index. Indeed, because intense exercise exhausts the ICM, an ICM fatigue index was calculated by measuring angle α on the ICP peak (Fig. 3). Practically, when the ICM was robust, the participant could maintain the contraction; the ICP did not decrease, and the curve remained almost horizontal during the whole contraction. In case of fatigue, however, the ICP decreased rapidly, forming an acute angle α. The more tired is the muscle, the more acute is this angle. Real-time changes of the mask according to angle α indicated to the participant the way the next contractions had to be made. With the use of this mask, there was no uniform sequence for all participants; the contraction rhythm (durations of contraction and rest) was left to the discretion of each participant and constantly changing according to the mask indications.

Recorded and Calculated Measurements

Measurements of ICM force cannot be directly obtained. However, because the CC is a closed blood-filled system during SS ICP, ICM force variations may be mathematically obtained from ICP variations using the above-shown fluid compressibility equation.

The penile cuff provides indirect measurements of ICP and avoids the use of invasive devices. Its validation has been achieved previously by simultaneous recordings of penile cuff pressure and direct ICP through a needle during artificial erection; the results showed a linear relationship and a highly positive correlation between the 2 measurements (ρ=.96, P<.001).[48]

After erection, in the absence of ICM contractions, the baseline pressure is an ICP equivalent to the mean arterial pressure (Fig. 2). A mean baseline was calculated over each whole session. The maximum baseline

(max baseline) was the highest moving average calculated over the best 2 minutes of each whole session.

DeltaP (ΔP) was the pressure reached above the baseline during ICP peaks on ICM contractions (ie, the peak pressure minus the baseline pressure) (Fig. 2). The main data considered or analyzed here were: (1) the number of ICP peaks per session; (2) the mean ΔP over each whole session; (3) the maximum ΔP (max ΔP), defined as the average ΔP during the best 2 minutes of each session; (4) the mean baseline; (5) the max baseline; and (6) angle α change or fatigue index.

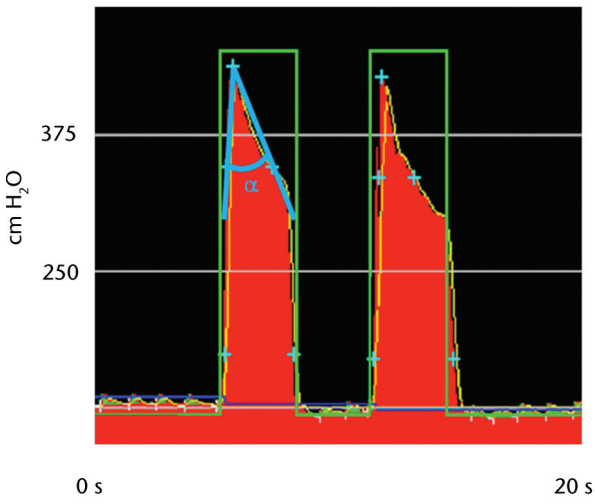

Figure 3.
Example of the adjustable mask. Each peak represents the change in intracavernous pressure during a single ischiocavernosus muscle contraction. The rectangle that surrounds each peak is the form to reproduce during each contraction, starting from the baseline. This algorithm-created mask is adjustable in each of its components: duration (width), amplitude (height), and ischiocavernosus muscle fatigue index (angle α).

Data Analysis

To describe the progress of max ΔP or that of the max baseline, the statistical analysis considered the following linear mixed-effects model that was applied separately to each group (ED and PE) and separately to max ΔP and max baseline:

$$y_{ij} = (\beta_0 + u_{0i}) + (\beta_1 + u_{1i}) \times j$$

In this model, $i=1,\ n$ denotes the participant, $j=1,\ m_i$ (not shown in the equation) denotes the session (m_i being the total number of sessions followed by participant i), and y_{ij} denotes the criterion under study (ie, max ΔP, max baseline, or max ΔP + max baseline for session j of participant i), β_0 denotes the mean (population) intercept of the linear regression, and β_1 denotes the mean (population) slope associated with the session rank (treatment effect). In the model, $u_{0i} \sim N(0,\sigma^2_0)$ is the random effect on the intercept and follows a normal distribution of mean 0 and variance σ^2_0, whereas $u_{1i} \sim N(0,\sigma^2_1)$ is the random effect on the coefficient associated with the session rank and follows a normal distribution of mean 0 and variance σ_1^2. In the "Results" section, the intercepts and the slopes are presented as well as the estimated effects of 5 sessions (ie, the effect of 5 sessions was obtained by multiplying each slope by 5).

