EVIDENCE FOR BENEFIT OF TRANSVERSUS ABDOMINIS TRAINING ALONE OR IN COMBINATION WITH PELVIC FLOOR MUSCLE TRAINING TO TREAT FEMALE URINARY INCONTINENCE: A SYSTEMATIC REVIEW.

Kari Bø, Professor, Phd, PT, Exercise scientist, Norwegian School of Sport Sciences, Department of Sports Medicine

Siv Mørkved, Associate professor, PhD, PT, Clinical Service, St. Olavs Hospital, Trondheim University Hospital, and Department of Community Medicine and General Practice, Norwegian University of Science and Technology, Trondheim, Norway

Helena Frawley, PhD, PT, Lecturer, School of Physiotherapy, The University of Melbourne, Senior Clinician, Royal Women's Hospital, Melbourne, Australia.

Margaret Sherburn, PhD, PT, Lecturer, School of Physiotherapy, The University of Melbourne, Physiotherapy Manager, Royal Women's Hospital, Melbourne, Australia

Correspondent author

Kari Bø, professor Phd, PT, Exercise scientist

Norwegian School of Sport Sciences, Department of Sports Medicine

PO Box 4014, Ullevål stadion, 0806 Oslo, Norway

Phone: + 47 23 26 20 00

Fax: + 47 22 23 42 20

E-mail: kari.bo@nih.no

Key words: pelvic floor dysfunction, pelvic floor muscles, physiotherapy, transversus abdominis, urinary incontinence

ABSTRACT

Aims

Pelvic floor muscle training (PFMT) has Level A evidence to treat female urinary incontinence (UI). Recently, indirect training of the pelvic floor muscles (PFM) via the transversus abdominis muscle (TrA), has been suggested as a new method to treat UI. The aim of this article is to discuss whether there is evidence for a synergistic co-contraction between TrA and PFM in women with UI, whether TrA contraction is as effective, or more effective than PFMT in treating UI and whether there is evidence to recommend TrA training as an intervention strategy.

Methods

A computerized search on PubMed, and hand searching in proceedings from the meetings of the World Confederation of Physical Therapy (1993-2007), International Continence Society and International Urogynecology Association (1990-2007) were performed.

Results

While a co-contraction of the TrA normally occurs with PFM contraction, there is evidence that a co-contraction of the PFM with TrA contraction can be lost or altered in women with UI. No RCTs were found comparing TrA training with untreated controls or sham. Two RCTs have shown no additional effect of adding TrA training to PFMT in the treatment of UI.

Conclusions

To date there is insufficient evidence for the use of TrA training instead of or in addition to PFMT for women with UI.

INTRODUCTION

Dysfunction of the pelvic floor muscles (PFM) may lead to urinary incontinence (UI), fecal incontinence, pelvic organ prolapse, sensory and emptying abnormalities of the lower urinary tract, defecatory dysfunction, sexual dysfunction and chronic pain syndromes (1). To date more than 50 randomized controlled trials (RCT) have demonstrated the effect of PFMT in treatment of UI, and it is recommended as first line treatment for stress and mixed UI in women (2,3,4). There is Level A evidence that PFMT programs effectively treat stress and mixed UI.

Recently, a theoretical model involving training of the deep abdominal muscles, in particular the transversus abdominis (TrA), to initiate tonic PFM activity has been introduced (5,6). This approach is based on the understanding that synergistic activity of the PFM and TrA occurs in normal trunk activities. The new approach is suggested to improve clinical outcomes of PFMT (5,6), and the author states that "PFM rehabilitation does not reach its optimum level until the muscles of the abdominal wall are rehabilitated as well" (Sapsford 2001, p 627)(5).

According to Herbert et al (7) clinical practice should not be changed due to theories or small experimental studies, but changes should be based on evidence from robust RCTs with high methodological quality and sufficient effect size demonstrating that the intervention is worthwhile. Hence, changes to established and proven methods of treating stress urinary incontinence (SUI), based on theoretical models, are not advised.

The aim of the present article is to present and discuss the scientific evidence for the statement that TrA training is effective alone or in combination with PFMT in treatment of SUI and mixed UI in women. This article focuses on descriptive and functional anatomy of the PFM and TrA and how they affect the urethra and continence mechanism, the evidence that there is a synergistic contraction between the TrA and the PFM, and whether training of the TrA is as effective as PFMT in treating UI. The main question is: should this new model replace the existing PFMT model and should current clinical practice change?

MATERIAL AND METHODS

Hand searching of the references used to support the new model from the reference lists in the two articles proposing the new model (5,6) was conducted. In addition, a computerized search on PubMed using the terms pelvic floor AND abdominals and pelvic floor AND transversus abdominis /deep abdominals was performed. Hand searching for basic studies and RCTs listed in abstract books from the World Confederation of Physical Therapy (1993-2007), International Continence Society and International Urogynecology Association (1990-2007) meetings were also performed. Key researchers in the area of PFMT were contacted to provide literature from journals not listed in PubMed. Only published studies and articles/books written in English, German or Scandinavian languages were included.

