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DISSERTATION

Evaluation funktioneller Beckenbodenstrategien und deren Einsatz in der konservativen Therapie von weiblichen Beckenbodenfunktionsstörungen

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von

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Abkürzungsverzeichnis

ACSM	American College of Sports Medicine
BB	Beckenboden
BBM	Beckenbodenmuskeln
BH	Blasenhals
BMI	Body mass index
EMG	Elektromyographie
EO	M. externus obliquus abdominis
IAD	Intraabdominellen Druck
ICI	International Consultation on Incontinence
IO	M. internus obliquus abdominis
PR	Puborektalisschlinge
PUS	Perinealer Ultraschall
RCT	Randomized controlled trial
TrA	M. transversus abdominis
TVT	Tension-free vaginal tape
VAL	Valsalvamanöver

Abstract

Deutsch

<u>Einführung</u>

Beckenbodenfunktionsstörungen wie Harninkontinenz sind häufig und können die Lebensqualität der Frauen stark beeinträchtigen. Die konservative Therapie gehört zu den ersten therapeutischen Maßnahmen.

In den drei Studien dieser kumulativen Publikationspromotion bestand die Frage, welche abdominalen Muskeln bei maximalen und submaximalen Beckenbodenmuskelkontraktionen aktiv sind (Co-Kontraktion) und wie intraabdomineller Druck (IAD) und Blasenhalsposition beeinflusst werden. Im Interesse der zweiten Studie war die Auswirkung maximaler und submaximaler Beckenbodenmuskelkontraktion auf Ausdauerleistung und Atmung. In einer Interventionsstudie mit Fokus auf motorischer Kontrolle, unter Einsatz des perinealen Ultraschalls als Untersuchungs- (individuelle Dysfunktion) und visuelles Biofeedbackmedium wurden zuvor evaluierte Teilaspekte integriert und Symptome prä- und posttherapeutisch an 55 Frauen untersucht. Submaximale Beckenbodenmuskelkontraktionen und deren Integration in Alltagssituationen waren Hauptbestandteile der Therapie.

<u>Methoden:</u>

Gemessen wurde bei gesunden Frauen während der Durchführung verschiedener willentlicher Muskelkontraktionen (Beckenbodenmuskeln und M. transversus abdominis) und Manöver (Brace- und Valsalvamanöver, Kopfanheben) die Aktivität der Beckenboden- und Bauchmuskeln (intramuskuläre EMG-Messung), der IAD (Rektalkatheter) und die Blasenhalsposition (PUS). Die Ausführung der Muskelkontraktionen und Manöver erfolgte mit unterschiedlichen (gentle, moderat, maximal) Kontraktionsstärken (Studie 1). Mittels Urodynamikerweiterung um perinealen US, Atembewegungsmessung und Bauchmuskelaktivitäts-EMG wurden maximale und submaximale Beckenbodenkontraktionen bei gesunden und harninkontinenten Frauen gemessen. Fokus waren Dauer der Beckenbodenmuskelkontraktion und adäquate Elevation des Blasenhalses (Studie 2). In einer Interventionsstudie (Studie 3) kam bei harninkontinenten 55 Frauen die sog. „Blasenhals-effektive, kontrollierte, integrative Beckenbodenrehabilitation" zum Einsatz.

Ergebnisse wurden mit dem validierten Deutschen Beckenbodenfragebogen prä- und posttherapeutisch untersucht.

Ergebnis:

Bereits bei submaximalen Kontraktionen eleviert der Blasenhals adäquat und die Ausdauerleistung der Beckenbodenmuskeln ist signifikant besser als bei maximalen (33 vs. 10 Sekunden) und die Co-Kontraktion des M. transversus abdominis ist vorhanden. Der Einsatz von maximalen Beckenbodenmuskelkontraktionen erhöht den intraabdominellen Druck stark (ca. 50 cmH_2O wie ein moderater Hustenstoß), was die Elevation des Blasenhalses limitiert (bei ca. 30 % der gesunden und inkontinenten Frauen kam es zu einer BH-Depression). V.a. die unter dem Rippenbogen liegenden Bauchmuskeln sind bei maximalen Beckenbodenmuskelkontraktionen aktiv, die Beckenbodenmuskeln müssen dem intraabdominellen Druck entgegenwirken.

67 % und 78 % der Frauen mit Belastungs- und Dranginkontinenz gaben Verbesserungen nach der Durchführung der „Blasenhals-effektiven, kontrollierten, integrativen Beckenbodenrehabilitation" an, wobei im Schnitt 2 (1-6) Behandlungstermine notwendig waren. Subjektive Verbesserungen der Blasen-symptome wurden von 91 % der Frauen angegeben ebenso wie Lebensqualitäts-verbesserungen.

Diskussion:

Submaximale Kontraktionen der Beckenbodenmuskeln in Verbindung mit einer Co-Kontraktion des M. transversus abdominis haben einen positiven Einfluss auf die Position des Blasenhalses, die Ausdauer der Beckenbodenmuskelkontraktion, die Integration in den Alltag und auf die Symptomverbesserung bei Frauen mit Harn-inkontinenz.

English

Introduction

Pelvic floor dysfunction including urinary incontinence is a common disease in women, having a negative impact on life quality. Pelvic floor muscle (PFM) training is recommended as first-line-treatment.

The three studies in this thesis evaluated abdominal muscle activity at maximum and submaximal PFM contractions (co-contraction) and how intraabdominal pressure (IAP) and bladder neck position (BN) are influenced. The second study focused on the effect of maximum and submaximal PFM contraction, endurance and breathing. An intervention study with 55 women was performed using motor control strategies and perineal ultrasound (PUS) as visual biofeedback tools and symptoms compared before and after treatment. Submaximal PFM contractions and their integration into everyday situations were main therapy components.

Methods:

Activity of the PF and abdominal muscles (fine-wire EMG), IAP (rectal catheter) and bladder neck position (PUS) were measured in healthy women during various voluntary muscle contractions (PFM and transversus abdominis muscle; TrA) and maneuvers (brace and Valsalva, head lifting). Muscle contractions and maneuvers were performed with different (gentle, moderate, maximum) contraction strengths (Study 1). Maximum and submaximal PFM contractions in healthy and incontinent women were measured by urodynamic adding PUS, respiratory movement measurement and abdominal muscle activity EMG. Focus was on PFM contraction duration and adequate BN elevation (Study 2). In an intervention study (Study 3), 55 women with urinary incontinence were treated with the "Bladder neck effective, controlled, integrative pelvic floor rehabilitation". Results were examined pre- and posttherapeutically with the validated German Pelvic Floor Questionnaire.

Results:

Even with submaximal contractions, the BN is adequately elevated and the PFM endurance is significantly greater compared with maximum contractions (33 vs. 10 seconds). TrA muscle co-contraction is present. Use of maximum PFM contractions greatly increases IAP (about 50 cmH_2O like a moderate cough), limiting the elevation of the BN (about 30% of healthy and incontinent women depressed the BN). Especially the abdominal muscles under the ribcage are active at maximum PFM contractions, the PFM have to counteract the IAP.

67% and 78% of women with stress and urge incontinence reported improvements after performing "Bladder neck effective, controlled, integrative pelvic floor rehabilitation", with an average of 2 (1-6) treatment appointments required. 91% of women reported subjective improvements in bladder symptoms and improvements in life quality.

Discussion:

Pelvic floor muscle submaximal contractions in conjunction with TrA co-contraction have a positive effect on the BN position, the PFM endurance, integration into everyday life and symptom improvement in women with urinary incontinence.

1 Einführung

1.1 Problemstellung

Die genaue Symptomevaluation und die vaginale Palpation als gezielte Untersuchung der Beckenbodenmuskeln (BBM) stellen international den Standard der konservativen physiotherapeutischen, d.h. nicht-medikamentösen Therapie, zur Behandlung von Belastungs- und Dranginkontinenz dar [1]. Das Behandlungsziel besteht größtenteils in der Verbesserung der Beckenbodenmuskelkraft [2]. Die Beckenbodenkontraktion soll bei Belastung auch die Position von Urethra und Blase sichern, wozu es einer anatomischen und funktionellen Integrität bedarf [3]. Zur Physiologie der Beckenbodenaktivität bei Alltagsbelastungen wie Husten z.B. ist jedoch wenig bekannt.