The significance of the mean slope was analyzed with the Wald test, and a 95% confidence interval (95% CI) was calculated using the profile likelihood method. The random effect on the number of sessions provides one slope per patient. A positive slope indicates that the patient is responding favorably to the intervention. The distribution of the random slopes (β_1+u_{1i}) was analyzed to estimate the proportion of participants with positive or negative slopes. This proportion gives an idea of the number of patients who respond favorably to the intervention.

In a first analysis, the first 20 sessions of each participant were analyzed to reduce the potential influence of the low number of participants with very high numbers of sessions. From this model, the mean expected difference between inclusion and the fifth session was calculated. The median number of sessions being 7, a complementary analysis was restricted to the first 7 sessions of each participant.

In order to make a comparison of the intercept and the slope obtained for the ED group (with the above-described model on the first 20 sessions) with the intercept and the slope obtained for PE group, another linear mixed-effects model considered the ED and PE groups together and included an effect of the dysfunction, an effect of the session rank, and an effect of the interaction between these 2 variables. A random "patient" effect also was considered on each fixed effect and on the intercept of the model. Slope comparison allows stating whether the progressions of ED and PE groups are the same.

All statistical analyses were performed with R software (http://www.r-project.org/). All statistical tests were 2-tailed, and P values smaller than .05 were considered for statistical significance.

Results

Summary ICM-RI Results

The median of the number of pressure peaks per session in the ED and PE groups was 318 (interquartile range [IQR]=277–375) and 312 (IQR=276–360), respectively. The median of the mean of baseline + ΔP in the ED and PE groups was 383 mm H_2O (IQR=277.6–503.7) and 407 mm H_2O (IQR=300.9–529), respectively.

Effects of the ICM-RI in the ED Group Over 20 Sessions

In the ED group, the max ΔP increased. The group slope that characterizes the linear trend of max ΔP was significant (11.91 cm H_2O per session, $P<.005$, 95% CI=8.43, 15.67). The random standard error of the slope (10.41 cm H_2O per session) led to estimating that 87% of the participants presented a positive trend (Tab. 2).

In addition, the max baseline increased. The group slope that characterizes the linear trend of max baseline was significant (1.64 cm H_2O per session, $P<.005$, 95% CI=0.96, 2.32). The random standard error of the slope (0.68 cm H_2O per session) led to estimating that 99% of the participants presented a positive trend (Tab. 2).

The group intercept of max ΔP was estimated at 336 cm H_2O. The group intercept of the max baseline was estimated at 146 cm H_2O. The mean expected progression after 5 sessions was 59.55 cm H_2O for max ΔP (5 × 11.91) and 8.2 cm H_2O for max baseline (5 × 1.64) (ie, more than seven-fold the baseline) (Tab. 2). When the criterion under study was max ΔP+max baseline, the mean expected progression of the ICP after 5 sessions was 62.85 cm H_2O (5 × 12.57) (Tab. 3).

Effects of the ICM-RI in the PE Group Over 20 Sessions

In the PE group, the max ΔP also increased. The group slope that characterizes the linear trend of max ΔP was significant (11.61 cm H_2O per session; $P<.005$; 95% CI=7.74, 16.04). The random standard error of the slope (9.71 cm H_2O per session) led to estimating that 88% of the participants presented a positive trend (Tab. 2).

In addition, the max baseline increased. The group slope that characterizes the linear trend of max baseline was significant (1.50 cm H_2O per session; $P=.006$; 95% CI=0.42, 2.61). The random standard error of the slope (2.50 cm H_2O per session) led to estimating that 72% of the participants presented a positive trend (Tab. 2).