RESULTS

Anatomical basis for the PFM or TrA to independently affect the urethra and continence mechanism

The pelvic floor muscles (PFM)

The PFM comprise the pelvic diaphragm separate to the urogenital diaphragm and urethral sphincter muscles, and consist of several muscles with different fibre directions, (8,9). The PFM arise from the posterior surfaces of the pubic bones lateral to the pubic symphysis, and from the arcus tendineus overlying the obturator internus muscles, which spans the distance from the pubic bone to the sacral spine. The muscle fibres pass medially and posteriorly to insert variously into the midline organs, the puborectalis (pubovisceral muscle) behind the rectum into its partner, with iliococcygeus inserting into the ano-coccygeal raphé. The PFM form a ‘U’ shaped sling around the urethra, vagina and anus and a contraction of the muscles has a direct influence on the urethra because they compress the urethra, thereby increasing the urethral pressure (9,10,11,12). In addition, the striated sphincter muscles of the urethra and the PFM act together with a PFM contraction (13).

The PFM also play an important role in maintaining adequate pelvic support, ensuring the optimum position of the bladder, uterus and rectum (9). Firmer muscle tone of the levator plate provides increased resistance to, and enables the PFM to counteract the downward movement of the internal organs created by intra-abdominal pressure (9,14). Parous women have been shown to have a more caudal position of the pelvic floor than nulliparous women (15). In incontinent women the pelvic floor may be stretched between its origin and insertion, so the muscle shape is more like a deep bowl than a shallow one, and so can be considered to be located at a lower position than in continent women (16,17).

A voluntary contraction of the PFM has been shown to lift the bladder base into a higher location inside the pelvic cavity (9,18,19,20), narrow the levator hiatus in the anterior-posterior (21) and transverse (22) direction, and prevent descent of the internal organs (15).

<u>The transversus abdominis (TrA)</u>

The TrA is the most internal muscle of the abdomen, located deep to the internal obliquus. It arises from the crest of the ilium for its anterior three-fourths, from the inner surface of the six lower ribs, interdigitating with the diaphragm and from the lumbar fascia. The muscle terminates in front in a broad aponeurosis and is inserted together with fibers of the internal oblique in the linea alba and pubic tubercle as the conjoint tendon (23).

Contraction of the TrA increases the intra-abdominal pressure and modulates this pressure with other trunk muscles, including the diaphragm (24), and tensions the thoracolumbar fascia. A TrA contraction can be observed as an inward displacement or narrowing of the abdominal wall without pelvic or spinal movement (24,25). Contraction of the lower TrA has been termed “the abdominal drawing-in action” or abdominal hollowing exercises” (25,26). The effect of TrA training in the treatment of UI is suggested to occur via a sub-maximal co-contraction of the PFM during TrA contraction (5,6,27).

Is there evidence to support the hypothesis that there is a co-contraction of the TrA with instruction of PFM contraction?

Several research groups have found that there is a co-contraction of different abdominal muscles in healthy volunteers during close-to maximum PFM contractions (13,28,29,30,31,32,33). Madill & McLean (33) found that with a PFM contraction there was an increase in maximum voluntary electrical activity of 9.61 microvolts (SD ± 7.42) % in the rectus abdominis, 224.3 (SD ±47.4) % in the TrA, 18.72 (SD ±13.33) % in the external oblique and 81.47 (±63.57) % in the internal oblique. The measurements were recorded by surface EMG on the different abdominal muscles, simultaneously with vaginal squeeze pressure.

Thompson et al (34) found that that during a PFM contraction, all the abdominal muscles were more active than the PFM in symptomatic women with mixed incontinence compared to asymptomatic women, and that the incontinent group increased the intra-abdominal pressure more than the continent group during PFM contraction. They recommended that PFM teaching should emphasize specific PFM contraction to prevent dominant abdominal and chest wall muscle substitution. Using EMG during a postural perturbation, Smith et al (35) compared co-contraction activity of the TrA and PFM contractions in those with and without incontinence. These authors showed that there was an alteration in the balance between PFM and TrA contractions in women with UI, with severely incontinent women using more TrA and less PFM activity during a postural task. No RCTs have been identified which investigated whether PFM contractions are effective in increasing TrA strength and function.

Is there evidence to support the hypothesis that there is a co-contraction of the PFM during TrA muscle contractions?

Table 1 shows the five experimental studies found investigating whether there is co-contraction of the PFM during different abdominal muscle contractions. All research groups included continent women only. In the study by Sapsford et al (36) which showed a similar increase in urethral pressure with instruction to contract either the PFM or TrA separately, inclusion criteria was observation of a co-contraction of the PFM during the TrA contraction.