Die Publikationen, die in dieser kumulativen Publikationspromotion zusammengefasst sind, beschäftigen sich zum einen mit der Frage, welche abdominalen Muskeln bei einer korrekten Beckenbodenmuskelkontraktion zusammenarbeiten (Frage nach der Co-Kontraktion) und welche Anspannungsstärke für eine adäquate Stabilität der Beckenbodenorgane notwendig ist. Zum anderen wurde in einer Interventionsstudie der Fokus auf eine funktionelle Beckenbodenrehabilitation gelegt und auf eine allgemeine Muskelkräftigung verzichtet. Die Auswirkung auf Inkontinenzsymptome schildern die Ergebnisse in einem Kollektiv von 55 Frauen.

1.2 Prävalenz

Harninkontinenz ist eine häufige Erkrankung der Frau mit einer Prävalenz von 25-45% bis hin zu 55% bei älteren Frauen ab dem 60. Lebensjahr. In 20-25% liegen schwere Symptome mit mehr als zehn Inkontinenzepisoden pro Woche vor [4]. Die Angaben zur Prävalenz variieren, da in Studien unterschiedliche Assessment-methoden benutzt werden, was eine Vergleichbarkeit schwierig macht. Außerdem besteht in verschiedenen Ländern eine unterschiedliche Akzeptanz dieser Symptome und Scham und Tabuisierung führen dazu, dass von einer hohen Dunkelziffer ausgegangen werden muss. Von Hunskaar et al. wurde in einer 4 Länder vergleichenden Studie mit über 29.000 Frauen [5] darüber hinaus ermittelt, dass uneinheitlich ärztliche Hilfe aufgesucht wird. Während in Ländern wie Deutschland 33% und Frankreich sogar 40% der Frauen einen Arzt wegen Inkontinenz aufsuchten, waren es in Spanien und UK nur ca. 25%.

Zunehmend wird bekannt, dass nicht nur peri- und postmenopausale Frauen von Harninkontinenz betroffen sind, sondern auch junge Frauen und besonders Sportlerinnen darüber berichten. In einer Studie von Da Roza wurden 386 Nulliparae mit einem Alter von durchschnittlich 21,6 Jahren (zwischen 14 und 33 Jahren), die normal- bis leicht übergewichtig waren (BMI 21,6 ± 2,5 (zwischen 15,4 und 28,5) kg/m^2), in 4 Klassen von wenig Bewegung bis hin zu Hochleistungssportlerinnen eingeteilt. Die Art der Inkontinenz (Belastungs- oder Dranginkontinenz), die Häufigkeit von Inkontinenzsymptomen pro Woche und die Menge an Urinverlust wurden evaluiert. In dieser Studie lag die Prävalenz jeglicher Art von Inkontinenz bei 20%, mit Belastungsinkontinenz als dem häufigsten Symptom. Frauen, die gemäß Definition des American College of Sports Medicine (ACSM) keinen Sport ausübten, waren aber bereits zu 15% betroffen, Leistungssportlerinnen zeigten eine erhöhte Risk Ratio von 2,53 (95% CIs, 1,3–2,7) gegenüber den Nichtsportlerinnen und eine Prävalenz von über 35%. Auch die Menge an Urin pro Urinverlust war signifikant erhöht [6].

1.3 Mechanismen der Harnkontinenz und Veränderungen bei Belastungsinkontinenz

Dem Erhalt bzw. Verlust der Kontinenz liegen Mechanismen und Pathomechanismen des Beckenbodens zugrunde. Auf dieser Basis wurden in der Vergangenheit unterschiedliche Hypothesen aufgestellt, die als Grundlage für die Entwicklung verschiedener Operationskonzepte dienen [7-9].

Bereits im Jahre 1996 stellte John DeLancey fest, dass bei unterschiedlichen Frauen unterschiedliche Pathomechanismen vorliegen, die auch unterschiedlich behandelt werden müssen [7]. Strukturelle Defekte sind hierbei nicht von funktionellen Defiziten zu trennen, was die Komplexität des Verständnisses sowohl der Harninkontinenz als auch der Genitalorgansenkung verdeutlicht. Es bestehen neben anatomisch-strukturellen Defiziten des Aufhängeapparates (z.B. Sakrouterinligamente) auch sog. paravaginale Defekte infolge von Verletzungen der endopelvinen Faszie [3]. Zusätzlich existieren strukturelle Defekte der Beckenbodenmuskeln, wie Avulsionen, Teil- oder Komplettabrisse der Muskeln von der Symphyse oder Muskel(faser)risse, die von HP. Dietz 3-D-sonographisch ausführlich evaluiert und beschrieben wurden [10].

Dass Harninkontinenz aber nicht ausschließlich ein anatomisches Problem des Beckenbodens ist, wurde 1994 in der sog. „Hammock-Hypothese“ verdeutlicht [8]. Ein Modell, das die strukturelle Unterstützung von Harnröhre und Blase bei Erhöhung des intraabdominellen Drucks (IAD) erklärt, die Gewährleistung der damit verbundenen Drucktransmission [11] und die Sicherung der Stabilität von Urethra und Blase (v.a. des sog. Blasenhalses) [3]. Zusätzlich zur stützenden Wirkung des Beckenbodens durch Bänder, Faszien und Muskulatur ist die Wirksamkeit bei Beckenbodenmuskelkontraktion von großer Bedeutung, denn sie beeinflusst über den Druck auf die Harnröhre drei Mechanismen, die für die Sicherung der Kontinenz wichtig sind: 1. den Urethraverschlussdruck, 2. den maximalen Harnröhrenverschlussdruck bei Belastung und damit 3. die Druckübertragungsrate von intraabdominellem Druck auf den Blasenhals bzw. die proximale Urethra [11].

Als weitere Inkontinenzmechanismen gelten die perinealsonographisch beurteilbare Blasenhalshypermobilität [8,10,12] sowie die fehlende neuromotorisch gesteuerte Präkontraktion des Beckenbodens [13,14].

Unsere Arbeitsgruppe eruierte die Kontinenzmechanismen synchron in Beckenboden-relevanter stehender Position [15]. Die sog. erweiterte Urodynamik umfasste neben der Messung des intraabdominalen und urethralen Druckes auch die sonographische Verfolgung der Blasenhalsposition, die Aufzeichnung der EMG-Aktivität des M. levator ani und der Abdominalmuskulatur sowie die Verfolgung der Atemexkursionen bei gesunden und inkontinenten Probandinnen beim Husten.

Die bereits bekannten funktionellen BB-Störungen wurden bestätigt und spezifiziert (Tab. 1): Bei Frauen mit Belastungsinkontinenz ist die Beckenbodenmuskel-Präkontraktion verzögert und der Blasenhals ist weniger stabil. Bei Hustenstößen ohne Harnverlust kam es bei kontinenten und inkontinenten Frauen zu einem Blasenhalsdeszensus. Bei Hustenstößen mit Harnverlust deszendieren Blasenhals und M. puborectalis (anorektaler Winkel) signifikant mehr.

Tab. 1 Funktionelle Unterschiede bei inkontinenten und gesunden Frauen

	Belastungsinkontinenz n=35	Kontrollgruppe n=18	P
BBM Präkontraktion (ms)	61 (32-140)	70 (20-220)	<0.001
BH Stiffness (cmH_2O/mm)	11.6 (4-100)	23.2 (8-92)	0.002
PR Stiffness (cmH_2O/mm)	52 (24-93)	76 (15-116)	0.211
Drucktransmissionsratio **Husten ohne Urinverlust** **Husten mit Urinverlust**	 1.17 (0.9-2.5) 0.77 (-0.4-2.4) p<0.001	 1.18 (0.9-2.6) na	 0.782
BH Vektor (mm) **Husten ohne Urinverlust** **Husten mit Urinverlust**	 -6 (-8.6 – 3) -9 (-21 – 5) p=0.012	 -4.2 (-7.4 - 3.2)	 0.112
PR Vektor (mm) **Husten ohne Urinverlust** **Husten mit Urinverlust**	 0 (-4 – 4) -3 (-12 - 10) p=0.028	 2.5 (-3.9 – 11) na	 0.017

na=not applicable, BBM (Beckenbodenmuskel), BH (Blasenhals), PR (Puborektalisschlinge): Median (min.-max.)

1.4 Rehabilitation der Beckenbodenmuskulatur

Während sich die Entwicklung von Operationsmethoden in der Urogynäkologie in den vergangenen Jahrzehnten an der funktionellen Anatomie und den Pathomechanismen orientierte, wird im Rahmen der Physiotherapie am häufigsten das sog. Beckenbodenmuskeltraining („pelvic floor muscle training") eingesetzt [16-18]. Es entstanden auf der einen Seite exzellente Operationsmethoden, wie beispielsweise die Burch-Kolposuspension, deren Erfolge in einer anatomischen Blasenhalselevation begründet ist sowie das „tension-free vaginal tape" (TVT) dessen Wirkung in einer mitturethralen Unterstützung bei Erhöhung des intraabdominellen Drucks (z.B. beim Husten) gesehen wird, also eher funktionell wirksam ist. Letztere Operationsmethode, mit einer Erfolgsquote von über 90% direkt nach der Operation und auch langfristig (mittlerweile nach 17 Jahren [19]), ist wahrscheinlich mit keiner Art von Beckenbodenmuskeltraining (weder Kraft noch Koordination) zu überbieten.

