

1 **Title**

2 Utilising synergism between the transverse abdominal and pelvic floor muscles at different  
3 postures in nulliparous women: a case control study

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29 **Conflict of interest**

30 The authors have no conflict of interests.

31 **Statement:**

32 Each author's participation in the manuscript

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44 **Abstract**

45 **Background:** To determine the effects of the pelvic floor muscle training (PFM-T) in  
46 combination with transverse abdominal muscle (TRA) activation (cPFM-T) in female urinary  
47 incontinence.

48 **Methods:** We enrolled nulliparous women in supine (SUG) (n = 22), sitting (SIG) (n = 19)  
49 and control (COG) (n = 14) groups. We performed the 8-week cPFM-T programme. We  
50 examined the effect of training on the parameters with the Kruskal–Wallis test, and the  
51 pairwise comparisons with the Mann-Whitney U-test and the Wilcoxon-rank test with the  
52 Bonferroni correction.

53 **Results:** Before training, 15 participants reported occasional urinary leakage. After cPFM-T  
54 seven participants reported that urinary leakage had disappeared. Maximal isometric  
55 contraction of the pelvic floor muscles (PFM) until fatigue improved significantly in the SUG  
56 ( $p < 0.001$ ) and SIG ( $p = 0.015$ ) and not significantly in the COG ( $p = 0.499$ ). Holding time  
57 increased in the SUG ( $p = 0.972$ ) and the SIG ( $p = 0.717$ ), and decreased in the COG ( $p =$   
58  $0.132$ ). The dynamic endurance of the PFM improved significantly in the SUG ( $p < 0.001$ ),  
59 but not in the SIG ( $p = 0.798$ ) and the COG ( $p = 0.153$ ). The number of maximal fast  
60 contractions within 1 minute increased in both the SUG ( $p < 0.001$ ) and the SIG ( $p=0.813$ )  
61 and decreased in the COG ( $p = 0.257$ ). Relaxation improved significantly in the SIG ( $p =$   
62  $0.011$ ). TRA thickness increased in both training groups.

63 **Conclusions:** Slow-twitch fibres of the PFM can be trained effectively with PFM-T in both  
64 the body positions.

65 **Trial registration:** This study was registered in the Hungarian National Healthcare Service  
66 Center: 019234/2014/OTIG Registered 07 April 2014

67 **Keywords:**

68 pelvic floor muscle training, transverse abdominal muscle, ultrasound measurement, urinary  
69 incontinence, vaginal surface electromyography

## 70 **Brief summary**

71 This physiotherapist-guided group training programme should be performed in both the  
72 supine and the sitting positions; this results in better and more cost-effective patient  
73 motivation.

74

## 75 **Background**

76 Worldwide, an estimated 20%–30% of young women have urinary incontinence (UI), making  
77 the frequency of this condition a fundamental problem [1].

78 According to Kegel, regular, specific strength training of the pelvic floor muscles (PFM) has a  
79 beneficial effect on female UI and pelvic organ prolapse [2].

80 The effectiveness of Kegel's PFM-T exercises—classified by the International Consultation  
81 on Incontinence as level A evidence in Evidence Based Medicine [3, 4] has been proven in  
82 numerous randomised controlled trials.

83 Several research groups have reported a co-contraction between the deep abdominal muscles  
84 and the PFM [5, 6, 7, 8].

85 Together, these results suggest the necessity of involving a coordinated approach of the PFM  
86 and the deep abdominal muscles in the effective treatment of UI.

87 Several studies have revealed significantly higher resting PFM activity in unsupported sitting  
88 as compared to supported sitting and in a standing posture as compared to a supine position  
89 [8, 9, 10, 11].

90 Chmielewska [11] reported a significant a long-lasting contraction during unsupported sitting,  
91 due to the superior recruitment by the sitting posture of the sensorimotor control system to  
92 that by the supine position. They identified different coactivation patterns of the PFM and  
93 abdominal muscles during sitting to those during standing and lying.

94 Sufficient evidence that regular PFM-T improves the symptoms of incontinence has been  
95 reported [3, 12, 13]. However, only a few studies support the effect of the coordination of the  
96 diaphragm, deep abdominal muscles and PFM on incontinence [14, 15].

97 Current evidence on skeletal muscle training and other factors (UI, supervised PFM-T  
98 programme, e.t.c.) are known to have an impact on women's participation in and adherence to  
99 PFM-T [3].

100 Here we aimed to investigate whether—based on trunk muscle synergism—the condition and  
101 functioning of the PFM would improve in the sitting and supine postures or in the control  
102 group during PFM-T with forced exhalation.

103

## 104 **Methods**

### 105 **Participants**

106 We performed our study at the Faculty of Health Sciences and Social Studies, University of  
107 Szeged, Hungary between October 1, 2016 and December 1, 2016. We enrolled 58 healthy,  
108 young (mean±SD: 21.27±1.46 years), nulliparous women in this trial. We recruited them  
109 through an online advertisement and then selected them for the training groups and the control  
110 group (Additional file 3). The participants had no previous experience of PFM-T. We divided  
111 them into two study groups depending on the strength of the PFM and treated them with  
112 cPFM-T in both the supine position and the sitting position. The assessment comprised one  
113 phase: 3 repetitions of sustained 5-second voluntary PFM contraction with 10-second

114 relaxation. We calculated the mean of 3 contractions and set the obtained values in ascending  
115 order. The 22 participants with lower muscle strength (under 60  $\mu\text{V}$ ) comprised the SUG and  
116 the 22 participants with higher muscle strength (over 60  $\mu\text{V}$ ) formed the SIG. Only 19  
117 participants, however, completed the programme in the SIG (Additional file 3). We enrolled  
118 these 19 participants with higher PFM tension (over 60  $\mu\text{V}$ ) in the SIG because the PFM must  
119 be stronger to resist gravity [16]. We created a control group (n = 14) (COG) comprising  
120 seven persons with a PFM tension under 60  $\mu\text{V}$  and seven individuals with a PFM tension  
121 over 60  $\mu\text{V}$ . The COG did not change their lifestyles and did not undergo PFM-T. We  
122 included in the study groups participants willing to participate in the study and able to  
123 contract the pelvic floor and TRA muscles correctly. Participants were required to maintain  
124 their everyday activities (attending lessons, sport activities, and so on). The local ethics  
125 committee (National Healthcare Service Center) approved the study (019234/2014/OTIG) and  
126 we received written, informed consent from all participants. Exclusion criteria were known  
127 neurological or rheumatological diseases and previous vaginal or abdominal surgery.