Using suprapubic ultrasonography Bø et al (20) assessed 20 women's health and sports physiotherapists performing three manoeuvres in random order: PFM contraction, TrA contraction and TrA + PFM contraction. They found that there was a downward movement of the levator plate during TrA contraction in 30% of the participants. In addition, in two women, a PFM contraction superimposed on a TrA contraction was not able to counteract the downward movement caused by TrA. The measured movement of the levator ani in a cranio-ventral direction (correct contraction) for the whole group was 61.6 % greater with PFM contraction alone compared with TrA contraction alone. This finding was supported by an MRI study (37) showing that instructions to contract the PFM were 31.4% and 50.8% more effective at eliciting a PFM response than those to contract the TrA and external rotators, respectively. Additionally, using 4D ultrasound in 13 women with POP, Bø et al (38) found that there was a mean constriction of the levator hiatus of 24% (SD 12.5) and 9.5% (SD 10.9) during instruction of PFM and TrA contraction, respectively. All women had constriction during instruction of PFM contraction, but two women opened up the levator hiatus during instruction of TrA contraction.

Jones et al (39) found that there was an automatic response of the PFM to a TrA manoeuver as indicated by cranio-ventral displacement of the ano-rectal angle in 9 SUI women and 22 continent women. However, measuring PFM automatic response to coughing, Jones et al (40) found that the response was delayed in SUI women compared to healthy volunteers.

How effective is TrA training in treatment of UI?

To date there are no RCTs investigating the effect of TrA training alone on UI. Only one RCT was found comparing the addition of TrA training to PFMT (41). Dumoulin et al (41) randomized 62 postpartum women with SUI to either PFMT + electrical stimulation (n=20), PFMT + electrical stimulation + TrA training (n=23) or control receiving back massage (n=19). The TrA training was done in accordance with recommendations by Richardson et al (25) and Sapsford (5). Cure rate, measured as < 2 grams of leakage on pad testing was 70 %, 74% and 0% in the PFMT, PFMT + TrA training and control, respectively. No significant additional beneficial effect was observed from adding TrA training to PFMT. The study protocol included a weekly training session with a physical therapist in addition to home exercise, over a period of 8 weeks. It was concluded that addition of TrA training did not further improve the outcome of pelvic floor rehabilitation beyond specific PFMT. After cessation of the original RCT the control group was randomized to one of the treatment groups. The results of this new study (n=29 and 30) confirmed the former results with 76% and 77% cure rate in PFMT + electrical stimulation and PFMT + electrical stimulation + TrA, respectively. There was no additional effect of adding TrA training (42).

Hung (43) compared a specially designed therapist-supervised exercise course including "diaphragmatic breathing, tonic activation, muscle strengthening, functional expiratory patterns and impact activities" with home (non-supervised) PFMT. The primary outcome measure was "self-reported" improvement in UI. The supervised group had significant higher score than the home group, however and endpoint improvement score is not a prospective measure, as it does not account for baseline status. Secondary outcomes were reported as within-group changes only. It cannot be assumed that the difference between the groups was due to the intervention (which included both PFM and TrA training), as the supervision of the exercise program may have been a strong confounder.

How effective is PFMT in treatment of UI?

A systematic review by Wilson et al (3), a Cochrane review (2) and recommendations from the Royal College of Obstetrics and Gynaecology (4) conclude that there is Level A evidence that for women with a wide range of urinary incontinence symptoms (stress, mixed, urge) PFMT is better than no treatment. To date, there are only a few RCTs in urge incontinence only, and in our opinion, the results of PFMT on overactive bladder symptoms are not convincing (2). Cure rates for SUI, measured as less than 2 grams of leakage on pad testing, vary between 44 and 70%, and are much more convincing (44). The 3rd International Consultation on Incontinence recommends PFMT as the first line treatment for female UI (45). Thus, there is strong evidence that specific PFMT is effective in the treatment of UI. Voluntary contraction before and during a cough (a manoeuvre named 'the Knack') has been shown to effectively reduce urinary leakage during a cough (46). Hence, simply learning to contract the PFM before a cough may be sufficient treatment for many women who only leak during coughing (47).

Several studies have demonstrated that there is a significant difference in maximum voluntary contraction (MVC) strength in continent compared to incontinent women (48,49,50,51,52,53,54). Regular PFMT has been shown to increase PFM strength (55,56,57,58,59,60), and has the potential to increase muscle volume (61) and lift the levator plate into a more cranial position (62). A positive association between increased MVC and improvement in urinary leakage has also been demonstrated (63,64,65,66,67).