Das Beckenbodenmuskeltraining andererseits bezieht seine Grundlage vor allem aus der Trainingstherapie, z.B. aus Empfehlungen des „American College of Sports" [20], weshalb v.a. die Studienlage über verschiedene Trainingsmodalitäten (Dauer, Anzahl, Geschwindigkeit, Häufigkeit der Kontraktionen, usw.) und Verbesserungen der Adhärenz sehr gut ist [16,17,21]. Andere Aspekte, wie beispielsweise die Koordination und Qualität der Muskelkontraktion sind deutlich weniger erforscht und es liegen hierzu kaum Publikationen vor, was daran liegen könnte, dass die Qualität von

Muskelkontraktionen nur mit größerem technischem Aufwand als die Quantität (Muskelaktivität/ Muskelkraft) messbar ist. Zur Quantifizierung der Beckenbodenaktivität werden Elektromyographie (Muskelaktivität) und Perineometrie (Muskelkraft/ squeeze-pressure) mit speziellen Vaginalsonden eingesetzt. So wird beispielsweise seit 2009 unverändert in den „International Consultation on Incontinence (ICI)“ an erster Stelle das Beckenbodenmuskeltraining bei Belastungsinkontinenz genannt. Das wichtigste Ziel ist hier, durch intensives Training, mittels maximaler BBM-Kontraktion, eine Muskelhypertrophie zu erreichen. Die beiden anderen „Biologischen Rationale für Beckenbodenmuskeltraining“, die Präkontraktion wird sicherlich häufig propagiert und in den Studien durchgeführt (allerdings nicht ausschließlich und verglichen mit anderen Trainingsmodalitäten), die Co-Kontraktion mit dem M. transversus abdominis (TrA) allerdings seltener und mit weniger Nachdruck [18]. In zwei Studien wird sogar von einer Kontraktion des TrA abgeraten [22,23] – siehe z.B. Bo et al. 2003: „Indirectly training the PFM via contractions of the TrA should be discouraged“ [22]. Bei der Untersuchung von Frauen mit Senkungsbeschwerden kam es bei 2 von 13 Frauen bei einer Kontraktion des TrA anstelle einer erwarteten Konstriktion und Verengung des Hiatus genitalis durch die BBM-Kontraktion zu einer Erweiterung [23]. In einer anderen Studie wurde bei 6 von 20 gesunden Frauen bei einer Kontraktion des TrA mittels transabdominalem Ultraschall ein Absinken der Blase evaluiert und eine größere Elevation der Blase, wenn auf die Co-Kontraktion des TrA verzichtet und nur eine Beckenbodenkontraktion instruiert wurde [22]. Bei beiden Studien fehlt die Erfassung anderer Parameter, wie die EMG-Messung von Bauch-, Hüft-, Becken- und Gesäßmuskeln. Deren Co-Kontraktion würde Auswirkung auf den IAD haben [24] und folglich das Ausmaß der Blasenelevation beeinflussen [12]. Dass die Kontraktion anderer Bauchmuskeln einen Einfluss auf die Position der Blase hat, wurde von Thompson et al. gezeigt. Hier konnten bei harninkontinenten Frauen unterschiedliche Rekrutierungsstrategien bei einer willkürlichen BBM-Anspannung evaluiert werden: Mittels parallel zum Ultraschall durchgeführtem Oberflächen-EMG der Bauchmuskeln wurde ein Zusammenhang von Bauchmuskelkontraktionen und dem Tiefertreten der Blase erkannt [25]. Die Co-Kontraktion von Beckenboden- und Bauchmuskeln (TrA, IO, EO) mittels intra-muskulären fine-wire-Elektroden bei gesunden Frauen wurde in einer Studie von Neumann und Gill als physiologisch erkannt, zusammen mit einer Erhöhung des IAD [24]. Allerdings wurde hier nicht erwähnt, mit welcher Intensität die BBM-Kontraktionen durchgeführt wurde.

Dass der Zeitpunkt der Beckenbodenmuskelkontraktion unmittelbaren Einfluss auf den Harnverlust beim Husten hat, wurde bereits 1998 von Miller et al. gezeigt [26]. Wenn die Probandin die Beckenbodenmuskeln vor dem Husten anspannte, traten bei einem mittleren Hustenstoß 98% weniger Harnverlust auf, bei einem starken Hustenstoß waren es 73%. Diese Aktion wird seither „The Knack“ genannt. Wegen der Kürze der Übungszeit (eine Woche), sind nach muskelphysiologischen Gesichtspunkten weder eine Verbesserung der Muskelkraft noch eine Muskelhypertrophie für diese Erfolge anzunehmen. Vielmehr kann von einer Verbesserung der Koordination und somit einer neuro-muskulären Leistung, wie sie im Rahmen des sog. motorischen Lernens angestrebt wird, ausgegangen werden. Diese Ergebnisse wurden aber nie in einer RCT mit anderen Methoden verglichen.

Die kurzfristigen Erfolge eines auf Muskelkraft beruhenden Beckenbodenmuskeltrainings liegen bei 70% [2]. Dies ist vergleichbar mit den Erfolgen der Präkontraktion „The Knack“ [26]. Daraus leitet sich die Frage ab, ob mit einem funktionellen und koordinativen, auf maximale Beckenbodenmuskelkontraktionen verzichtenden Beckenboden-Rehabilitationsprogramm, welches in den Alltag integriert werden soll, bessere und vor allem langfristige Erfolge zu verzeichnen sind.

2 Einzelne Studien

1. **Effect of abdominal and pelvic floor tasks on muscle activity, abdominal pressure and bladder neck.**

   Junginger B, Baessler K, Sapsford R, Hodges PW (2010) IUJ; 21: 68–77

Fragestellung

Welchen Einfluss haben willentlich durchgeführte Kontraktionen der den Bauchraum umhüllenden Muskeln (Beckenbodenmuskeln, M. transversus abdominis (TrA), M. internus obliquus abdominis (IO), M. externus obliquus abdominis (EO)) auf den Anstieg des intraabdominellen Drucks? Wie wirkt sich dies auf die Blasenhalsposition aus?

Klinische Relevanz

Erarbeitung von Empfehlungen für eine korrekte Beckenbodenkontraktion unter Berücksichtigung der physiologischen Zusammenarbeit (Co-Kontraktion) von Beckenbodenmuskeln, TrA, IO und EO.

Gemessene Parameter und eingesetzte validierte Messmethoden

Die Position des Blasenhalses wurde mittels perinealem Ultraschall evaluiert, die EMG-Muskelaktivität der Bauchmuskeln M. transversus abdominis, Mm. obliquus internus et externus abdomins mittels unter US-Kontrolle eingesetzter intramuskulärer fine-wire Elektroden, die EMG-Aktivität der Beckenbodenmuskeln (BBM) mit einer vaginal platzierten Oberflächenelektrode (Periform®-Sonde). Die intraabdominelle Druckmessung erfolgte mit einer Rektalsonde.

Material und Methoden

Neun gesunde Frauen, evaluiert mit dem „Australian Pelvic Floor Questionnaire“ [27], führten im Liegen sechs verschiedene Kontraktionen bzw. Manöver durch: 1.vorsichtige Kontraktion des Beckenbodens (BBM gentle), 2. moderate Kontraktion des Beckenbodens (BBM moder.), 3. Kontraktion des M. transversus abdominis (TrA). Bei den Manövern - 4. Brace, 5. Valsalva (VAL) und 6. Kopf anheben (Head lift) - waren mehr cranial und oberflächig liegende Bauchmuskeln aktiv (M. internus und externus obliquus abdominis und M. rectus abdominis).

Bei der ersten Durchführung der sechs Kontraktionen und Manöver wurde mittels perinealem Ultraschall die Position des Blasenhalses, bei der zweiten Serie mit einer Vaginalelektrode die EMG-Aktivität der Beckenbodenmuskeln untersucht. Die spezifischen Kontraktionen wurden zuvor unter Ultraschallkontrolle der Bauchmuskulatur eingeübt.

Eine modifizierte Borg Skala diente zur Standardisierung der Muskelkraft, mit der die verschiedenen Muskelkontraktionen (gentle 2 von 15, moderat 8 von 15) durchgeführt wurden. Alle Kontraktionen und Manöver sollten „gentle" (2/15) ausgeführt werden, die Beckenbodenmuskelkontraktion „gentle" und „moderat" (8/15).