## 128 **Subjective measurements**

129 In the study, before and after the training programme, we used a self-administered  
130 questionnaire (Additional file 7), based on three validated questionnaires (the King's health  
131 questionnaire, the Incontinence impact questionnaire and the Urogenital distress inventory)  
132 [17]. We included in the questionnaire risk factors for UI (obstetric history, height and weight,  
133 stress, physical activity level, sport, vaginal and abdominal surgery) and questions relating to  
134 the urinary tract and anal canal (involuntary urinary leakage, cystitis, constipation) and sexual  
135 activity (orgasm problems).

136

## 137 **Objective measurements**

## 138 **Vaginal surface electromyography (vsEMG)**

139 We measured changes in PFM activity with a vaginal surface electromyographic (vsEMG)  
140 instrument (FemiScan™ MultiTrainer™, Mega Electronics, Finland), which measures the  
141 electronic signals of PFM activity, using a sterile Periform™ intravaginal probe with vsEMG  
142 electrodes [7]—a pear-shaped device 8 cm in length and 3.4 cm in medial–lateral diameter at  
143 its peak width, but tapering at the introitus, with nickel detection surfaces on both sides and an  
144 indicator to help patients to perform the tasks correctly. A correct voluntary contraction of the  
145 PFM contributes to downward (posterior) movement of the indicator [18]. We positioned a  
146 reference electrode on the patient’s left forearm.

### 147 **Procedure**

148 We tested the participants in a lying position with the hips and knees flexed, feet resting on a  
149 plinth and knees supported to allow the hips and PFM to relax [7]. We instructed the  
150 volunteers on the proper placement of a FemiScan™ vsEMG probe in situ within the vagina.  
151 The same physiotherapist (T.M.) assessed all participants twice (at 0 weeks and at 8 weeks),  
152 at which times PFM activities were measured in a supine position. Before each measurement,  
153 the therapist instructed the participants how to perform PFM tasks. The participants were not  
154 allowed to move the hips and lumbar spine. We displayed the vsEMG data as line graphs,  
155 thus providing visual feedback for the participants, and recorded the values in microvolts.

156 The participants performed three tasks:

- 157 1. PFM relaxation state for 30 seconds;
- 158 2. maximal isometric contraction till fatigue: one maximum voluntary tonic contraction  
159 of the PFM, held until fatigue, carried out once;
- 160 3. dynamic endurance: fast, sudden maximum voluntary phasic contractions of the PFM,  
161 performed for one minute.

162

### 163 **Transabdominal ultrasound measurement**

164 We performed the TRA measurements at the same time as the vaginal measurements and  
165 PFM tasks. We measured the degree of the change in the muscle thickness. We measured the  
166 thickness of the TRA because Madill and McLean [7] found that the synergistic coactivation  
167 between the TRA and the PFM was stronger than that between the rectus abdominis muscle  
168 (RA), the external oblique muscle (EO) and the PFM. Thus we decided that it was sufficient  
169 to measure the thickness of the TRA only, assessing it by ultrasound (US) visualisation  
170 (Z.ONARE™ SP/Musculoskeletal, 8 MHz, 35-mm curved linear array transducer) on the  
171 lateral abdominal wall. The same operator (A.S.), who is an expert in US evaluation, and was  
172 blind to the grouping of the patients, performed all imaging procedures. The technique of  
173 acquiring images of the TRA and the measurement techniques have been previously described  
174 [19]. She placed the centre of the transducer in the transverse plane just superior to the iliac  
175 crest in line with the mid-axillary line, performing the measurement of muscle thickness on  
176 the left side of the participant at rest and during the isometric tasks before and after cPFM-T.  
177 The participants were not allowed any movement of the hip and lumbar spine. We acquired  
178 the following recordings: (1) the thickness of the TRA during PFM relaxation, and (2) the  
179 TRA thickness during maximal isometric contraction till PFM fatigue. We measured the  
180 thickness of the TRA at the point where the muscle was at its thickest.

181

### 182 **Pelvic floor muscle training**

183 A physical therapists (T.M.) supervised the training, and carried out the evaluation. We  
184 divided the participants into two study groups depending on the strength of the PFM and  
185 treated them with cPFM-T in both supine (n = 22) (SUG) and sitting (n = 19) (SIG) positions.

186 We also set up one control group (n = 14) (COG). The treatment for the SUG and the SIG  
187 comprised 8 sessions, with a 1-hour cPFM-T session each week in a group and 15 minutes of  
188 individual home training, six times a week for a total of 8 weeks of treatment. Before the  
189 cPFM-T, we instructed all participants in the anatomy of the PFM and the lower urinary tract,  
190 the mechanism of continence and unsupported sitting posture. We discouraged the slumped  
191 sitting posture since unsupported sitting postures require greater PFM activity than supported  
192 sitting postures [9]. All training sessions comprised warming-up, gradual muscle  
193 strengthening and relaxation exercises. We found palpation and visualisation to be very  
194 powerful tools for re-educating muscles and very helpful, especially in the training of  
195 invisible muscles [20, 21]. During the training sessions, the physiotherapist taught awareness  
196 through palpation and visualisation. Any woman can feel both TRA and PFM activity at the  
197 medial anterior superior iliac spina (ASIS), because the initial intravaginal pressure is  
198 predominated by PFM activity and the later increase in pressure (up to 70% maximum  
199 pressure) is produced by the combined activation of the PFM, the RA, the internal oblique  
200 muscle (IO) and the TRA [22]. It is possible for anybody to feel the different levels of PFM  
201 contractions by TRA/PFM co-contraction at the medial ASIS (through the abdominal wall).  
202 The RA muscle had to be relaxed.

- 203 I. In the first 4 weeks of cPFM-T all study groups (n = 41) did exercises in the supine  
204 position with the hip and knees flexed, feet resting on the plinth, a hip width apart.
- 205 II. In the second 4 weeks the participants performed exercises, but while the SUG (n =  
206 22) did exercises in the supine position with the hips and knees flexed, feet resting on  
207 the plinth, the SIG (n = 19) did exercises while sitting upright without support, feet  
208 resting on the plinth.