DISCUSSION

Co-contraction between PFM and TrA

This review has shown that there is some evidence that a co-contraction of the TrA during PFM contraction exists. However, only two of these research groups used wire or needle EMG (13,31), the remainder utilized surface EMG. In the surface EMG studies, there is a risk of overflow from other abdominal muscles contaminating the true result, hence the results from studies using surface electrodes need to be interpreted with caution (68). It is well known that a PFM contraction increases urethral pressure (1,9). In the study by Sapsford et al (36) evaluating the effect of TrA contraction on urethral pressure, inclusion criteria was observation of a co-contraction of the PFM during the TrA contraction. Therefore, the effect of a TrA contraction alone on urethral pressure is not known. Sapsford (2004, p.9)(6) also states that "Patients must be able to report their subjective awareness of the periurethral and /or perivaginal and perianal tensioning response during the independent TrA activation, and /or the release as the abdominal wall is released. This is critical to the success of this approach". Hence, in clinical practice one can not assume that such co-contraction occurs involuntarily.

One important factor in the continence mechanism is that the PFM should contract automatically with correct timing and with sufficient strength to counteract the downward impact on the pelvic floor from the abdominal muscle contraction. Hence a co-contraction of the PFM during TrA contraction in continent women is expected and normal. While there is also some evidence that PFM contraction occurs during TrA contraction in continent women (13,28,29,30,31,32,33), there is evidence that this co-contraction is lost or altered in some women with UI (20,35,39,40). No studies have been found which demonstrate that a co-

contraction of the PFM with TrA training increases PFM strength or position of the levator plate inside the pelvis, factors which have a known association with continence.

Some authors have advocated that PFMT be carried out with surface EMG on the abdominal muscles to ensure that the abdominal muscles are relaxed during PFMT (69). Abdominal muscle contraction may increase intra-abdominal pressure (24) and hence, negatively impact the pelvic floor (6,34). On the other hand, if maximum or close to maximum PFM contraction is only possible with abdominal co-contraction, such co-contraction must be allowed during training, as close to maximum contraction is important in building muscle volume and strength (70).

A MVC may be important for the effectiveness of a learned pre-contraction. Bump et al (71) showed that 49% of women did not increase the urethral pressure by a voluntary PFM contraction. Hence, the effect of a learned pre-contraction is related to the ability to perform a contraction which is both correct and strong enough to close the urethra.

Can TrA training treat UI?

There are no RCTs evaluating whether TrA training alone can treat or improve urinary incontinence, change anatomy or improve PFM function. Only one RCT was found comparing PFMT with and without addition of TrA training applying the same amount of attention, frequency of training and visits with therapists in the intervention groups (41)**.** To increase power of the study the control group was also randomized to PFMT either with or without training of the TrA after cessation of the original study. Neither of these studies showed any additional effect of adding TrA training to PFMT (41,42). In addition to adding supervised muscle training in the TrA training group, Hung et al (43) also included several other exercises (including strength training of the PFM) to TrA training. Hence, this study can not be used to prove that indirect training of the PFM via TrA training is effective. Several RCTs have shown that supervised PFMT is more effective than non-supervized training (2-4).

It is an extrapolation from results of small experimental studies showing a co-contraction of the PFM with TrA contraction in healthy women, to a recommendation for all women with UI to train the TrA instead of or in addition to PFMT. In addition, other theories and models have been recently proposed, suggesting that postural changes and breathing patterns are important in restoration of pelvic floor rehabilitation (72,73). As with TrA training to restore pelvic floor function, these theories need to be tested in high quality RCTs to show a positive effect and to prove their clinical relevance.

It has been proposed that contraction of the TrA instead of the PFM is useful as many women are not able to contract the PFM and therefore contraction of the TrA is one way of activating the PFM (39). However, other muscles such as hip adductor, gluteal and external rotator muscles of the hips have also been found to co-contract with PFM contraction (13,18,29,37). It has not been shown that TrA activation is superior to contraction of these other pelvic muscles in facilitating a PFM response (37). An increase in intra-abdominal pressure without simultaneous co-contraction of the PFM may cause caudal displacement of the pelvic floor (20). However, in clinical practice it is rare that patients are not able to learn to contract the PFM following sufficient expert instruction. Bø et al (55) found that only 4 out of 52 women with SUI were not able to learn to contract correctly after 6 months of PFMT. Hence, at this stage, training which primarily targets muscles other than the PFM does not appear to be justified.

Based on anatomical knowledge and evidence from RCTs we conclude that the PFM is the optimal muscle group to target in treatment of female UI. However, the PFMT protocols used in the many published RCTs vary widely. Some of these protocols include group training with strength training of other muscles groups, while others specifically attempt to minimize abdominal muscle contraction. Hence, to date the optimal method to achieve continence via PFMT is not known (47). Is it a pure, isolated strength training program? Motor control strategies? Functional re-training? Combined synergistic training with TrA, spinal and respiratory patterns? To uncover the optimal strategy, different exercise programs must be compared in RCTs.