<u>Ergebnisse</u>

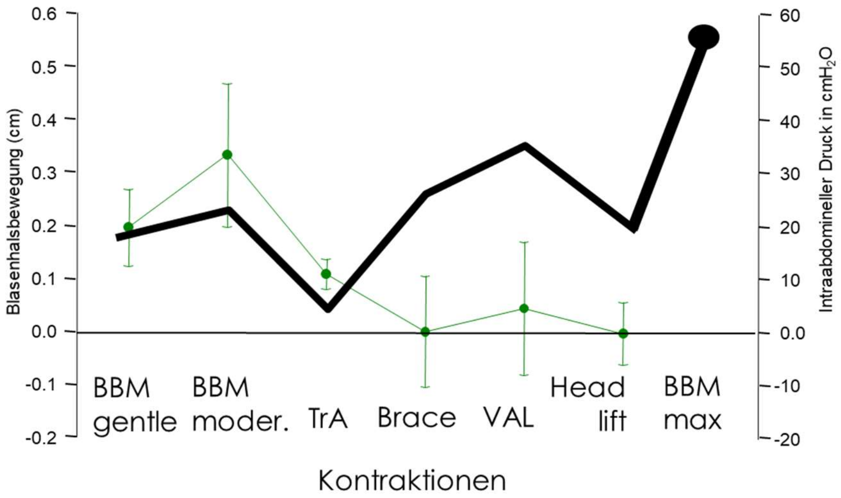

Abb. 1 Veränderungen von intraabdominellem Druck (schwarz) und Blasenhalselevation (grün) bei den sechs unterschiedlichen Muskelkontraktionen.

Bei Kontraktion der Beckenbodenmuskeln (gentle und moderat) und des M. transversus abdominis steigt der intraabdomineller Druck wenig an und es kommt zu einer signifikanten Elevation des Blasenhalses. Bei den Manövern, die eine Mm. internus et externus obliquus abdominis-Kontraktion generieren, kommt es zu einem größeren Anstieg des IAD und die Elevation des Blasenhalses kann nicht evaluiert werden.

Da bei den gesunden Studienteilnehmerinnen die Beckenbodenmuskeln immer aktiv waren, wurde ein Tiefertreten des Blasenhalses verhindert und geschlussfolgert, dass im Falle einer fehlenden oder schlechten Beckenbodenkontraktion eine Depression der Blase resultieren könnte.

Fazit

Diese Studie führt zur Konklusion, dass bei der Rehabilitation von Harninkontinenz submaximale Beckenbodenmuskelkontraktionen vorzuziehen sind und auf maximale verzichtet werden sollte.

2. **Submaximal pelvic floor muscle contractions: similar bladder neck elevation, longer duration, less intraabdominal pressure.**

   Junginger B, Vollhaber H, Baessler K (2018) IUJ; 29: 1681–1687

Fragestellung

Aus den Ergebnissen der ersten Studie, v.a. der starken Erhöhung des intraabdominellen Drucks bei maximaler Beckenbodenmuskelkontraktion und der daraus resultierenden selbst bei Gesunden kontraproduktiv auf die Blasenhalselevation wirkende Effekt, entwickelte sich die Fragestellung der 2. Studie. Es wurde untersucht, ob eine submaximal durchgeführte Beckenbodenkontraktion bereits effektiv ist und eine adäquate Blasenhalsstabilität bewirkt und ob diese andauernder bewahrt werden kann.

Klinische Relevanz

Eine submaximale Kontraktion der Beckenbodenmuskeln könnte bereits eine Reduktion des Harndrangs bei Draninkontinenz zur Folge haben und ausdauernder gehalten werden, wenn beispielsweise Urinverlust vor Erreichen der Toilette als Symptom von der Patientin angegeben wird. Bei andauerndem Husten könnte eine ausdauernde Beckenbodenkontraktion notwendig sein. Diese Ausdauer könnte mit submaximaler Beckenbodenmuskelkontraktion erreicht werden.

Gemessene Parameter und eingesetzte validierte Messmethoden

Die erweiterte Urodynamik mit perinealem Ultraschall, Elektromyographie der Beckenbodenmuskeln, Elektromyographie der Bauchmuskeln und die Aufzeichnung der Atemexkursionen mittels Atemsensor kamen zum Einsatz.

Material und Methode

Achtundsechzig Frauen mit dominanter Belastungsinkontinenz und 14 symptomfreie Frauen wurden in diese Studie einbezogen. Zur Unterscheidung gesunder und harninkontinenter Frauen kam die deutsche Version des „Australian Pelvic floor Questionnaires“ zum Einsatz [28].

Ergebnisse

Submaximale Kontraktionen führen zu einer adäquaten Blasenhalselevation und können signifikant ausdauernder gehalten werden als maximale, unabhängig davon, ob die Frauen gesund oder harninkontinent waren. Bei annähernd 30% beider untersuchten Gruppen kam es zu einem Absinken des Blasenhalses bei maximalen Kontraktionen, aber nicht bei submaximalen. Während der submaximalen Beckenbodenmuskelkontraktion atmeten die meisten Frauen weiter (71 % der inkontinenten und 70 % der kontinenten Frauen). Bei der maximalen Beckenbodenmuskelkontraktion stoppten 21% der inkontinenten und sogar 50% der kontinenten Frauen die Atmung.

3. **Bladder-neck effective, integrative pelvic floor rehabilitation program: follow-up investigation.**

   Junginger B, Seibt E, Baessler K (2014); EJOG 174: 150–153

Fragestellung

Wie wirksam ist ein Beckenbodenrehabilitationsprogramm mit Fokus auf 1. korrekte Beckenbodenmuskelkontraktion unter Vermeidung der maximalen Anspannung, 2. Verbesserung der Qualität der Kontraktion unter Einbeziehung individueller Defizite (evaluiert im Ultraschall und durch vaginale funktionelle Beckenbodenpalpation), 3. Integration der korrekten Beckenbodenmuskelkontraktion in den Alltag und in individuelle Symptommomente?

Klinische Relevanz

Eine mögliche Verbesserung der Langzeitergebnisse erscheint möglich, da die Hintergründe des Programms den Prinzipien des motorischen Lernens folgen.

Gemessene Parameter und eingesetzte validierte Messmethoden

Sowohl vor der Behandlung als auch mehrere Monaten nach der Behandlung wurde der validierte Beckenboden-Fragebogen [28] einschließlich Nachkontrollmodul [29] eingesetzt.

Material und Methode

In einer prospektiven Interventionsstudie, die 55 Frauen mit Belastungsinkontinenz, Dranginkontinenz und einer Kombination aus beiden Formen umfasste, erfolgte die Behandlung gemäß der individuellen Funktionsdefizite mit gezielter

Beckenbodenmuskelrehabilitation und unter Einsatz des perinealen Ultraschalls als Untersuchungs- und visuelles Biofeedbackmedium. Die Funktionsuntersuchung (beim Anspannen, Pressen, Husten, etc.) erfolgte im Liegen und im Stehen. Mittels perinealem Ultraschall wurden die individuellen Defizite erläutert, weshalb die Patientinnenschulung (patient education) einen Teil der Behandlung darstellte. Die Progression erfolgte nach Prinzipien des motorischen Lernens, was in der später entwickelten Checkliste (Tab. 2) abgebildet ist.

Ergebnisse

Im Schnitt erfolgten zwei (von 1 bis 6) einstündige Therapiesitzungen. Bei 67 % (31 von 46) der Frauen mit einer Belastungsinkontinenz kam es zu einer Verbesserung der Inkontinenz, 17 gaben keine Symptome mehr an, 14 eine Verbesserung. Bei der Dranginkontinenz waren die Verbesserungen noch deutlicher, 78 % (36 von 46), wovon 25geheilt, 11 verbessert waren. Die Verbesserungsskalen für Blasenfunktion zeigten, dass 91 % (50 von 55) der Frauen, davon 22 eine etwas bessere und 28 Frauen eine viel bessere Blasenfunktion angaben. Keine der Frauen gab eine Verschlechterung ihrer Symptome an. Bei 63 % der Nachkontrollen lag die Therapie mehr als 6 Monate zurück (1-16 Monate; Median 7, Mean 7,6 Monate). Die Therapieerfolge verschlechterten sich nicht mit einer längeren Nachkontrollzeit.