209 The Additional file 8 provides a detailed exercise regimen (based on the Sapsford's method  
210 [23]) and progression, including prerequisites, exercise position, instructions, feedback and a  
211 home exercises set for each week.

## 212 **Statistical analysis**

213 We report our data as mean $\pm$ SD or median [1st quartile–3rd quartile] and sample size for each  
214 parameter and study group. We examined the effect of training on the parameters with the  
215 Kruskal–Wallis test. We performed the pairwise comparisons with the Mann–Whitney U-test  
216 and the Wilcoxon-rank test with the Bonferroni correction. We performed all statistical  
217 analyses using R statistical programme (version 3.5.1, R Foundation for R statistical  
218 computing). We considered values of  $p < 0.05$  to be statistically significant. A statistician (M.  
219 SZ) performed the evaluation.

## 220 **Results**

### 221 **Questionnaire results**

222 The participants were aged between 18 years and 25 years, with a body mass index (BMI) of  
223 19.77 kg/m<sup>2</sup>–23.32 kg/m<sup>2</sup>. In Additional file 1(Table 1) we list the characteristics of  
224 participants.

225 At the beginning of the training programme 15 participants (4 SUG, 8 SIG and 3 COG  
226 participants) complained of urinary leakage during stress (coughing, sneezing, laughing, nose  
227 blowing). After the training programme urinary leakage disappeared in 7 participants (3 SUG  
228 and 4 SIG participants), while the symptoms of the COG remained unchanged. All  
229 participants experienced the leakage of a few drops of urine, but rarely urinary loss (first  
230 degree SI).

231 Women with a sexual partner (n = 31) reported positive changes after the training programme  
232 in their sexual life.

233 20 participants (10 SUG, 8 SIG and 2 COG participants) complained of air flow to the vagina  
234 in unusual positions. After the training programme only 5 participants (2 SUG, 1 SIG and 2  
235 COG participants) reported unchanged conditions.

236 6 participants (3 SUG and 3 SIG participants) suffered from constipation, which was in all  
237 cases resolved by the end of the training programme.

### 238 **Electromyographic and ultrasound results**

239 We present the data in Additional file 2. The maximal isometric contraction of the PFM till  
240 fatigue improved significantly in both study groups; however, after cPFM-T, this increase was  
241 higher in the SUG. The tonic contraction of the PFM improved in the COG, but the  
242 improvement was not significant ( $p = 0.499$ ) (Additional file 4, Fig. 2. A). Although in both  
243 study groups, the holding time of the maximal isometric contraction of the PFM till fatigue  
244 and the thickness of the TRA during the maximal isometric contraction of the PFM till fatigue  
245 both increased, these changes were not significant (Additional file 4, Fig. 2. B). The latter  
246 parameter decreased significantly in the COG (Additional file 4, Fig. 2. C) (Additional file 2,  
247 Table 2).

248 On the other hand, while the strength of the maximal fast contractions of the PFM within one  
249 minute increased significantly in the SUG, it decreased in the SIG and the COG; this  
250 decrease, however, was not significant (Additional file 5, Fig. 3. A). In both study groups, the  
251 number of maximal fast contractions within a minute increased, but the increase was  
252 significant only in the SUG. This parameter decreased in the COG (Additional file 2, Table 2)  
253 (Additional file 5, Fig. 3. B).

254 In both study groups, the values for relaxation of the PFM decreased but the decrease was  
255 significant only in the SIG ( $p = 0.011$ ). This value increased in the COG (Additional file 6,  
256 Fig. 4. A). The thickness of the TRA during relaxation of the PFM decreased in the SUG ( $p =$   
257  $0.422$ ) and the COG ( $p = 0.209$ ), but not in the SIG ( $p = 0.717$ ). Neither of these changes were  
258 significant (Additional file 6, Fig. 4. B) (Additional file 2, Table 2).

## 259 **Discussion**

260 Our study demonstrated that an eight-week period of cPFM-T with forced exhalation,  
261 performed by young nulliparous women in both the supine posture and the sitting posture,  
262 using trunk muscle synergies, is effective in improving cases of incontinence.

263 Furthermore, the holding period, rapid reaction and resting function of the PFM—as well as  
264 the thickness of TRA—improved due to both the modification of body position and the  
265 exhalation technique. Improvements in the holding function of the PFM were significant in  
266 both the supine position and the sitting position, but improvements in the rapid reaction of the  
267 PFM were significant only in the supine position, while those in the resting function of the  
268 PFM were significant only in the sitting position. The thickness of the TRA improved in both  
269 the supine position and the sitting position.

270 Assessments of the PFM can be used to determine which structural or functional features are  
271 deficient, and to inform the design of subsequent training regimens to address these  
272 dysfunctions. A diversity of exercises, possibly tailored to the abilities of each woman, may  
273 be used and proposed training includes raising the number of repetitions of contractions  
274 [24]—a recommendation endorsed by our results.

275 Sapsford [23] advocated a new approach to the rehabilitation of urinary incontinence—motor  
276 relearning for diaphragmatic, deep abdominal muscles and the PFM rather than selective  
277 muscle strengthening.

278 Thompson et al. [25] suggested careful monitoring of Sapsford's complex rehabilitation  
279 training, because abdominal muscles are more active than PFMs in symptomatic women.  
280 These results suggest that a coordinated approach involving both deep abdominal muscles and  
281 PFM is necessary.

282 The correct breathing technique is very important in PFM-T. The diaphragm is a respiratory  
283 muscle participating in the stabilisation of the lumbar spine by enhancing abdominal pressure  
284 [26], which in turn stabilises the lumbar spine. Hodges et al. [27] reported synergism between  
285 the diaphragm and the TRA. We also utilised this synergism by forced exhalation in our study.  
286 Neumann and Gill [6] suggested that the activation of deep abdominal muscles is essential for  
287 an effective contraction of the PFM, because their continent participants were unable to  
288 contract the PFM effectively while maintaining relaxation of the TRA and the IO. Similarly,  
289 Madill and McLean [22] found that the patterns of abdominal muscle activity appear to occur  
290 due to voluntary PFM contractions in healthy continent women.