The group intercept of max ΔP was estimated at 417 cm H_2O. The group intercept of the max baseline was estimated at 157 cm H_2O. The mean expected progression after 5 sessions was 58.05 cm H_2O for max ΔP (5 × 11.61) and 7.5 cm H_2O for max baseline (5 × 1.5) (Tab. 2). When the criterion under study was max ΔP+max baseline, the mean expected progression of the ICP

Table 2.
Parameters Stemming From the Linear Mixed-Effects Model Applied to Participants in the ED and PE Groups Over the First 20 Sessions[a]

Estimated Parameters	ED Group (n=122)	PE Group (n=108)	P[b]
Max ΔP			
Slope (SE), cm H_2O per session[c]	11.91 (1.74)[d]	11.61 (1.86)[d]	.459
Intercept (SE), cm H_2O[e]	336 (13.4)	417 (14.8)	<.001
SE of the random effect on the slope, cm H_2O per session[c]	10.41	9.71	
Percentage of positive slopes	87	88	
Max baseline			
Slope (SE), cm H_2O per session[c]	1.64 (0.34)[d]	1.50 (0.54)[d]	.872
Intercept (SE), cm H_2O[e]	146 (3.1)	157 (4.1)	.045
SE of the random effect on the slope, cm H_2O per session[c]	0.68	2.50	
Percentage of positive slopes	99	72	

[a] ED=erectile deficiency; PE=premature ejaculation; SE=standard error; max ΔP=maximum ΔP (the average contraction-generated difference in intracavernous pressure, measured during the highest moving average of the best 2 minutes of each session); max baseline=maximum baseline (the intracavernous pressure plateau at full erection, measured during the highest moving average of the best 2 minutes of each session).
[b] *P* values resulting from ED group vs PE group comparisons using Wald tests on the parameters estimated from the linear mixed-effects models (detailed in the "Method" section of the text).
[c] Estimated mean linear trend.
[d] *P* value <.05 resulting from a Wald test assessing whether the coefficient is different from zero.
[e] Estimated mean starting value.

Table 3.
Main Indicators of ICP per Session[a]

ICP Indicators	Max ΔP	Max Baseline	Max ΔP + Max Baseline
ED group (n=62)[b]			
Mean (SD) at first session, cm H_2O	352.7 (165.7)	151.7 (38.7)	504.4 (180.8)
Mean (SD) at fifth session, cm H_2O	398.6 (162.9)	151.4 (44.2)	549.9 (181.6)
Observed slope (SD), cm H_2O per session[c]	11.46 (38.30)	−0.09 (12.03)	11.37 (43.63)
Estimated slope (SE), cm H_2O per session[d]	11.91 (1.74)	1.64 (0.34)	12.57 (1.79)
PE group (n=65)[b]			
Mean at first session (SD), cm H_2O	404.4 (172.4)	148.2 (48.2)	552.6 (186.3)
Mean at fifth session (SD), cm H_2O	441.6 (199.9)	158.7 (41.6)	600.3 (220.0)
Observed slope (SD), cm H_2O per session[c]	9.29 (49.51)	2.64 (12.06)	11.92 (56.56)
Estimated slope (SE), cm H_2O per session[d]	11.61 (1.86)	1.50 (0.54)	12.83 (2.16)

[a] Observed means over the first 5 sessions and model-estimated slope obtained with up to 20 sessions. ICP=intracavernous pressure, ED=erectile deficiency; PE=premature ejaculation; SE=standard error; max ΔP=maximum ΔP (the average contraction-generated difference in intracavernous pressure, measured during the highest moving average of the best 2 minutes of each session); max baseline=maximum baseline (the intracavernous pressure plateau at full erection, measured during the highest moving average of the best 2 minutes of each session).
[b] Participants who had at least 5 therapy sessions.
[c] (Mean at fifth session − mean at first session)/4.
[d] The effect of one session obtained with the linear mixed-effects model considering up to 20 sessions.

after 5 sessions was 64.15 cm H_2O (5 × 12.83) (Tab. 3).

Comparison Between the Parameters of the 2 Models for Max ΔP and Max Baseline

When considering the ED and PE groups together, the effect of the dysfunction was significantly different from 0 for max ΔP and max baseline (Wald test: $P<.001$ and $P=.045$, respectively; Tab. 2). Thus, the intercepts relative to the ED and PE groups can be considered as different (ie, the max baseline and the max ΔP at the onset of the ICM-RI were not the same in the ED and PE groups).