Sapsford (6) stated that “Rigorous research is needed to prove these concepts before such programs will be universally accepted”. To date, one small RCT has demonstrated that there is no additional benefit of adding TrA training to PFMT (40). Hence, we suggest that training to restore PFM function should be based on evidence from high quality RCTs and follow updated consensus statements (3). To date, there is not a compelling reason to change practice when there is a substantial body of evidence from RCTs with sufficient effect sizes for existing methods. Introduction of new treatments prior to scientific evaluation of their effectiveness may not be in the best interests of patients, health care professionals, nor funders of the service.

CONCLUSIONS

From the studies available, there is evidence that a co-contraction of the TrA occurs during PFM contraction, but a co-contraction of the PFM during TrA contraction may be lost or weakened in patients with symptoms of pelvic floor dysfunction. There is strong evidence that

PFMT for the treatment of UI should be performed with the focus on strengthening the PFM and incorporating a learned pre-contraction during increased intra-abdominal pressure. Other elements of a treatment program may be added once PFMT has begun, or to complete the optimal rehabilitation, and may confer additional durability and prevent recurrence of UI, but to date there is no evidence that such strategies are effective on their own or add to the success rate of PFMT. There is an urgent need for RCTs with high methodological and interventional quality evaluating the effect of TrA training on UI. In addition, basic studies and case-control studies in representative groups of women with and without UI using ultrasound and MRI are recommended in order to assess PFM function during TrA contraction and increases in intra-abdominal pressure.

REFERENCES

1. Bump R, Norton P. Epidemiology and natural history of pelvic floor dysfunction. Obstetrics and gynecology clinics of North America 1998; 25(4): 723-746

2. Hay-Smith EJC, Dumoulin C. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. The Cochrane Database of Systematic Reviews, 1st issue. The Cochrane Collaboration. UK, Wiley & Sons, Ltd, 2006

3. Wilson PD, Berghmans B, Hagen S, Hay-Smith J, Moore K, Nygaard I, Sinclair L, Yamanishi T, Wyman J. Adult conservative treatment. In: Abrams P, Cardozo L, Khoury S, Wein A: Incontinence, Vol 2. Health Publication Ltd, 2005, pp855-964

4. Welsh A. Urinary incontinence.The management of urinary incontinence in women. National Collaborating Centre for Women's and Children's Health. Commissioned by the National Institute for Health and Clinical Excellence. Royal College of Obstetrics and Gynaecology, UK, 2006

5. Sapsford R. The pelvic floor. A clinical model for function and rehabilitation. Physiotherapy 2001; 87: 620-630

6. Sapsford R. Rehabilitation of pelvic floor muscles utilizing trunk stabilization. Manual Therapy 2004; 9: 3-12

7. Herbert R, Jamtvedt G, Mead J, Hagen KB. Practical evidence-based physiotherapy. Elsevier, UK. Butterworth Heinemann, 2005

8. DeLancey JOL, Morgan DM, Fenner DE, Kearney R, Guire K, Miller JM, Hussain H, Umek W, Hsu Y, Ashton-Miller JA. Comparison of levator ani muscle defects and

function in women with and without pelvic organ prolapse. Obstetrics and Gynecology 2007; 109: 295-302

9. Ashton-Miller J, DeLancey JOL. Functional anatomy of the female pelvic floor. In: Bø K, Berghmans B, Mørkved S, van Kampen M: Evidence based physical therapy for the pelvic floor – bridging science and clinical practice. Elsevier, UK, 2007, ch 3: pp 19-33

10. Lose G. Simultaneous recording of pressure and cross-sectional area in the female urethra: a study of urethral closure function in healthy and stress incontinent women. Neurourology and Urodynamics 1992; 11(2): 54-89

11. Bump R, Hurt WG, Fantl JA, Wyman JF. Assessment of Kegel exercise performance after brief verbal instruction. American Journal of Obstetrics and Gynecology 1991; 165: 322-329

12. Bø K, Talseth T. Change in urethral pressure during voluntary pelvic floor muscle contraction and vaginal electrical stimulation. International Urogynecology Journal and Pelvic Floor Dysfunction 1997; 8: 3-7

13. Bø, K, Stien R. Needle EMG registration of striated urethral wall and pelvic floor muscle activity patterns during cough, valsalva, abdominal, hip adductor, and gluteal muscles contractions in nulliparous healthy females. Neurourology and Urodynamics 1994; 13: 35-41

14. Ashton-Miller J, Howard D, DeLancey JOL. The functional anatomy of the female pelvic floor and stress continence control system. Scandinavian Journal of Urology and Nephrology 2001; 207(Suppl.): 1-7

15. Peschers U, Schaer G, Anthuber C, DeLancey JOL, Schussler B. Changes in vesical neck mobility following vaginal delivery. Obstetrics and Gynecology 1996; 88: 1001-1006

16. Howard D, Miller J, DeLancey JOL, Ashton-Miller J. Differential effects of cough, valsalva, and continence status on vesical neck movement. Obstetrics and Gynecology 2000; 95: 535-540