291 As a representation of vaginal closure force, the isometric contraction was considered to be  
292 greater in the supine than in the standing position. Subsequent studies, however, have  
293 determined that women are able to perform equally strong PFM contractions in either body  
294 position [7, 8, 11].

295 The PFM is a striated muscle, with two thirds of its fibres are type I (slow-twitch fibres),  
296 responsible for the resting tone of the levator muscle and one third of its fibres, type II (fast-  
297 twitch fibres), responsible for sudden, fast but powerful contractions. The activity of the slow  
298 fibres is necessary for the resting potential and the retention of urine and stool, while the fast  
299 fibres are responsible for resistance during sudden abdominal pressure [28]. We monitored the  
300 activity of these two fibre types (retention and rapid function) in our study with vsEMG  
301 measurements and trained both types in weaker and stronger PFM-T.

302 The fact that SUI happens most frequently in the upright position informed our study of the  
303 functional (static and dynamic) parameters occurring in everyday life. The holding function of  
304 the PFM is important for the patients—that is, they need to be able to get to the toilet in time  
305 before their urine starts leaking. The quality of breathing plays an important role in PFM  
306 training. It is necessary to teach participants the correct abdominal breathing technique which  
307 activates the TRA. In our study, we activated the TRA and voluntary contraction of the PFM  
308 with strong exhalation techniques during both measurements and training. Using biofeedback  
309 (TRA ultrasound imaging and vsEMG curves of PFM) we visualised the co-contraction of the  
310 two muscles with the participants. Our vsEMG findings indicate that the static isometric  
311 contraction force of the PFM increased significantly in both study groups—and the holding  
312 time of static isometric contraction of the PFM increased slightly—with forced exhalation. In  
313 the COG, the static strength of the PFM increased slightly, but this increase was not  
314 significant and was characterised by a short retention time. The thickness of TRA during  
315 maximal isometric contraction of the PFM till fatigue improved in both training groups, but in  
316 neither group was this improvement significant. The COG claimed that this parameter  
317 decreased significantly because, during our study, they had spent much more time in a sitting  
318 position and were therefore in an enforced inactive lifestyle. Another study obtained similar  
319 results for musculus multifidus [29].

320 Hung et al. [14] 2010 investigated the effects of combining voluntary PFM- and deep  
321 abdominal muscle training in different body positions. The TRA activity was significantly  
322 greater in the sitting and standing positions than in the supine position. Chmielewska et al.  
323 [11] also reported that long-lasting contractions in the unsupported sitting position utilised the  
324 sensorimotor control system significantly compared with those in the supine position.  
325 However, in our study, cPFM-T in both the weaker PFM (in the SUG) and the stronger PFM

326 (in the SIG) led to significant development in long-lasting contractions regardless of the body  
327 position of the measure.

328 Chmielewska et al. [11] measured the rapid activity of the PFM with vsEMG in the supine  
329 position and in the sitting position, finding no significant differences between the PFM  
330 average peak amplitudes in the investigated positions, while we found these values to be  
331 significantly improved in the supine position. In our study, only in the supine position did the  
332 strength and repetition of dynamic fast contractions increase\ significantly; in the sitting  
333 position, changes in dynamic fast contractions were not significant. The fast activity of the  
334 PFM is responsible for resistance during sudden abdominal pressure. In the COG, dynamic  
335 strength and repetition decreased and did not manifest significant changes.

336 Capson et al. [8] and Chmielewska et al. [11] measured the relaxation tone of the PFM in the  
337 supine position and in the sitting position. They deduced that gravity forces increase the  
338 pressure on the PFM in the vertical position, increasing its tone and leading to a higher resting  
339 activity of the PFM in the sitting position than in the supine position. During our measures,  
340 the SIG participants found it easier to relax in the horizontal position. Based on our results,  
341 practising relaxation exercises can be beneficial not only in the horizontal position but also in  
342 the vertical position. Improvement in the relaxation ability of the PFM is also a beneficial  
343 result, because especially during urination, for a healthy, normal urination mechanism it is  
344 necessary to consciously relax the PFM. The relaxation state of the PFM improved  
345 significantly due to gravity forces only in the SIG.

346 We observed that the conditioning capabilities of the PFM improved in the SUG during the 8  
347 week period of cPFM-T. The ability to sustain isometric contractions improved significantly,  
348 while holding time also improved, but this improvement was not significant. There was also a  
349 significant improvement in dynamic endurance and repetitions. Therefore we recommend a  
350 more intense strengthening of the TRA in the horizontal body position.

351 In the case of the SIG, the maximal isometric contraction of the PFM till fatigue also  
352 improved significantly, together with the holding time, but the latter improvement was not  
353 significant. The dynamic endurance decreased and the number of repetitions improved  
354 slightly, but these changes were not significant. The relaxation state of the PFM improved  
355 significantly due to gravity forces. The resting tone of the TRA remained unchanged after 8  
356 weeks. Thus, even more intense TRA activation is required in the vertical position, as a  
357 reliance on the enhanced gravitational forces caused by the lumbopelvic posture or on the  
358 activated TRA induced by strong exhalation is insufficient to induce the necessary changes in  
359 the functioning of the TRA.

360 In the case of the COG, all parameters decreased—particularly the thickness of TRA during  
361 maximal isometric contraction of the PFM till fatigue, which decreased significantly—by  
362 reason of sedentary lifestyle.

363 We also established that young nulliparous women might also be affected by urinary leakage  
364 (27%) as confirmed by the results of Haslam et al. [1].

365 In the case of the SUG, both training exercises and measurements were performed in the  
366 supine position, whereas the SIG participants were measured in the lying position but  
367 performed all the exercises in the sitting position. Since SUI takes place most frequently in  
368 the vertical position, we should not measure and strengthen the static and dynamic functions  
369 of the PFM only in the supine position. We recommend that during cPFM-T, isometric and  
370 relaxation tasks should be performed both in the supine position and in the sitting position.

371 According to Sapsford et al. [5], the antigravity posture requires more intense PFM activity.  
372 Furthermore, Chmielewska et al [11] reported a significant difference between the sustained  
373 1-minute contraction of the PFM in the supine position and that in sitting position, while we  
374 found that the maximal isometric sustained contraction of PFM till fatigue significantly  
375 improved both in the supine position and in the sitting position.