However, the coefficient associated with the interaction between the dysfunction and the session rank could not be considered as significantly different from 0 (Wald test: $P=.46$ for max ΔP and $P=.87$ for max baseline; Tab. 2) (ie, the effect of the session rank, that is the overall progression, cannot be considered as different between the ED and PE groups).

Effects of ICM Contractions Over 7 Sessions

Close results were obtained when the first 7 sessions were analyzed. The slopes that characterize the linear trend of max ΔP were significant in the ED group (11.46 cm H_2O per session; $P<.005$; 95% CI=6.29, 16.82) and in the PE group (13.47 cm H_2O per session; $P<.005$; 95% CI=5.54, 21.53).

The group slopes that characterize the linear trends of max baseline were estimated in the ED group at 0.90 cm H_2O per session ($P=.28$; 95% CI=−0.76, 2.57) and in the PE group at 1.86 cm H_2O per session ($P=.12$; 95% CI=−0.52, 4.24).

Effects of the ICM-RI Sessions on Fatigue

To study the impact on fatigue, we analyzed the acute angle α using the same linear mixed-effects model we used to study max ΔP or max baseline. Analyses were conducted separately for each group (ED and PE), and only the first 20 sessions of each participant were analyzed.

In the ED group, the mean (population) slope associated with the session rank was 0.045 (95% CI=−0.12, 0.06). In the PE group, the mean (population) slope associated with the session rank was −0.06 (95% CI=−0.17, 0.05). Thus, we cannot conclude that the number of sessions had an effect on fatigue. In both groups, the fatigue slope was not different from zero during the treatment. This finding means that fatigue did not increase during ICM-RI.

Discussion

The present study was designed to analyze the results and the efficacy of a new rehabilitation intervention destined to increase ICP and penile rigidity through strengthening the ICM.

On the system recordings, the muscular phase of erection was studied through contraction-related ICP pressure changes (max ΔP), and the vascular phase was studied through baseline ICP pressure changes (max baseline). These 2 measures were

considered more relevant than the corresponding mean ΔP and mean baseline because the conditions for application of the fluid compressibility law were better met during the best 2 minutes of each session— during which max ΔP and max baseline were collected—than during a whole session. Indeed, at the beginning of each session, before the full efficacy of PGE1, the gradual increase in ICP from 10 to 150 cm H_2O was not an ideal condition for using the compressibility law.

One feature of the present study is that the results were analyzed according to fixed numbers of sessions instead of over the duration of the treatment. Because some participants had to cancel some weekly sessions without interrupting the treatment, the same number of sessions was carried out over a longer period.

As expected, the intercept of max ΔP (the extrapolated muscular phase indicator before treatment) was lower in the ED group than in the PE group (336 versus 417 cm H_2O). This finding may be explained by the probable integrity of the muscular phase in the PE group. However, the intercept of the max baseline was lower in the ED group than in the PE group (146 versus 157 cm H_2O). This small difference between patients supposedly with (versus without) a vascular problem was a surprise and suggests that the pathophysiological difference would be linked to the muscular facet rather than to the vascular facet. The use of PDE5-Is in the ED group also probably explains the small difference in the intercepts of max baseline between the ED and PE groups.

The intercepts of max baseline values had the same order of magnitude as the mean arterial pressure, which confirms that, at full erection, the ICP has nearly the value of the mean arterial pressure (ie, nearly 150 cm H_2O or 110.33 mm Hg).[23] Surprisingly, the estimated slopes of max ΔP were very close in the ED and PE groups (11.91 versus 11.61 cm H_2O per session, respectively), although the PE group was, on average, younger, assumed free from ED, and without PDE5-I treatment. These results suggest that whatever the patient group or the ICM force at the beginning of the treatment, similar ICM progressions may be reached with or without PDE5-Is. This finding suggests that PDE5-Is were not implicated in the progression of the muscular phase. Similarly, the use of androgens in the ED group is thought to have played only a minor role because of close slopes of max ΔP in the ED group and the PE group (who did not use androgens).