17. Miller J, Perucchini D, Carchidi L, DeLancey JOL, Ashton-Miller J. Pelvic floor muscle contraction during a cough and decreased vesical neck mobility. Obstetrics and Gynecology 2001; 97: 255-260

18. Peschers U, Gingelmaier A, Jundt K, Leib B, Dimpfl T. Evaluation of pelvic floor muscle strength using four different techniques. International Urogynecology Journal and Pelvic Floor Dysfunction 2001; 12: 27-30

19. Bø K, Lilleås, Tasleth T, Hedlund H. Dynamic MRI of the pelvic floor muscles in an upright sitting position. Neurourology and Urodynamics 2001; 20: 167-174

20. Bø K, Sherburn M, Allen T. Transabdominal measurement of pelvic floor muscle activity when activated directly or via a transversus abdominis muscle contraction. Neurourology and Urodynamics 2003; 22: 582-588

21. Guaderrama NM, Liu J, Nager CW, Pretorius DH, Sheean G, Kassab G, Mittal RK. Evidence for the innervation of pelvic floor muscles by the pudendal nerve. Obstetrics and Gynecology 2005; 106(4): 774-781

22. Verelst M, Leivseth G. Force-length relationship in the pelvic floor muscles under transverse vaginal distension: a method study in healthy women. Neurourology and Urodynamics 2004a; 23: 662-667

23. Gray H. Anatomy, descriptive and surgical. Philadelphia, Pennsylvania: Running Press, 1974

24. Hodges PW, Gandevia S. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. Journal of Applied Physiology 2000; 89: 967-976

25. Richardson C, Jull G, Hodges P, Hides J. Therapeutic exercise for spinal segmental stabilization in low back pain. Edinburgh: Churchill Livingstone, 1999

26. O'Sullivan P, Twomey L, Allison G. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine 1997; 22: 2959-2967

27. Sapsford R, Hodges P. Contraction of the pelvic floor muscles during abdominal maneuvers. Archives of Physical Medicine and Rehabilitation 2001; 82: 1081-1088

28. Dougherty M, Bishop K, Mooney R, Gimotty PS, Landy LB. Variation in intravaginal pressure measurement. Nursing Research 1991; 40: 282-285

29. Bø K, Kvarstein B, Hagen R, Larsen S. Pelvic floor muscle exercise for the treatment of female stress urinary incontinence: II.Validity of vaginal pressure measurements of pelvic floor muscle strength and the necessity of supplementary methods for control of correct contraction. Neurourology and Urodynamics 1990a; 9: 479-487

30. Sapsford R, Hodges P, Richardson C, Cooper D, Markwell S, Jull G. Co-activation of the abdominal and pelvic floor muscles during voluntary exercises. Neurourology and Urodynamics 2001; 20: 31-42

31. Neumann P, Gill V. Pelvic floor and abdominal muscle interaction: EMG activity and intra-abdominal pressure. International Urogynecology Journal and Pelvic Floor Dysfunction 2002; 13: 125-132

32. Chritchley D. Instructing pelvic floor contraction facilitates transversus abdominis thickness increase during low-abdominal hollowing. Physiotherapy Research International 2002; 7(2): 65-75

33. Madill SJ, McLean L. Relationship between abdominal and pelvic floor muscle activation and intravaginal pressure during pelvic floor muscle contractions in healthy continent women. Neurourology and Urodynamics 2006; 25: 722-730

34. Thompson J, O'Sullivan P. Levator plate movement during voluntary pelvic floor muscle contraction in subjects with incontinence and prolapse: a cross-sectional study and review. International Urogynecological Journal and Pelvic Floor Dysfunction 2003; 14: 84-88

35. Smith MD, Coppieters MW, Hodges PW. Postural response of the pelvic floor and abdominal muscles in women with and without incontinence. Neurourology and Urodynamics 2007a; 26(3): 377-384

36. Sapsford R, Markwell SJ, Clarke B. The relationship between urethral pressure and abdominal muscle activity. Abstract. 7th National CFA conference on incontinence, Australia, 1998

37. Dumoulin C. Papers to be read by title. International Continence Society Annual Meeting, Christchurch, New Zealand, 2006

38. Bø K, Brækken I, Majida M, Engh ME. Constriction of the levator hiatus during instruction of pelvic floor or transversus abdominis contraction: a 4D ultrasound study. International Urogynecology Journal and Pelvic Floor Dysfunction. 2008 Sept 20 Epub ahead of print

39. Jones RC, Peng Q, Shishido K, Perkash I, Constantinou CE. 2D ultrasound imaging and motion tracking of pelvic floor muscle (PFM) activity during abdominal manoeuvres in stress urinary (SUI) women. Neurourology and Urodynamics 2006a; 25(6): 596-597