376 Group training and individual training, according to recent research, are equally effective, and  
377 group training is more cost-effective [30]. Furthermore, due to differences in knowledge and  
378 behaviour, physiotherapist-guided training can help and motivate patients in persistent PFM-T  
379 [31].

380

### 381 **Conclusions**

382 TRA relaxation is easier in the horizontal position and strengthening is more effective in the  
383 horizontal body position. Physiotherapist-guided group training is more efficient.

384 The authors suggest that during PFM training the isometric tasks should be performed both in  
385 the supine position and in the sitting position, the dynamic endurance tasks of the PFM should  
386 be performed at the beginning of the training only in the supine position and more intensive  
387 strengthening of the TRA should be performed in the supine position to achieve maximal  
388 PFM contraction.

389

### 390 **Abbreviations**

ANOVA	analysis of variance
ASIS	anterior superior iliac spine
cPFM-T	combined pelvic floor muscle training
COG	control group
EO	external oblique muscle
IO	internal oblique muscle
PFM	pelvic floor muscles
PFM-T	pelvic floor muscle training
RA	rectus abdominis muscle

SD	standard deviation
SIG	sitting group
SUI	stress urinary incontinence
SUG	supine group
TRA	transverse abdominal muscle
RCT	randomised controlled trial
UI	urinary incontinence
US	Ultrasound
vsEMG	vaginal surface electromyography

391

392 **Declarations**

393 **Ethics approval and consent to participate**

394 The protocol and consent forms were approved by ethics committee of the Hungarian  
395 National Healthcare Service Center. The title of the ethics approval: Non-interventional study  
396 "Effect of PFM on Urinary Incontinence and Sexual Quality of Life". The number of the  
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400 +36(1)8869329. E-mail: [amd@ogyei.gov.hu](mailto:amd@ogyei.gov.hu). All participants provided written informed  
401 consent.

402 **Consent for publication**

403 Not applicable.

404 **Availability of data and materials**

405 The datasets used and/or analysed during the current study are available from the  
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#### 407 **Competing interests**

408 All financial and non-financial competing interests must be declared in this section.

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#### 414 **Authors' contributions**

415 Each author's participation in the manuscript

416 T M: project development, study design, ultrasound investigation, data collection, manuscript  
417 writing and editing

418 A D: project development, study design, manuscript revision

419 M Sz: data collection, statistical analysis,

420 A S: study design, ultrasound investigation, manuscript writing, editing and revision

421 J B: project development, manuscript revision

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#### 424 **Author informaiton**

425 This may include details about the authors' qualifications, current positions they hold at  
426 institutions or societies, or any other relevant background information. Please refer to authors  
427 using their initials.

#### 428 **Legend to the tables**

429 TABLE 1. Participant characteristics

430 TABLE 2. PFM activity while resting during tonic and phasic contractions in the COG, the  
431 SIG and the SUG, and the thickness of TRA during isometric contraction of PFMs until  
432 fatigue and in a relaxed state

433

#### 434 **Legend to the figures**

435 FIGURE 1. Flow chart of study participants

436 FIGURE 2. (A) vsEMG values of the maximal isometric contraction of PFMs till fatigue; (B)  
437 holding time of maximal isometric contraction of PFMs till fatigue; (C) the thickness of TRA  
438 during maximal isometric contraction of PFMs till fatigue.

439 FIGURE 3. (A) EMG values of strength of maximal fast contractions within 1 min. (B)  
440 Number of maximal fast contractions within 1 min.

441 FIGURE 4. (A) Relaxation values for PFMs. (B) Thickness of TRA during relaxation of  
442 PFMs.

443

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533 **Additional file 1**

534 **Table1. Participant Characteristics**

Age (years)	21.00 [20.00–22.00] (SUG)			
	21.00 [20.00–22.00] (SIG)			
	21.50 [21.00–23.00] (COG)			
Number of participants (positions)	22 (SUG)			
	19 (SIG)			
	14 (COG)			
BMI (kg/m <sup>2</sup> )	21.85 [20.77–22.95] (SUG)			
	21.30 [20.00–22.20] (SIG)			
	22.00 [19.77–23.32] (COG)			
Number of participants doing regular physical activity more than twice a week	9 (SUG)			
	9 (SIG)			
	5 (COG)			
BMI	SUM	SUG	SIG	COG

	(n = 55)	(n = 22)	(n = 19)	(n = 14)
Normal BMI 18-24	45	18	16	11
Overweight BMI 25-29	9	3	3	3
Underweight BMI <18	1	1	0	0

535

536 Values are median [ $1^{st}$  -  $3^{rd}$ ] quartiles for age and BMI and numbers of participants.

537 BMI: body mass index; SUG: the supine study group; SIG: the sitting study group; COG: the  
538 control group

539 **Additional file 2**

540 **Table 2. PFM activity while resting and during tonic and phasic contractions in COG,**  
541 **SIG and the SUG as well as the thickness of TRA during isometric contraction of PFM**  
542 **until fatigue and in a relaxed state**

	Before training	After training	p-value
	median [Q <sub>1</sub> – Q <sub>3</sub> ]		
<b>Maximal isometric contraction of PFM till fatigue (tonic) (μV)</b>			
COG	56.25 [44.23–83.62]	58.65 [54.27–89.07]	0.499
SIG	91.20 [63.55–124.20]	115.60 [84.50–131.80]	0.015
SUG	42.90 [27.73–53.42]	59.00 [50.10–73.85]	<0.001
<b>Holding time of PFM (s)</b>			
COG	21.25 [14.58–27.50]	17.00 [12.50–19.41]	0.132
SIG	17.00 [12.75–27.50]	19.50 [15.50–23.00]	0.717
SUG	19.50 [16.50–29.75]	21.25 [13.25–28.62]	0.972
<b>Dynamic endurance of PFM (phasic) (μV)</b>			