The slopes of max ΔP and max baseline showed positive trends. This finding means a progression of both the muscular phase and the vascular phase, and there appears to be a link between the increase in the muscular phase and the increase in the vascular phase. It is possible that ICM enhancement better compresses the veins that pass through the ICM, which decreases the venous outflow and, therefore, increases the ICP. However, the progressions in the muscular and vascular phases did not follow the same magnitude; indeed, the slope of max ΔP that represents the muscle component of erection was nearly 7 times higher than that of the max baseline that represents the vascular component of erection. This finding shows that the increase in ICP is mainly obtained through an action of the muscle component. Because ICM-RI is meant to act on the muscular phase and not on the vascular phase, we may infer that the difference in ICP is in favor of the ability of ICM-RI to increase ICP.

During this ICM-RI, it was difficult to determine exactly which muscles contracted and what effects they had on ICP. According to current knowledge, only ICM directly influences ICP,[4] which was confirmed by simultaneous recordings of ICP and ICM EMG activity (by coaxial needle electrode) during contraction.[5,13,14] We observed large and easily reached ICP increases during ICM contractions (confirmed by palpation) and small increases following the contraction of other perineal or even distant muscles (external anal sphincter or thigh, buttock, or abdominal muscles). With the physician and the screen indications, all participants at all educational levels (high school and above) were able to understand the method, use it within a few minutes, and avoid—to a certain extent—the contraction of these accessory muscles. The ICM force was assessed indirectly, although we propose the measurement of ICM EMG activity. This choice was made because: (1) there is no evidence for a linear relationship between EMG activity and ICM force,[50] (2) the recording of this activity through self-adhesive electrodes would have given a global signal of perineal muscles located beneath the electrodes, and especially (3) the use of a coaxial needle instead of adhesive electrodes is an invasive procedure that generates pain during exercise, which would not be accepted by most participants.

The indirect measurement of the ICM force was an essential part of the present study. Ideally, a force transducer should have been used, but the specific anatomy and the physiology of the ICM do not allow the use of a force transducer. Thus, the ICM force was indirectly calculated from ICP using the compressibility law: $dP = -K\ (dV/V)$. However, this law requires a constant blood mass and a constant volume envelope, whereas these conditions cannot be strictly met. The SS ICP peaks stretch the TA, which may

slightly increase the volume of the CC and thus decrease dP and underestimate ΔP. In previous work,[48] CC circumference changes measured during high pressure increases revealed nonsignificant increases due to Young modulus of TA and thus nonsignificant volume increases during ICM contractions. Thus, the force approximated from ICP and ΔP (ie, ΔICP) is a good approximation of ΔICM force.

The use of drug treatments (PGE1 during exercise and PDE5-Is in the ED group) must have contributed to the improvement of the vascular component of erection, but the extent to which this intervention affected ICM involvement in ICP improvement is very difficult to assess. The use of antidepressants (paroxetine and clomipramine) in patients with PE is expected to impede erection, which argues for a positive role of ICM-RI in these patients. Besides, the slopes of ICP progression in patients with ED and PE are nearly the same, whereas PDE5-Is are supposed to increase this progression and antidepressants are supposed to decrease it, leading to an overall important difference in those slopes. The close slopes of the max baseline (1.64 cm H_2O per session in the ED group versus 1.50 cm H_2O per session in the PE group) suggest a low implication (effect or duration) of PDE5-Is.

The link between ICP and penile rigidity is indirect. Intracavernous pressure is a pressure and rigidity is a tension, but fluid mechanics laws allow calculating rigidity from ICP. The terms "vascular treatment" and "muscular treatment" are often used for didactic reasons. Vascular treatment includes PDE5-Is and PGE1, whereas muscular treatment includes rehabilitation intervention and androgen therapy. Nevertheless, the boundary between the 2 treatments does not seem clear-cut. Indeed, vascular treatments might improve muscular rehabilitation by better muscle vascularization, and ICM reinforcement might improve the vascular phase by decreasing the venous outflow. Future research should check whether ICM results are able to reverse veno-occlusive dysfunction.