40. Jones RC, Peng Q, Shishido K, Constantinou CE. 2D ultrasound evaluation of dynamic responses of female pelvic floor muscles (PFM) to a cough. Neurourology and Urodynamics 2006b; 25(6): 624-625

41. Dumoulin C, Lemieux MC, Bourbonnais D, Gravel D, Bravo G, Morin M. Physiotherapy for persistent postnatal stress urinary incontinence: a randomized controlled trial. Obstetrics and Gynecology 2004; 104: 504-510

42. Dumoulin C, Morin M, Lemieux M_C, Bourbonnais D, Bravo G, Gravel D. Efficacy of deep abdominal training combined with pelvic floor muscle training for stress urinary incontinence: a single blind randomized controlled trial. Abstract: Progres en Urologie 2004; 16, 3, Suppl 3: 16

43. Hung HC. Indirect training of the pelvic floor muscles via transversus abdominis for females with urinary incontinence: A randomized controlled trial. Abstract: World Confederation of Physical Therapy, RR-PL-2294, Vancouver, 2007. Physiotherapy:93 (S1): 141

44. Bø K. Is there still a place for physiotherapy in the treatment of female incontinence? European Association of Urology Journal Update Series 2003a; 1: 145-153

45. Abrams P, Cardozo L, Khoury S, Wein A. Incontinence, Vol 2, UK Vol 2: Management. Health Publications Ltd, 2005

46. Miller JM, Ashton-Miller JA, DeLancey JOL. A pelvic muscle precontraction can reduce cough-related urine loss in selected women with mild SUI. Journal of American Geriatric Society 1998; 46: 870-874

47. Bø K. Pelvic floor muscle training is effective in treatment of female stress urinary incontinence, but how does it work? International Urogynecology Journal and Pelvic Floor Dysfunction 2004a; 15: 76-84

48. Gunnarson M, Mattiasson A. Circumvaginal surface electromyography in women with urinary incontinence and in healthy volunteers. Scandinavian Journal of Urology and Nephrology 1994; 157(Suppl.): 89-95

49. Hahn I, Milsom I, Ohlson BL, Ekelund P, Uhlemann C, Fall M. Comparative assessment of pelvic floor function using vaginal cones, vaginal digital palpation and vaginal pressure measurements. Gynecology and Obstetrics Investigation 1996; 41(4): 269-274

50. Mørkved S, Salvesen KÅ, Bø K, Eik-Nes S. Pelvic floor muscle strength and thickness in continent and incontinent nulliparous pregnant women. International Urogynecology Journal and Pelvic Floor Dysfunction 2004, 15: 384-390

51. Verelst M, Leivseth G. Are fatigue and disturbances in pre-programmed activity of pelvic floor muscles associated with female stress urinary incontinence? Neurourology and Urodynamics 2004b; 23: 143-147

52. Morin M, Bourbonnais D, Gravel D, Dumoulin C, Lemieux MC. Pelvic floor muscle function in continent and stress urinary incontinent women using dynamometer measurement. Neurourology and Urodynamics 2004; 23(7): 668-674

53. Amaro JL, Moreira ECH, Gameiro MOO, Padovani CR. Pelvic floor muscle evaluation in incontinent patients. International Urogynecology Journal and Pelvic floor dysfunction 2005, 16: 352-354

54. Thompson JA, O'Sullivan PB, Briffa KN, Neumann P. Difference in muscle activation patterns during pelvic floor muscle contraction and valsalva manouevre. Neurourology and Urodynamics 2006; 25: 148-155

55. Bø K, Hagen RH, Kvarstein B, Jørgensen J, Larsen S. Pelvic floor muscle exercise for the treatment of female stress urinary incontinence: III. Effects of two different degrees of pelvic floor muscle exercise. Neurourology and Urodynamics 1990b; 9: 489-502

56. Bø K, Talseth T, Holme I. Single blind, randomised controlled trial of pelvic floor exercises, electrical stimulation, vaginal cones, and no treatment in management of genuine stress incontinence in women. British Medical Journal 1999; 318: 487-493

57. Mørkved S, Bø K. The effect of postpartum pelvic floor muscle exercise in the prevention and treatment of urinary incontinence. International Urogynecology Journal and Pelvic Floor Dysfunction 1997; 8: 217-222

58. Mørkved S, Bø K. Effect of postpartum pelvic floor muscle training in prevention and treatment of urinary incontinence: a one-year follow up. British Journal of Obstetrics and Gynaecology 2000; 107: 1022-1028

59. Mørkved S, Bø K, Fjørtoft T. Is there any effect of adding biofeedback to pelvic floor muscle training for treatment of female urodynamic stress incontinence? Obstetrics and Gynecology 2002; 100: 730-739

60. Mørkved S, Bø K, Schei B, Salvesen KÅ. Pelvic floor muscle training during pregnancy to prevent urinary incontinence - a single blind randomized controlled trial. Obstetrics and Gynecology 2003; 101: 313-319