COG	88.16 [62.84–97.22]	77.05 [60.23–87.83]	0.153
SIG	122.00 [95.30–142.20]	115.16 [94.68–128.42]	0.798
SUG	53.15 [35.61–64.28]	70.97 [56.10–83.80]	<0.001
<b>Number of repetitions of fast contractions of PFM (repetitions)</b>			
COG	33.00 [29.25–36.00]	31.00 [29.25–33.75]	0.257
SIG	29.00 [22.00–39.00]	30.00 [23.00–35.50]	0.813
SUG	26.00 [21.75–33.50]	32.00 [27.25–39.75]	<0.001
<b>Relaxation state of PFM (<math>\mu</math>V)</b>			
COG	8.60 [6.48–17.98]	10.55 [3.85–19.40]	0.851
SIG	21.40 [8.35–27.05]	12.40 [3.00–19.45]	0.011
SUG	13.40 [9.20–20.75]	13.25 [6.83–18.50]	0.465
<b>TRA (cm) during relaxation state of PFM</b>			
COG	0.38 [0.33–0.44]	0.31 [0.27–0.34]	0.209
SIG	0.26 [0.23–0.32]	0.26 [0.23–0.31]	0.717
SUG	0.28 [0.26–0.31]	0.27 [0.25–0.31]	0.422
<b>TRA (cm) during maximal isometric contraction of PFM till fatigue</b>			
COG	0.63 [0.61–0.74]	0.49 [0.45–0.57]	0.007
SIG	0.51 [0.38–0.63]	0.56 [0.41–0.75]	0.231
SUG	0.53 [0.44–0.73]	0.58 [0.46–0.68]	0.570

543 Values are median [ $1^{st}$ – $3^{rd}$ ] quartiles for isometric contractions, resting of the PFM and the

544 TRA and phasic contractions of the PFM.

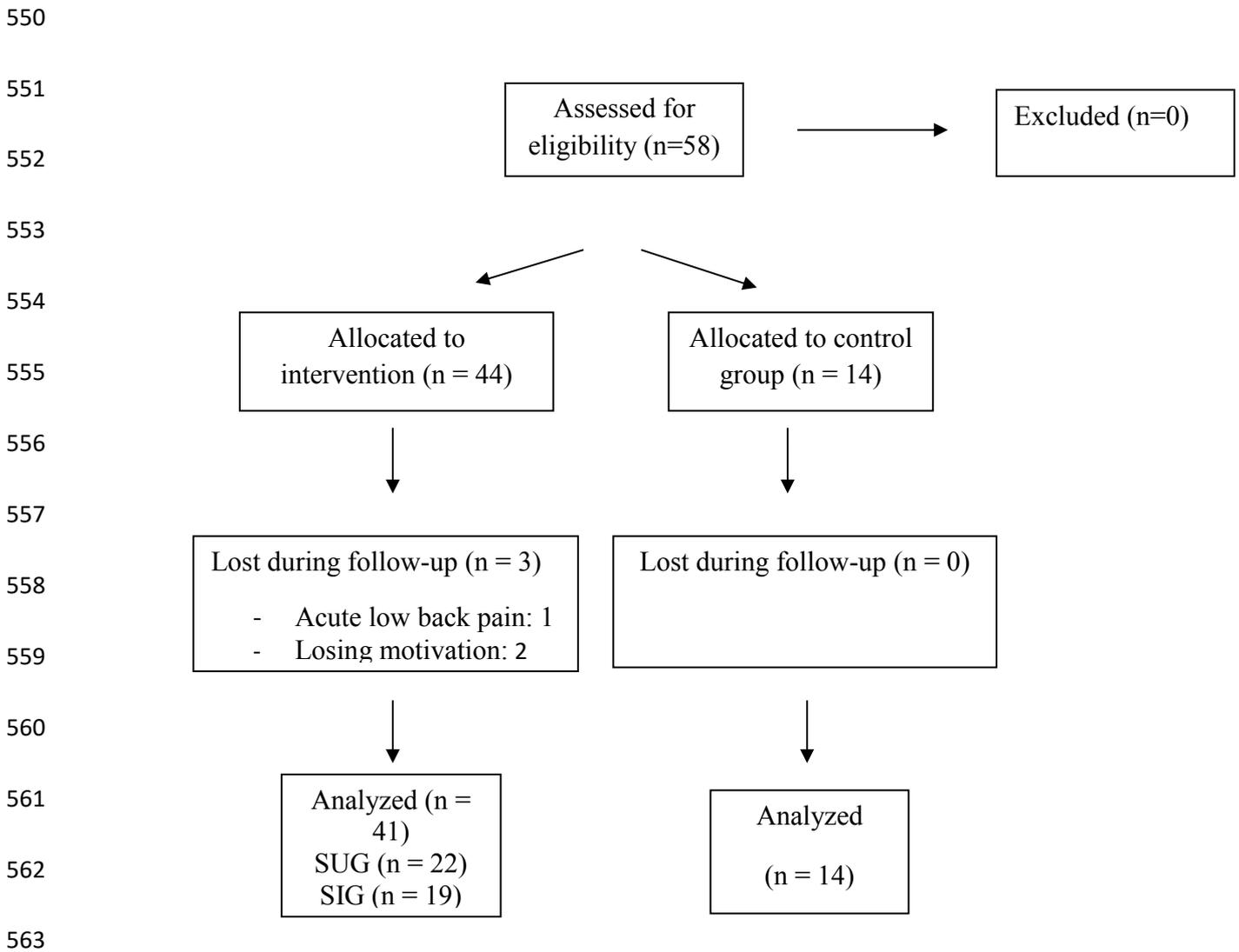
545 Key: SUG: number of participants in the supine study group; SIG: number of participants in

546 the sitting study group; COG: number of participants in the control group; PFM: pelvic floor

547 muscles; TRA: transverse abdominal muscle

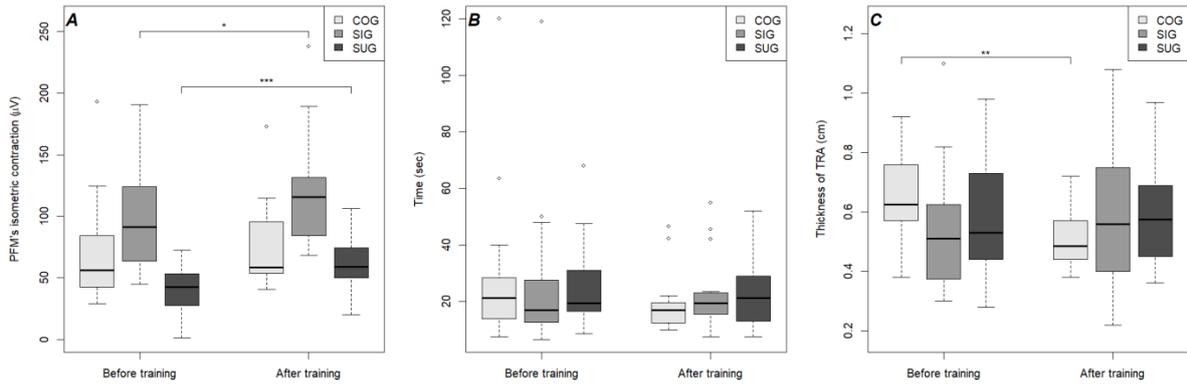
548 **Additional file 3**

549 **FIGURE 1. Flow chart of study participants**



564 **Additional file 4**

565 **FIGURE 2. (A)** vsEMG values of maximal isometric contraction of the PFM till fatigue; **(B)**  
566 holding time of maximal isometric contraction of the PFM till fatigue; **(C)** the thickness of the  
567 TRA during maximal isometric contraction of the PFM till fatigue.