The present study advocates the use of ICM strengthening for sexual rehabilitation but might present the classical limitations of observational studies. Among these is the well-known regression toward the mean: patients with transitory dysfunctions improve spontaneously. This selection bias was unlikely because most patients with ED and PE had long-lasting dysfunctions. More solid results or conclusions would have stemmed from a comparison with a nonmedicated control group. However, in monotherapy, self-controlled experiments may give a clear picture of the efficacy of a treatment through a final versus the initial status comparison. In the case of improvement with a combination of therapies (the case here), the beneficial results were obtained with ICM-RI plus drug therapy and suggest an important role of ICM-RI, as argued above. A randomized controlled design is needed, but the choice of the control arm is not obvious, and carrying out a trial in a clinical setting would be very difficult and time-consuming because of an expectable high rate of patients' refusal to participate. Among the studies that can be carried out in an experimental setting, one would be an open comparative randomized parallel group clinical trial. Besides the drug treatment, one arm would receive ICM-RI only at the beginning and at the end of the trial, whereas the other arm would undergo several ICM-RI sessions for the duration of the trial. Another study would be to propose the same drug-associated treatment and the same ICM-RI design to the 2 arms, with ICM being monitored in the test arm and another perineal muscle but not the ICM being monitored in the control arm; such a study would assess the placebo effect. A third study would compare 2 active ICM-RI arms, and a factorial design would then simultaneously test the monthly frequency (eg, once or twice a month) and the duration of the treatment (eg, 6 months or 2 years). In the ED group, for instance, a study would consider 3 arms and 2 comparisons. The first arm would have a drug treatment associated with ICM-RI, the second a drug treatment only, and the third ICM-RI only. A comparison between the first arm and the third arm would test the effect of drugs in presence of ICM-RI, whereas a comparison between the second and third arms would examine ICM-RI versus drug treatments.

Finally, in patients with ED, the present results are significantly better than those obtained by other authors.[39–43] With max ΔP, the model led to an estimate that 87% of the patients showed a positive effect in relation to the number of sessions (ie, a favorable positive slope). However, the criteria for efficacy are not the same: the other authors investigated the improvement in intercourse satisfaction, not a constant physiological improvement. There are difficulties with using intercourse satisfaction questionnaires: (1) they cannot be administered to every patient because this approach depends on the motive of the consultation, on the personal life situation and the psychology of the patient, and on the number sessions taken and their continuity or regularity over time; and (2) a reliable questionnaire analysis (potentially statistical) requires a minimum number of completed questionnaires, which requires a lot of time. Nevertheless, in our future works, investigating the improvement of intercourse sat-

isfaction should occupy a better place. Besides, the results may differ according to the etiology and previous duration of ED and to patient cooperation and motivation; these factors warrant specific investigations. Another interesting subfield of our research would be the inclusion of patients with neuropathy because the prevalence of ED among them appears to be high.[51]

In conclusion, the present study focused on ICP improvement, the major component of erection. In the ED group, with max ΔP, the model led to the estimate that 87% of the participants showed a positive effect, and with max baseline, this proportion was estimated at 99%. In the PE group, 88% of the participants showed a positive effect regarding ICP, but the effects on PE-specific symptoms were much more difficult to assess.

The ICM behaves like any other striated muscle subjected to strengthening interventions. The ICM force is expected to progress during rehabilitation and persist after it. This expectation suggests that ICM-RIs allow a sustainable effect that probably depends on training. Because ICM atrophy is likely to occur in prolonged ED or after prostate surgery, it seems essential to check ICM force in such conditions and propose ICM-RI in case of atrophy.

Although we may strongly believe that ICM-RI is efficient, we still cannot assert it definitively because, currently, the specific effect of each ICM-RI component is not clearly established. Randomized clinical trials are strongly needed to estimate the respective contributions of medical treatment and rehabilitation and to improve ICM-RI by optimizing each of its components.

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References

1 Dean C, Lue TF. Physiology of penile erection and pathophysiology of erectile dysfunction. *Urol Clin North Am*. 2005;32:379–395.

2 Gratzke C, Angulo J, Chitaley K, et al. Anatomy, physiology, and pathophysiology of erectile dysfunction. *J Sex Med*. 2010;7:445–475.

3 Tajkarimi K, Burnett AL. The role of genital nerve afferents in the physiology of the sexual response and pelvic floor function. *J Sex Med*. 2011;8:1299–1312.

4 Poirier P, Charpy A. *Traité d'Anatomie Humaine*. Paris, France: Masson; 1901:197–201.

5 Lavoisier P, Courtois F, Barres D, Blanchard M. Correlation between intracavernous pressure and contraction of the ischiocavernosus muscle in man. *J Urol*. 1986;136:936–939.