Zusammenfassung

Mit einem Training mit Fokus auf motorisches Lernen und dessen Progressionen (korrekte Anspannung des BBM, korrekte Co-Kontraktion des TrA, Einsatz von Ultraschall als visuelles Biofeedbackverfahren, Integration in den Alltag), waren die Ergebnisse sehr gut und den in der Literatur beschriebenen ähnlich. Außerdem waren die Ergebnisse auch im Schnitt nach sieben Monaten ohne weitere Interventionen stabil. Dies erscheint als ein Vorteil gegenüber reinem Beckenbodenmuskeltraining, dessen Problem die Sicherung des Behandlungserfolgs nach Beendigung des Trainings ist. Beide Methoden werden derzeit in einer randomisierten Studie verglichen [30].

3 Diskussion

In den drei Publikationen wurde das Ziel verfolgt, die Komponenten einer korrekten Beckenbodenkontraktion zu ermitteln, deren Effektivität auf den Blasenhals und schließlich die subjektiven und objektiven Verbesserungen eines entwickelten Trainingskonzepts zu evaluieren.

3.1 Was ist eine korrekte, physiologische Beckenbodenmuskelkontraktion?

Eine willentlich durchgeführte Kontraktion der Beckenbodenmuskeln verkleinert den anorektalen Winkel, der durch die Bewegung der sog. Puborektalisschlinge nach cranio-ventral gezogen wird. Evaluiert wird dies mit perinealem US, ebenso wie die daraus resultierende cranio-ventrale Bewegung des Blasenhalses. Hierfür genügt bereits eine submaximale Kontraktion (Studie 1 und 2), die von einer physiologischen Co-Kontraktion des M. transversus abdominis begleitet wird (Studie 1). Hierbei steigt der intraabdominelle Druck nur gering an. In der 2. Studie konnte im Ultraschall beobachtet werden, dass eine maximale Kontraktion der Beckenbodenmuskeln bei gleichzeitig stark erhöhter Bauchmuskelaktivität, wie sie z.B. beim Husten oder Niesen vorkommt, zum Blasenhalsdeszensus führt. Bei den submaximal ausgeführten Kontraktionen blieb der Blasenhals stabil. Ferner kann eine submaximale Kontraktion länger gehalten werden als eine maximale, was sicher von Vorteil ist bei repetitivem und anhaltendem Husten oder längerer Strecke bis zum Erreichen der Toilette.

Eine korrekte Anspannung der Beckenbodenmuskulatur kann am einfachsten durch vaginale Palpation evaluiert werden [1], das nach-innen-Bewegen des Perineums als Surrogatparameter ist nicht-evidenz-basiert untersucht worden. Parallel erfolgt zum Ausschluss von nicht erwünschten Co-Kontraktionen die Beobachtung und Eliminierung von Becken- und Wirbelsäulenbewegungen, Stagnation der Atmung, Kontraktion von Oberschenkel- und Gesäßmuskeln, etc. Die Reproduzierbarkeit hierfür ist aber gering. Palpation und Beobachtung (subjektive Methoden) werden in den vorliegenden Studien ergänzt mit objektivierbaren Methoden, wie US, IAD- und EMG-Messungen und damit auf physikalisches Niveau gebracht. Ferner sind bei zwei der drei vorliegenden Arbeiten diese erstmals zeit-synchron durchgeführt worden.

3.2 Neues Beckenbodenkonzept für die Rehabilitation

Das auf motorischem Lernen beruhende Konzept zeigte Verbesserungen der Belastungsinkontinenz von 67% und bei Dranginkontinenz von 78%. Zur Standardisierung der Progression innerhalb dieses Konzepts wurde eine Checkliste erstellt, die in der Tabelle (Tab. 2) zusammengefasst ist. Die Schlüsselkomponenten waren hier gezielte, unter perinealem US als visuelles Biofeedbackverfahren durchgeführte Beckenbodenmuskelkontraktionen, die sich an den individuellen, in der funktionellen Untersuchung dargestellten Defiziten der Patientin orientierten. Defizite waren z.B. das fehlende Bewahren der Kontraktion bei Inspiration (Problem der Koordination von Muskelkontraktion und Anstieg des intraabdominellen Drucks) oder der Verlust der Kontraktion bei forcierter Exspiration (z.B. beim Husten). Andere Funktionsstörungen waren das Tiefertreten von Blase und Harnröhre infolge zu starker Anspannung des M. internus obliquus abdominis und der damit verbundenen Erhöhung des intraabdominellen Drucks bei gleichzeitigem Verlust der Beckenbodenmuskelkontraktion. Die Integration der korrekten Beckenbodenmuskelkontraktion in andere Ausgangsstellungen, wie Sitzen oder Stehen, und vor allem zusätzlich in die individuellen Symptommomente waren Bestandteil der Therapie in dieser Studie. Ein weiterführendes Training der Beckenbodenmuskel fand nicht statt. 71% der Probandinnen berichteten, dass sie die Präkontraktion routinemäßig im Alltag einsetzen. Ob dies der Grund dafür ist, dass die Ergebnisse auch noch nach 7 Monaten vorlagen, oder ob die motorische Integration in den Alltag teilweise als „automatisch vorhanden“ ist, lässt sich nicht beantworten, wäre aber das Fernziel dieses nachhaltigen Beckenboden- und Verhaltenstrainings.

Mittlerweile wurde dieses Konzept in einer randomisierten kontrollierten Studie (RCT) mit einer auf reinem Muskeltraining beruhender Beckenbodentherapie verglichen [30]. In den 3 und 6 Monats-Nachkontrollergebnissen sind die Ergebnisse nicht schlechter, wenn auf den Faktor „Muskeltraining“ verzichtet wird und vielmehr die submaximale Kontraktion unter Beibehaltung bei Aktivitäten des täglichen Lebens unter Berücksichtigung der Prinzipien des motorischen Lernens erfolgt.

3.3. Kritische Auseinandersetzung mit eigenen Methoden und Ergebnissen

Wie bereits erwähnt, sind zur Bestimmung der Qualität der Beckenbodenanspannung zeitsynchrone Messungen von intraabdominellem Druck, von EMG-Aktivität der Bauchraum-umhüllenden Muskeln und der Atmung erforderlich. Hierzu wurde im

Rahmen der DFG-Studie eine sog. „erweiterte Urodynamikmethode“ entwickelt. Im Vordergrund stand die Untersuchung der Blasenhalsposition (perinealer Ultraschall) in Abhängigkeit des durch IO, EO und TrA generierten IAD. Handelsübliche Vaginalelektroden zur Aufzeichnung des Beckenboden-EMGs (genutzt z.B. bei der vaginalen Biofeedbacktherapie) behinderten zum einen die gleichzeitige Positionierung der Sonde für den perinealen Ultraschall und zum anderen die Bewegung von Harnröhre, Blase und Darm. Die in den 90er Jahren entwickelte Schwammelektrode (Dantec 13L81) erlaubte dagegen eine parallele Messung mit Ultraschall und Beckenboden-EMG.

In der hier beschriebenen ersten Studie war technisch die Unterscheidung der drei Bauchmuskeln mittels intramuskulärer, fine-wire EMG von besonderer Bedeutung. Die Erkenntnisse über den Einfluss der Aktivität von IO, EO sowie TrA auf die Veränderung des IAD und folglich auf die Aktivität der BBM waren wegweisend für die beiden folgenden Studien. In diesen wurde die Position des Blasenhalses in einer parallelen Messung dokumentiert (Studie 2 und 3).

Die Interventionsstudie (Studie 3) enthält keine Kontrollgruppe, was die Güte dieser Studie schmälert. Außerdem war der Zeitpunkt der Nachkontrollen der einzelnen Patientinnen nicht einheitlich – durchschnittlich 7 Monate (1-18 Monate). Allergings kann aus der Erkenntnis, dass keine Korrelation von Verbesserung der Inkontinenzsymptome und Nachkontrollzeitpunkt besteht, geschlussfolgert werden, dass eine mögliche physiologische (evtl. sogar automatische) Integration der Präkontraktion bei Patientinnen mit Inkontinenz erfolgt. Immerhin 71% der Frauen bestätigten das Praktizieren einer Präkontraktion, was auch mit besseren Kontinenzraten assoziiert war. Im weiteren Verlauf wurde eine randomisierte, kontrollierte Studie zum Vergleich der nach Inhalten benannten „Blasenhals-effektiven, kontrollierten, integrativen Beckenbodentherapie“ und einem mit EMG-Biofeedback unterstützten Beckenbodenmuskeltraining konzipiert.