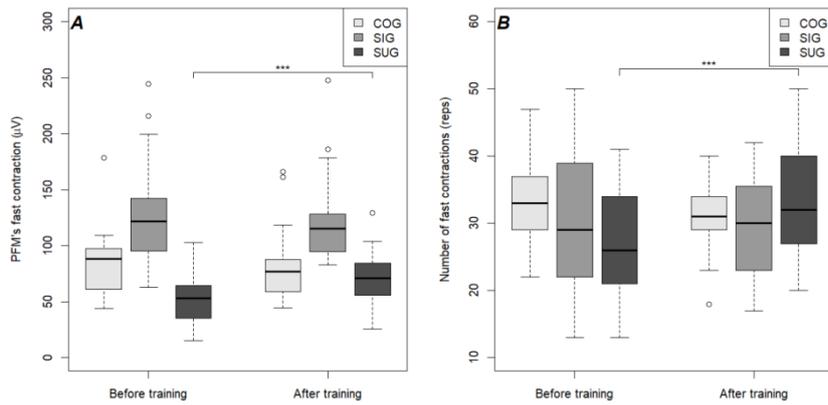


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569 **Additional file 5**

570 **FIGURE 3. (A)** EMG values of strength of maximal fast contractions within 1 min **(B)**  
 571 **Number of maximal fast contractions within 1 min**

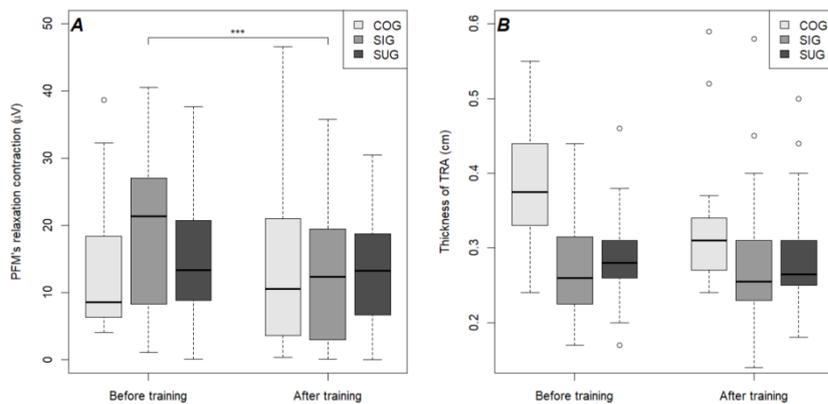
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574 **Additional file 6**

575 **FIGURE 4. (A)** Relaxation values for the PFM **(B)** Thickness of the TRA during relaxation  
 576 **of the PFM**



577

578 **Additional 7**  
579 **Questionnaire**

580 **Questionnaire**

- 581 1. Name:
- 582 2. Age:
- 583 3. Height:
- 584 4. Body weight:
- 585 5. Sports? YES NO
- 586 6. If so, what sport?.....
- 587 7. How many times a week, and what time does the sport  
588 entail?.....
- 589 8. Do you smoke? YES NO
- 590 9. Do you take any medicine? YES NO
- 591 10. If so, what?.....
- 592 11. Are you suffering from any gynaecological or urological disease? YES NO
- 593 12. If so, from what illness do you suffer?
- 594 13. Are you suffering from any coughing disease (hay fever, asthma, chronic bronchitis  
595 and so on)? YES NO
- 596 14. How much fluid do you drink daily?
- 597 a) 0–1 L
- 598 b) 1–2 L
- 599 c) 2–3 L
- 600 15. Menstrual cramps on a 1–10 scale where 1 is a very mild and 10 is a very strong,  
601 almost unbearable, pain!
- 602 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

- 603 16. Do you experience leakage of urine drops? YES NO
- 604 17. If yes, to what extent?
- 605 a) mild: 1–2 drops
- 606 b) medium: 10–15 drops
- 607 c) large volume: 15–30 drops
- 608 18. When does urine leak?
- 609 a) during jumping, coughing
- 610 b) climbing stairs, during lifting
- 611 c) at rest, without any activity
- 612 d) Other:
- 613 19. Do you have stool or gas retention problems? YES NO
- 614 20. Do you suffer from haemorrhoids? YES NO
- 615 21. Do you suffer from constipation?
- 616 a) sometimes
- 617 b) very often
- 618 c) almost never or very rarel
- 619 22. Does your vagina feel dilated? YES NO
- 620 23. Do you feel the airflow in your vagina? YES NO
- 621 24. . If so, when does it occur?
- 622 a) during sexual intercourse
- 623 b) during change in position (line up)
- 624 c) Other:
- 625 25. After swimming or bathing in the tub, do you still feel water dripping from your
- 626 vagina for a long time? YES NO
- 627 26. Do you have a sexual life? YES NO

- 628 27. If so, how often?
- 629 a) 1 time per month
- 630 b) 1 time per week
- 631 c) 2–4 times per week
- 632 d) 5–7 times per week
- 633 e) occasionally
- 634 f) Other: .....
- 635 28. Do you feel pain when penetrating a tampon or sexual intercourse? YES NO
- 636 29. Sexual libido on a scale of 1 to 10, where 1 is low and weak and 10 is strong libido!
- 637 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10
- 638 30. Frequency of orgasm on a 1–10 scale, where 1 means very rarely and 10 is almost
- 639 always during sexual intercourse!
- 640 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