6 Lavoisier P, Proulx J, Courtois F, et al. Relationship between perineal muscle contractions, penile tumescence, and penile rigidity during nocturnal erections. *J Urol*. 1988;139:176–179.

7 Lavoisier P, Aloui R, Iwaz J, Kokkidis MJ. The physiology of penile rigidity. *Prog Urol*. 1992;2:119–127.

8 Beckett SD, Hudson RS, Walker DF, et al. Blood pressures and penile muscle activity in the stallion during coitus. *Am J Physiol*. 1973;225:1072–1075.

9 Beckett SD, Walker DF, Hudson RS, et al. Corpus spongiosum penis pressure and penile muscle activity in the stallion during coitus. *Am J Vet Res*. 1975;36:431–433.

10 Beckett SD, Walker DF, Hudson RS, et al. Corpus cavernosum penis pressure and penile muscle activity in the bull during coitus. *Am J Vet Res*. 1974;35:761–764.

11 Beckett SD, Purohit RC, Reynolds TM. The corpus spongiosum penis pressure and external penile muscle activity in the goat during coitus. *Biol Reprod*. 1975;12:289–292.

12 Purohit RC, Beckett SD. Penile pressures and muscle activity associated with erection and ejaculation in the dog. *Am J Physiol*. 1976;231:1343–1348.

13 Schmidt MH, Valatx JL, Sakai K, et al. Corpus spongiosum penis pressure and perineal muscle activity during reflexive erections in the rat. *Am J Physiol*. 1995;269:904–913.

14 Bernabé J, Rampin O, Sachs BD, Giuliano F. Intracavernous pressure during erection in rats: an integrative approach based on telemetric recording. *Am J Physiol*. 1999;276:441–449.

15 Lavoisier P, Aloui R, Schmidt M, Gally M. Supra-systolic elevation of the intracavernous pressure secondary to stimulation of the glans penis. *Ann Urol (Paris)*. 1993;27:166–171.

16 Lavoisier P, Schmidt M, Aloui R. Intracavernous pressure increases and perineal muscle contraction in response to pressure stimulation of glans penis. *Int J Impot Res*. 1992;4:157–164.

17 Shafik A. Response of the urethral and intracorporeal pressures to cavernosus muscle stimulation: role of the muscles in erection and ejaculation. *Urology*. 1995;46:85–88.

18 Shafik A, El Sibai O, Shafik AA, Shafik IA. Cavernosus muscle contraction during erection: is it voluntary or reflex, given the striated nature of the muscles? *J Androl*. 2006;27:695–699.

19 Karacan I, Aslan C, Hirshkowitz M. Erectile mechanisms in man. *Science*. 1983;220:1080–1082.

20 Karacan I, Hirshkowitz M, Salis PJ, et al. Penile blood flow and musculovascular events during sleep-related erections of middle-aged men. *J Urol*. 1987;138:177–181.

21 Meehan JP, Goldstein AM. High pressure within corpus cavernosum in man during erection: its probable mechanism. *Urology*. 1983;21:385–387.

22 Lavoisier P, Proulx J, Courtois F. Reflex contractions of the ischiocavernosus muscles following electrical and pressure stimulations. *J Urol*. 1988;139:396–399.

23 Widmaier EP, Raff H, Strang KT. *Vander's Human Physiology: The Mechanisms of Body Function*. 11th ed. New York, NY: McGraw-Hill; 2009:308, 437, 438.

24 Beckett SD, Reynolds TM, Hudson RS, Holley RS. Serial angiography of the crus penis of the goat during erection. *Biol Reprod*. 1972;7:365–369.

25 Buvat J. Pathophysiology of premature ejaculation. *J Sex Med*. 2011;8(suppl 4):316–327.

26 Giuliano F, Clément P. Serotonin and premature ejaculation: from physiology to patient management. *Eur Urol*. 2006;50:454–466.

27 Piediferro G, Colpi EM, Castiglioni F, Nerva F. Premature ejaculation, 1: definition and etiology. *Arch Ital Urol Androl*. 2004;76:181–187.