3.4. Warum sind existierende Therapiekonzepte bislang limitiert?

Eine deutliche Einschränkung heutiger Therapieforschung im Beckenbodenbereich scheint hinsichtlich der Gewichtung der Themen „Muskeltraining“ und „neuromuskuläre Steuerung und Kontrolle“ zu bestehen. Obwohl die Präkontraktion in der Beckenbodentherapie bereits 1998 mit dem „KNACK“ aufgegriffen wurde [26], wird diese in den publizierten Studien und Beckenbodenkonzepten nur beiläufig erwähnt und eingesetzt [31]. Es fehlen Studien, die gezielt die BB-Präkontraktion als Therapie untersuchen, unerklärlich, da, wie bereits in Kapitel 1.4. erläutert, ein einwöchiges Praktizieren der Präkontraktion zur Reduktion des Harnverlusts um 73% (bei starkem Husten) und um 98% (bei normalem Husten) führte und diese Resultate nicht mit Muskelkraft vergesellschaftet waren [26].

Die schlechten Langzeiterfolge, die das größte Problem des herkömmlichen Trainings der Beckenbodenmuskeln darstellen, könnten durch Studien hinsichtlich der neuromuskulären Steuerung und Kontrolle verbessert werden. Studien in der Rückenschmerzforschung, die sich mit Rezidivraten und deren Reduktion bei Rückenschmerzen beschäftigten, zeigten die Überlegenheit eines auf motorischer Kontrolle basierenden Konzepts nach 1 und 3 Jahren mit Rezidivraten von nur 30% (35%) gegenüber 84% (75%) der Kontrollgruppe ohne diese Therapie [32].

3.5. Ausblick

Unter dem Aspekt, dass Beckenbodensymptome zusätzlich zu strukturell bedingten (Muskel-/ Bindegewebsdefekte) auch neuromuskuläre, unter die Rubrik „Störung der motorischen Kontrolle“-fallende Ursachen haben, sollte zukünftige Forschung auch im Bereich der Neurologie verortet sein. Funktionelle Kernspintomographie (fMRI) des Gehirns wurde bereits 2006 von Di Gangi Herms et al. eingesetzt um Veränderungen vor und nach einem BBM-Training zu evaluieren [33]. Vergleiche von gesunden und inkontinenten Frauen wären denkbar, wenn beispielsweise eine BBM-rekrutierung nicht möglich ist. Themen wie „pain inhibition“ der Beckenbodenmuskeln, das bei Rückenschmerzen bereits 1996 erforscht wurde [34] sowie emotionale Ursachen mit Tendenz zum „catastrophizing“ [35] könnten auch am Beckenboden Dysfunktionen auslösen.

Mit einer für Diversität offenen Forschung wäre es denkbar, in Zukunft Störungen des Beckenbodens nach Funktionsstörungen und Pathomechanismen zu klassifizieren und nicht nach Symptomen und Diagnosen. Dies stellte eine Chance dar, spezifische Methoden und genaue Dosierungen der Physiotherapie gezielt zuzuordnen, was Prognosen ermöglichen und v.a. Forschungsergebnisse vergleichbar machen würde.

4. Fazit

Durch die Beobachtung der Physiologie des Beckenbodens bei Alltagsaufgaben wie Valsalva oder Kopfanheben wurde der Zusammenhang zwischen Stärke der Beckenbodenkontraktion, dem intraabdominellen Druck und der Blasenhalsposition erkannt. Die genauen Auswirkungen von maximalen und submaximalen Beckenbodenkontraktionen wurden dann im Stehen untersucht, wie auch die mögliche Dauer der Kontraktion. Aus den Ergebnissen wurde ein physiotherapeutisches Therapiekonzept zur Behandlung von Belastungs- und Dranginkontinenz entwickelt und in einer Interventionsstudie überprüft.

Diese Arbeiten führen zu einer klinisch relevanten Erweiterung der konservativen Behandlung von Beckenbodendysfunktionen, wie Belastungs- und Dranginkontinenz. Der perineale Ultraschall kann nicht nur zur dynamischen Evaluation von Blasenhals und Beckenbodenmuskeln eingesetzt werden, sondern auch als visuelles Biofeedbackinstrument um eine korrekte Blasenhals-elevierende Kontraktion der Beckenbodenmuskeln zu instruieren.

Tab. 2: Checkliste für die einzelnen Behandlungssitzungen

Spezifische Beckenbodentherapie nach dem Blasenhals-effektiven-integrativen-kontrollierten-Beckenbodenkonzept:				
	Termin 1	Termin 2	Termin 3	Termin 4
1. Erklärung des Konzepts				
2. Blasenhals-wirksame Beckenbodenkontraktion (Ultraschall)				
3. Palpable Beckenbodenkontraktion				
4. Für Patientin wahrnehmbare Beckenbodenkontraktion				
5. TrA-Kontraktion palpabel und für Patientin wahrnehmbar				
6. TrA-BBM-Co-Kontraktion				
7. TrA-BBM-Co-Kontraktion für Patientin spürbar				
8. Co-Kontraktion 1. während Atmung halten, 2. während Arm- oder Beinbewegung halten				
9. Transfer der Kontraktion ins Sitzen				
10. Transfer der Kontraktion ins Stehen				
11. Transfer in Bewegung (z.B. aufstehen vom Sitz, Heben von Gegenständen, etc.)				
12. Integration in Inkontinenzsituationen				
13. Integration in Drangsituationen				
14. Integration in Alltag				
15. Integration in Sport				
16. Automatismusstrategien erklärt				
17. Toilettenverhalten erklärt (nicht pressen wegen Urge/ Urgency)				
18. Toilettenverhalten erklärt (Double voiding wegen Deszensus)				
19. Toilettenverhalten erklärt (nicht pressen wegen Deszensus)				

TrA = M. transversus abdominis, BBM = Beckenbodenmuskel

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Anhang

Inhalt

Eidesstattliche Versicherung

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Anteilserklärung an den erfolgten Publikationen

Publikation 1: Effect of abdominal and pelvic floor tasks on muscle activity, abdominal pressure and bladder neck.

Junginger B, Baessler K, Sapsford R, Hodges PW

Int Urogynecol J 2010 Jan; 21 (1): 69-77

Beitrag im Einzelnen: Mitarbeit bei der Entwicklung von Studienidee und Erstellung des Studiendesigns, mehrheitliche Rekrutierung der Probandinnen, Durchführung der Datenerhebung (Ultraschall), deren Vermessung (off-screen) und Datenauswertung, Interpretation der Daten, größtenteils Erstellung des Manuskripts

Publikation 2: Submaximal pelvic floor muscle contractions: similar bladder-neck elevation, longer duration, less intra-abdominal pressure.

Junginger B, Vollhaber H, Baessler K

Int Urogynecol J 2018 Nov; 29 (11); 1681–1687

Beitrag im Einzelnen: Mitarbeit bei der Entwicklung der Studienidee und der Erstellung des Studiendesigns, Rekrutierung der Probandinnen, Mitarbeit bei der Entwicklung der Messvorrichtungen, größtenteils Durchführung der Datenerhebung und -eingabe, Auswertung der Ultraschallvideos, der EMG- und Druckmessungen, Mitarbeit bei der statistischen Auswertung sowie der Interpretation der Ergebnisse, größtenteils Erstellung des Manuskripts

Publikation 3: Bladder-neck effective, integrative pelvic floor rehabilitation program: follow-up investigation.

Junginger B, Seibt E, Baessler K

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Beitrag im Einzelnen: Entwicklung der Studienidee und des Studiendesigns, Rekrutierung der Probandinnen, Durchführung der Datenerhebung und -eingabe (vor der Therapie), Durchführung der Behandlungen, Mitarbeit bei der statistischen Auswertung, Interpretation der Ergebnisse, Verfassen des Manuskripts

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ORIGINAL ARTICLE

Effect of abdominal and pelvic floor tasks on muscle activity, abdominal pressure and bladder neck

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Abstract
Introduction and hypothesis Although the bladder neck is elevated during a pelvic floor muscle (PFM) contraction, it descends during straining. This study aimed to investigate the relationship between bladder neck displacement, electromyography (EMG) activity of the pelvic floor and abdominal muscles and intra-abdominal pressure (IAP) during different pelvic floor and abdominal contractions.
Methods Nine women without PFM dysfunction performed maximal, gentle and moderate PFM contractions, maximal and gentle transversus abdominis (TrA) contractions, bracing, Valsalva and head lift. Bladder neck position was assessed with perineal ultrasound. PFM and abdominal muscle activities were recorded with a vaginal probe and fine-wire electrodes, respectively. IAP was recorded with a rectal balloon.
Results Bladder neck elevation only occurred during PFM and TrA contractions. PFM EMG and IAP increased during all tasks from 0.5 (gentle TrA) to 45.7 cmH_2O (maximal Valsalva).
Conclusion Bladder neck elevation was only observed when the activity of PFM EMG was high relative to the IAP increase.