641

642 **Additional file 8**

643 Detailed exercise regimen and estimated progression in the present trial (Sapsford, 2004;  
644 Hung, 2010)

Stage	Exercise regimen
I. Before the training programme: Patient education	Teaching about the anatomy of the PFM, risk factors, symptoms of PFM dysfunction and feeling PFM contractions through palpation and visualisation. <i>Position:</i> supine <i>Instruction:</i> Try to lift your PFM as if you want to hold your urine or faeces. <i>Home exercise:</i> Awareness through feeling PFM contractions

	<p><i>Feedback:</i> palpation, mirror and during urination</p>
<p>II. Week 1: Diaphragmatic breathing, tonic TRA and PFM activation, warm-up, voluntary concentric and isometric PFM contractions</p>	<p><i>Group position:</i> supine</p> <p><i>Instructions:</i> Try to raise the abdomen while your chest expands only minimally during inhalation, then lower your abdomen during exhalation; try to lift your lower abdomen cranially and keep pulling it in towards your spine; tensing exercises for the muscles (hip extensor, adductor) surrounding the pelvic floor; lift PFM gradually (25%, 50%, 75% and 100%) and try to hold it; try to relax PFM as far as possible by diaphragmatic breathing and hip movements. Spinal and pelvic movements are prohibited.</p> <p><i>Feedback:</i> in front of a mirror to see lower abdominal and rib movements; tactile input at the medial ASIS by both the therapist and the participant; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> in supine position:  Diaphragmatic breathing 30 repetitions <math>\times</math> 2 sets/day; holding the TRA contraction as long as possible (target: 40 s) <math>\times</math> 2 sets/day; contracting the gluteal and hip adductor 15 repetitions; pulling PFM up gradually (25%, 50%, 75% and 100%), 5 repetitions and hold at different levels for 5–10 s <math>\times</math> 2 sets/day. Make sure PFM are relaxed.</p>
<p>III. Week 2: PFM voluntary eccentric and quick contraction</p>	<p><i>Prerequisites:</i> the participant can perform the tasks of Week 1.</p> <p><i>Group position:</i> supine</p>

	<p><i>Instruction:</i> Repeat the home exercises of Week 1 as a warm-up; try to let PFM down slowly from 25%, 50%, 75% and 100% and hold at different levels; try to pull PFM up quickly as far as possible and make sure PFM are relaxed.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the participant to check the TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> in supine position:  Diaphragmatic breathing 30 repetitions × 2 sets/day; holding the TRA contraction as long as possible (target: 40 s) × 2 sets/day; contracting the gluteal and hip adductor 15 repetitions; maximal PFM contraction 5 repetitions; pulling PFMs up gradually 25%, 50%, 75% and 100%, 5 repetitions; hold at different PFM levels for 5–10 s; pull up and let down from 50% to 100%, 5 repetitions; pull PFM up quickly at 100% and relax for 30 s, 5 repetitions. All repetitions × 2 sets/day. Make sure PFM are relaxed.</p>
IV. Week 3:	<p><i>Prerequisites:</i> the participant can perform the tasks of Weeks 1 and 2</p> <p><i>Group Position:</i> supine</p> <p><i>Instruction:</i> Try to keep the PFM contraction at 100% combined with slow movement of the limbs and trunk; pull the PFM up quickly at 100% together with fast limb movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is</p>

	<p>palpated by both the therapist and the participant to feel the TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> in supine position: same as the home exercise of Week 2.</p>
<p>V. Week 4:</p>	<p><i>Prerequisites:</i> tonic TRA/PFM contraction can be maintained easily together with limb and trunk movements</p> <p><i>Group position:</i> lying on the side</p> <p><i>Instruction:</i> Try to keep PFM contraction at 100% combined with slow limb and trunk movements, pull PFM up quickly at 100% together with fast limb and trunk movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the participant to feel TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> SUG in supine and SIG in sitting position: same as the home exercise of Week 2.</p>
<p>VI. Week 5:</p>	<p><i>Prerequisites:</i> TRA/PFM contraction can be maintained easily together with limb and trunk movements</p> <p><i>Group Position:</i> on hands and knees</p> <p><i>Instruction:</i> Keep PFM contraction at 100% combined with slow limb and trunk movements; pull PFM up quickly at 100% together with fast limbs movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the</p>

	<p>participant to feel TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> SUG in supine and SIG in sitting position: same as the home exercise of Week 2.</p>
<p>VII. Week 6:</p>	<p><i>Prerequisites:</i> TRA/PFM contraction can be maintained easily together with limb and trunk movements</p> <p><i>Group Position:</i> sitting</p> <p><i>Instruction:</i> Keep PFM contraction at 100% combined with slow limb and trunk movements; pull PFM up quickly at 100% together with fast limb movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the participant to feel TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> SUG in supine and SIG in sitting position: same as the home exercise of Week 2.</p>
<p>VIII. Week 7:</p>	<p><i>Prerequisites:</i> The TRA/PFM contraction can be maintained easily together with limb and trunk movements</p> <p><i>Group Position:</i> standing</p> <p><i>Instruction:</i> Keep the PFM contraction at 100% combined with slow limb and trunk movements; pull the PFM up quickly at 100% together with fast limb movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the participant to feel the TRA/PFM co-</p>

	<p>contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> SUG in supine and SIG in sitting position: same as the home exercise of Week 2.</p>
IX. Week 8:	<p><i>Prerequisites:</i> The TRA/PFM contraction can be maintained easily together with limb and trunk movements</p> <p><i>Group Position:</i> walking, steps, unstable</p> <p><i>Instruction:</i> Keep the PFM contraction at 100% combined with slow limb and trunk movements; pull the PFM up quickly at 100% together with fast limbs movements.</p> <p><i>Feedback:</i> tactile input, the medial ASIS is palpated by both the therapist and the participant to feel the TRA/PFM co-contraction; participant's subjective feeling of tensing response around the perineal region.</p> <p><i>Home exercise:</i> SUG in supine and SIG in sitting position: same as the home exercise of Week 2.</p>
X. After the training programme	<p>The participants are advised to continue the programme for another 4 weeks to achieve sufficient muscle strength. Thereafter they are required to do the PFM-T 3 times per week, which is essential for maintaining the achieved level.</p>