28 Waldinger MD. The neurobiological approach to premature ejaculation. *J Urol*. 2002;168:2359–2367.

29 Waldinger MD. Premature ejaculation: different pathophysiologies and etiologies determine its treatment. *J Sex Marital Ther*. 2008;34:1–13.

30 Metz ME, Pryor JL. Premature ejaculation: a psychophysiological approach for assessment and management. *J Sex Marital Ther*. 2000;26:293–320.

31 Ballard DJ. Treatment of erectile dysfunction: can pelvic muscle exercises improve sexual function? *J Wound Ostomy Continence Nurs*. 1997;24:255–264.

32 Dorey G. Restoring pelvic floor function in men: review of RCTs. *Br J Nurs*. 2005;14:1014–1018, 1020–1021.

33 Hernando-Berríos M, Rivera-Martínez MS, Gualda-Vergara V. Non-pharmacological interventions for the treatment of erectile dysfunction in adult men: systematic review. *Enferm Clin*. 200;18:64–69.

34 Dorey G. Conservative treatment of erectile dysfunction, 3: literature review. *Br J Nurs*. 2000;9:859–863.

35 Dorey G. Pelvic floor exercises as a treatment for men with erectile dysfunction. *Nurs Times*. 2004;100:65–67.

36 La Pera G, Nicastro A. A new treatment for premature ejaculation: the rehabilitation of the pelvic floor. *J Sex Marital Ther*. 1996;22:22–26.

37 Pastore AL, Palleschi G, Leto A, et al. A prospective randomized study to compare pelvic floor rehabilitation and dapoxetine for treatment of lifelong premature ejaculation. *Int J Androl*. 2012;35:528–533.

38 La Pera G. Awareness of the role of the pelvic floor muscles in controlling the ejaculatory reflex: preliminary results. *Arch Ital Urol Androl*. 2012;84:74–78.

39 Claes H, van Hove J, van de Voorde W, et al. Pelvi-perineal rehabilitation for dysfunctioning erections: a clinical and anatomo-physiologic study. *Int J Impot Res*. 1993;5:13–26.

40 Claes H, Baert L. Pelvic floor exercise versus surgery in the treatment of impotence. *Br J Urol*. 1993;71:52–57.

41 Van Kampen M, De Weerdt W, Claes H, et al. Treatment of erectile dysfunction by perineal exercise, electromyographic biofeedback, and electrical stimulation. *Phys Ther*. 2003;83:536–543.

42 Dorey G, Speakman MJ, Feneley RC, et al. Pelvic floor exercises for erectile dysfunction. *BJU Int*. 2005;96:595–597.

43 Dorey G, Speakman M, Feneley R, et al. Randomized controlled trial of pelvic floor muscle exercises and manometric biofeedback for erectile dysfunction. *Br J Gen Pract*. 2004;54:819–825.

44 Schmidt MH, Schmidt HS. The ischiocavernosus and bulbospongiosus muscles in mammalian penile rigidity. *Sleep*. 1993;16:171–183.

45 Paillard T, Noé F, Passelergue P, Dupuis P. Electrical stimulation superimposed onto voluntary muscular contraction. *Sport Med*. 2005;35:951–966.

46 Johnson RD, Kitchell RL. Mechanoreceptor response to mechanical and thermal stimuli in the glans penis of the dog. *J Neurophysiol*. 1987;57:1813–1836.

47 Cardinale M, Rittweger J. Vibration exercise makes your muscles and bones stronger: fact or fiction? *J Br Menopause Soc*. 2006;12:12–18.

48 Lavoisier P, Courtois F, Proulx J, et al. Validation of a non-invasive device to measure intracavernous pressure as an index of penile rigidity. *Br J Urol*. 1990;65:624–628.

49 Shafik A. Perineal nerve stimulation: role in penile erection. *Int J Impot Res*. 1997;9:11–16.

50 Thomas CK, Johansson RS, Bigland-Ritchie B. EMG changes in human thenar motor units with force potentiation and fatigue. *J Neurophysiol*. 2006;95:1518–1526.

51 Amarenco G, Sheikh Ismaël S, Verollet D, et al. Clinical and electrophysiological study of sensory penile alterations: a prospective study of 44 cases. *Prog Urol*. 2013;23:946–950.