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Keywords Bladder neck movement · Intra-abdominal pressure · Muscle EMG activity · Pelvic floor re-education · Perineal ultrasound

Abbreviations

ASIS	Anterior superior iliac spine
APFQ	Australian Pelvic Floor Questionnaire
EMG	Electromyography
Hz	Hertz
IAP	Intra-abdominal pressure
kHz	Kilohertz
lowTrA	Lower TrA
MHz	Megahertz
midTrA	Middle TrA
OE	Obliquus externus abdominis muscle
OI	Obliquus internus abdominis muscle
PUS	Perineal ultrasound
RA	Rectus abdominis muscle
RMS	Root mean square
TrA	Transversus abdominis muscle
VAL	Valsalva

Introduction

Voluntary contraction of pelvic floor muscles (PFM) elevates the bladder neck [1–4] and compresses the urethra [5]. The contraction also provides a firm base against which the urethra is closed by the increased intra-abdominal pressure (IAP) [6, 7]. These factors contribute to the maintenance of continence, but the extent of elevation of the bladder neck is probably not determined by PFM activity alone; increased IAP may prevent elevation or induce caudal displacement of the bladder neck [1, 3, 7].

Consistent with this proposal, opposite directions of pelvic floor motion have been observed but not quantified during voluntary contraction of the PFM (elevation) and a Valsalva (depression), but contraction of other muscles rather than IAP has been argued to explain the results [8]. Abdominal and PFM are co-activated during voluntary [9, 10] and involuntary [11, 12] tasks. The abdominal activation may displace the bladder neck but this effect may be different between the structurally and functionally different muscles of the abdominal wall (obliquus internus abdominis (OI), obliquus externus abdominis (OE), rectus abdominis (RA) and transversus abdominis (TrA)). Furthermore, the timing of the abdominal and PFM contraction in relation to the IAP can be important. Although continence may be dependent on the net effect of each of these factors [13], no study has comprehensively investigated multiple elements simultaneously or the potential of subtle differences in coordinative mechanisms.

Variable patterns of abdominal muscle co-activity occur during PFM contraction. PFM activity has been reported with activity of all abdominal muscles [9], selective activation of TrA [14] or co-activation of TrA and OI [10, 15]. The variation in results may be due to differences in contraction intensity (e.g. gentle vs. maximal contraction), the instruction used and the recording methods (e.g. intramuscular or surface electromyography (EMG)).

Conservative rehabilitation of PFM dysfunction requires optimisation of the muscle's function. Although PFM strength must be restored, PFM co-ordination must be established to stabilise and elevate the bladder neck. For PFM rehabilitation, it may be important to understand the relationship between PFM and abdominal muscle recruitment patterns, IAP and consequent bladder neck elevation to plan optimal and individual treatment.

This study aimed to investigate normal muscle recruitment patterns and the relationship between displacement of the bladder neck, PFM, OI, OE, RA and TrA EMG and IAP during abdominal and pelvic floor tasks with submaximal efforts. Although a co-contraction of the TrA and PFM has been demonstrated [9], it is unclear whether this pattern is also present during abdominal tasks such as Valsalva and brace which would involve OI and OE contractions. Furthermore, tasks and contractions with submaximal effort—which would appear to be predominant in daily life—have not been studied much. The specific aims of our study were: (1) to compare displacement of the bladder neck, IAP, PFM and abdominal EMG between a range of different abdominal and PFM contractions that aimed to induce different pressures and muscle activation patterns including submaximal efforts and (2) to compare activity of the PFM and abdominal muscles and IAP between maximal contractions of each muscle.

Methods

Subjects

A convenience sample of nine female volunteers without PFM disorders with a mean (range) age, height and weight of 42 (32–59) years, 165 (157–174) cm and 66 (57-72) kg, respectively, participated in the study. Four women were nulliparous and five women had one or two normal vaginal deliveries. Subjects were excluded if they had a history of back or pelvic pain in the last 6 months, hip or abdominal surgery or a history of PFM dysfunction as motor control deficits have been shown in these diseases. The Australian Pelvic Floor Questionnaire (APQF) [16] was used to screen for PFM disorders. We did not perform a vaginal examination but checked for pelvic organ prolapse on perineal ultrasound [17]. Subjects were also excluded if they had a history of laparotomy. This study was approved by the Institutional Ethics Committee and conformed to the Declaration of Helsinki.

Bladder neck displacement

Displacement of the bladder neck was assessed with perineal ultrasound (PUS) using a Logiq9 ultrasound (GE Medical, USA) with a curved transducer (3.5–6 MHz). Subjects were positioned supine with the hips and knees slightly flexed and abducted. The transducer was positioned on the perineum in the sagittal plane to view the pubic symphysis, bladder and urethra. Images were made at rest and during the experimental tasks. The position of the bladder neck was estimated using a coordinate system through the pubic symphysis [3] (Fig. 1). Displacement of the bladder neck in the anterior–posterior and caudal–cranial directions and a net displacement vector were calculated (Fig. 1).

EMG

Vaginal PFM EMG was recorded with a Periform® probe (Neen Mobilus Healthcare group, UK) that has previously been shown to record PFM EMG without recording crosstalk from adjacent muscles such as hip muscles [11, 18]. Vaginal EMG and perineal ultrasound were recorded in separate trials as placement of the intravaginal EMG probe interfered with the perineal ultrasound image.

Abdominal muscle EMG was recorded on the right side with a combination of fine-wire and surface electrodes. Fine-wire recordings were made with bipolar electrodes fabricated from Teflon-coated stainless-steel wire (75 µm, 1-mm Teflon removed, tips bent back ~1 and 2 mm, threaded into a hypodermic needle 0.32×0.50 mm/0.32×0.50 mm). Electrodes were inserted with ultrasound

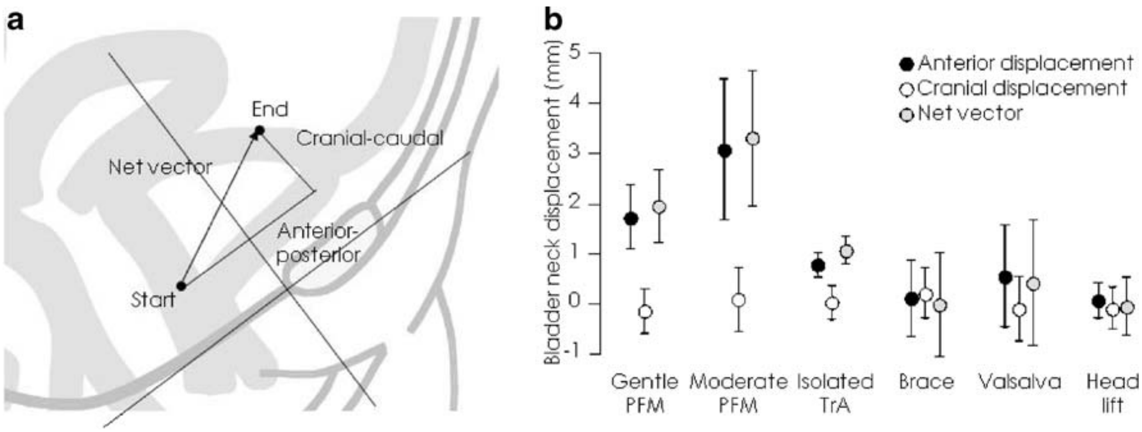

Fig. 1 **a** Measurement of bladder neck movement. The *x-axis* of the coordinate system was aligned to bisect the pubic symphysis; the *y-axis* is perpendicular to this line. The positions of the bladder neck at rest (*start*) and at contraction (*end*) are identified and the vectors are calculated as shown. **b** Bladder neck movements during the experimental tasks. Mean and standard deviation are shown. *PFM* pelvic floor muscle, *TrA* transversus abdominis

guidance (7-MHz linear vector transducer) [19] into the lower TrA (lowTrA) and the OI, ~2 cm medial and inferior to the anterior superior iliac spine (ASIS), the middle TrA (midTrA) and OE, halfway between the ASIS and the rib cage, and RA, ~2 cm lateral and inferior to the umbilicus [20]. Surface EMG electrodes were placed over OI medial to the ASIS (~15° from horizontal) and over OE inferior to the rib cage in parallel with the muscle [21].

EMG data were amplified 2,000 times, band-pass-filtered between 10 Hz and 1 kHz and sampled at 2 kHz using Spike2 software and a Power1401 Data acquisition system (CED, UK). Root mean square (RMS) EMG amplitude was calculated for 1 s at rest and during the tasks. EMG data were normalised to the maximum RMS EMG amplitude recorded for each muscle across a series of maximal contractions.