61. Bernstein I, Juul N, Grønvall S, Bonde B, Klarskov P. Pelvic floor muscle thickness measured by perineal ultrasonography. Scandinavian Journal of Urology and Nephrology 1991; 137(Suppl.): 131-133

62. Balmforth JR, Mantle J, Bidmead J, Cardozo L. A prospective observational trial of pelvic floor muscle training for female stress urinary incontinence. British Journal of Urology International 2006; 98: 811-817

63. Taylor K, Henderson J. Effects of biofeedback and urinary stress incontinence in older women. Journal of Gerontological Nursing 1986; 12(9): 25-30

64. Hahn I, Milsom I, Fall M, Ekelund P. Long-term results of pelvic floor training in female stress urinary incontinence. British Journal of Urology 1993; 72(4): 441-447

65. Boyington AR, Dougherty MC, Kaspar CE. Pelvic muscle profile types in response to pelvic muscle exercise. International Urogynecology Journal and Pelvic Floor dysfunction 1995: 6: 68-72

66. Gunnarson M, Mattiasson A. Female stress, urge, and mixed urinary incontinence are associated with a chronic and progressive pelvic floor/vaginal neuromuscular disorder: an investigation of 317 healthy and incontinent women using vaginal surface electromyography. Neurourology and Urodynamics 1999; 18: 613-621

67. Bø K. Pelvic floor muscle strength and response to pelvic floor muscle training for stress urinary incontinence. Neurourology and Urodynamics 2003b; 22: 654-658

68. Fowler C, Benson J, Craggs M, Vodusek D, Yang C, Podnar S. Clinical Neurophysiology. In: Abrams P, Cardozo L, Khoury S, Wein A editors. Incontinence. Plymouth: Plymbridge Distributors Ltd, 2002: Chap 8: 389-424

69. Cammu H, Van Nylen M. Pelvic floor exercises versus vaginal weight cones in genuine stress incontinence. European Journal of Obstetrical and Gynecological Reproductive Biology 1998; 77: 89-93

70. Pollock ML, Gaesser GA, Butcher JD, Despres JP, Dishman RK, Franklin BA, Ewing Garber C. The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults. Medicine and Science in Sports and Exercise 1998; 30: 975-991

71. Bump R, Hurt WG, Fantl JA, Wyman JF. Assessment of Kegel exercise performance after brief verbal instruction. American Journal of Obstetrics and Gynecology 1991; 165: 322-329

72. Hodges PW, Sapsford R, Pengel LHM. Postural and respiratory functions of the pelvic floor muscles. Neurourology and Urodynamics 2007; 26(3): 362-371

73. Smith MD, Coppieters MW, Hodges PW. Postural activity of the pelvic floor muscles is delayed during rapid arm movements in women with stress urinary incontinence. International Urogynecology Journal and Pelvic Floor Dysfunction 2007b; 18: 901-911

Table 1: Studies on co-contraction of the pelvic floor muscles (PFM) during abdominal muscle contraction in females.

	N	Population	Method for measurement of PFM activation	Maneuvers/ abdominal muscle tested	Results
Bø & Stien -94	6	continent	Concentric needle EMG	Pelvic tilt and sit up with straight legs in supine position (predominately m. rectus abdominis)	Co-contraction of PFM with pelvic tilt and sit up in all participants
Sapsford et al -98	7	continent	Urethral pressure	1.Abdominal hollowing (TrA+ OI) 2. Bulging	Similar increase in urethral pressure with PFM (18.5 cm H_2O) and hollowing (21.9 cm H_2O) no variation given and PFM

					contraction with inward lift was assured (TrA & OI & PFM). Bulging (-12.9 cm H2O)
Sapsford et al -01	1	continent	Fine-wire EMG	1. Hollowing (assumed TrA) 2. "Bracing" (assumed TrA + OI) with or without breathing	Hollowing: increase in PFM EMG activity of 52% (39-62) Bracing with breathing: 47% (36-58) Bracing with breath hold: 82% (68-97)
Sapsford & Hodges al -01	6 (including one from Sapsford et al 2001?)	continent	Vaginal surface EMG	Supine and standing: 1.gentle abdominal hollowing	1.Co-contraction of the PFM during abdominal

				(assumed TrA) 2.Moderate abdominal hollowing (assumed all abdominal muscles) 3. Strong abdominal contraction (assumed all abdominal muscles)	contraction. 2.Increase in PFM EMG greater with strong contraction level. 3. No difference in PFM EMG between max PFM contraction and abdominal contraction
Neumann & Gill -02	4	continent	Vaginal surface EMG	1.lifting head and both legs (all abdominal muscles) 2.Belly in (TrA)	1.44% more PFM activity than max PFM contraction 2.40%

					increase PFM activity

1 TrA= transversus abdominis

2 OI= obliques internus