IAP

IAP was recorded with a custom-made air-filled pressure catheter inserted into the rectum. The catheter was attached to a pressure transducer (Valydine, USA), covered with a condom and lubricated. The catheter was positioned cranial to the external anal sphincter. Correct placement was confirmed when IAP increased during a “sniff” but not to direct compression by contractions of the PFM and anal sphincter muscles. Pressure data were amplified and sampled at 1,000 Hz.

Experimental tasks

Subjects performed a series of six abdominal and PF manoeuvres and standardised maximal contractions of each muscle. Subjects were positioned supine with the knees and hips flexed over a pillow.

Gentle PFM contraction Subjects gently contracted the PFM with an effort of 2 on a 15-point modified Borg scale [22] indicating a “very light effort”. The Borg scale was developed for rating an individual’s perceived exertion during exercise and was used here to standardise the effort between tasks. One investigator checked the EMG and provided feedback. Subjects were instructed to relax completely and then “gently lift and tighten the PFM with a very light effort” and maintain the contraction before breathing in.

Moderate PFM contraction Using a similar procedure to that described above, subjects performed a moderate PFM contraction with an effort of 8 on the Borg scale, indicating a “moderate” or a “somewhat hard effort”.

Isolated contraction of TrA Subjects were instructed to contract TrA with an effort of 2 on the Borg scale without activity of the other abdominal muscles. Subjects were instructed to very gently “draw in” or flatten the lower abdominal wall below the umbilicus whilst ensuring that the other abdominal muscles remained relaxed, which was confirmed by observation of the EMG recordings. Subjects were also provided with feedback from palpation of the muscle and real-time ultrasound imaging of the abdominal muscles in the lateral abdominal wall [23].

Brace contraction Subjects were instructed to brace the abdominal muscles by tightening the abdominal muscles whilst widening the waist with an effort equivalent to 2 on the modified Borg scale.

Valsalva Subjects performed a forced expiration against a closed glottis with an effort equivalent to 2 on the modified Borg scale.

Head lift Subjects performed a very gentle sit-up with an effort of 2 on the modified Borg scale.

For all tasks, subjects were instructed to take a relaxed breath in and out, completely relax the muscles and then to perform the manoeuvre without breathing. During the abdominal tasks, they were not given any instruction related to the PFM. Subjects indicated with a finger when they were relaxed and when they had performed the task to indicate the time to freeze the ultrasound and place time markers on the EMG and IAP recording. Tasks were repeated three times with a break of 1–2 min between repetitions. All procedures were completed twice: once with the intravaginal EMG in situ and once with perineal ultrasound measurement. The correct abdominal muscle manoeuvres were confirmed by EMG changes that were assessed on the computer screen by the investigator.

Standardised maximal voluntary contractions were performed at the start of the trial in the supine position. Maximal contractions were maintained for ~5 s and separated by 30–120 s. The tasks included: PFM—maximal elevation and tightening of the PFM; maximal TrA—maximal forced expiration ("huff") to residual lung volume; OI—ipsilateral rotation of the trunk in crook lying position with the arms at 90° in front of the body and resistance applied to the knee and forearms; OE—contralateral rotation of the trunk in crook lying position with the arms at 90° in front of the body and resistance applied to the knee and forearms; RA—trunk flexion with resistance applied to the upper trunk and thighs; IAP—maximal Valsalva manoeuvre against a closed glottis.

Statistical analysis

Displacement of the bladder neck and changes in IAP between tasks were compared with a repeated-measures analysis of variance (ANOVA). To determine whether the displacement and change in IAP were different to "no change", data for each task were compared to zero with a *t* test for single samples. To adjust for multiple comparisons, the significance was adjusted to $P<0.0083$ (0.05 divided by number of tasks) for this comparison.

Normalised EMG data were compared between rest and contraction and between tasks and between muscles using a repeated-measures ANOVA with two repeated measures (contraction, task) and one independent factor (muscle). Post hoc analysis was undertaken with Duncan's multiple-range test.

IAP and EMG were compared between maximal contractions of the PFM and abdominal muscles with repeated-measures ANOVA and post hoc Duncan's multiple-range test. Normalised EMG amplitude during the maximal contractions of the PF and abdominal muscles was compared between tasks (repeated measure) and muscles (EMG analysis only: independent factor) with a repeated-measures ANOVA and post hoc testing with Duncan's multiple-range test. The alpha level was set at $P<0.05$.

Results

The bladder neck was elevated between 1.0 (0.3) and 3.3 (1.5) mm during the contraction of the pelvic floor muscle (gentle and moderate) and TrA (interaction: task × measure—$P<0.0001$, post hoc: all—$P<0.0002$) but not with the brace, the Valsalva and the head lift (all: $P>0.56$; Fig. 1). The bladder neck elevation during the moderate pelvic floor contraction was greater than during all other tasks (all other tasks: $P<0.002$). Bladder neck elevation during the gentle pelvic floor contraction was greater than during all abdominal manoeuvres ($P<0.04$). Contraction of the TrA resulted in a greater bladder neck elevation than a head lift or brace ($P<0.03$). There was no difference in bladder neck elevation between the head lift, the brace and the Valsalva tasks ($P>0.33$). According to the coordinate system used in the present study, the motion was primarily in the ventral direction and there was no significant cranial motion (*y*-axis change) of the bladder neck in any task ($P>0.21$).

IAP increased in all tasks from 0.46 cmH_2O (TrA) to 1.59 cmH_2O (VAL; all: $P<0.05$; Fig. 3). Brace and Valsalva increased the IAP more than TrA contraction (main effect: task: $P<0.02$, post hoc: $P<0.02$; $P<0.002$, respectively). The IAP increase during the TrA contraction was less than during the moderate pelvic floor muscle task ($P<0.046$).

PFM EMG increased with all pelvic floor and abdominal tasks (interaction: task × contraction × muscle—$P<0.0002$, post hoc: all—$P<0.01$; Fig. 3). In the gentle pelvic floor task, the PFM EMG activity was less than in the moderate pelvic floor task ($P<0.01$) but greater than during brace, head lift and Valsalva ($P=0.01$). PFM activity was similar during a gentle PFM and TrA contraction ($P=0.179$). PFM EMG activity was greater during the moderate pelvic floor task ($P=0.014$) than all other tasks (all: $P<0.01$).

Low TrA EMG activity increased with all manoeuvres except the gentle pelvic floor task (all: $P<0.007$; gentle pelvic floor: $P=0.54$; Fig. 2). Although the increase in lowTrA EMG was not statistically significant during the gentle pelvic floor task, there was a small but variable increase in activity of this muscle for all subjects.

MidTrA EMG increased with the brace ($P<0.02$) and Valsalva ($P<0.09$) tasks (Fig. 2). There was no change in midTrA EMG with the TrA, gentle and moderate pelvic floor contractions (all: $P>0.18$).

OI EMG increased with the moderate pelvic floor, the brace and Valsalva tasks (all: $P<0.02$), but not with the

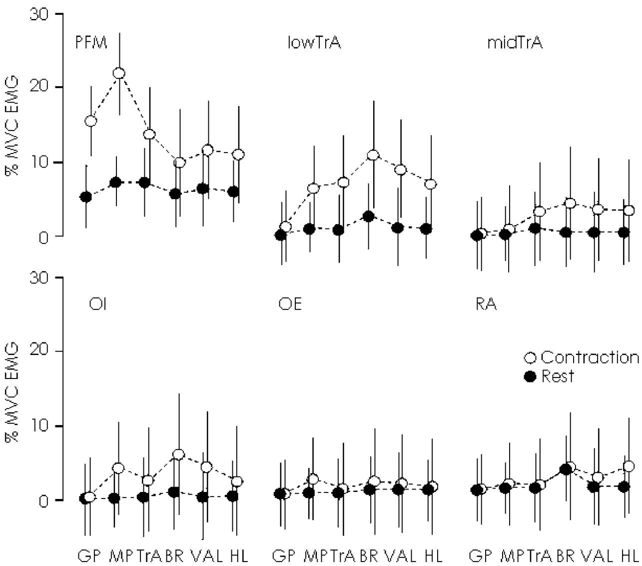

Fig. 2 Mean normalised EMG amplitude at rest and during contraction for all tasks. Mean and standard deviation are shown. *PFM* pelvic floor muscle, *lowTrA* low region of transversus abdominis, *midTrA* mid-region of TrA, *OI* obliquus internus abdominis, *OE* obliquus externus abdominis, *RA* rectus abdominis, *GP* gentle pelvic floor, *MP* moderate pelvic floor, *TrA* isolated transversus abdominis, *BR* brace, *VAL* Valsalva, *HL* head lift

gentle tasks (head lift, TrA, PFM; all: $P>0.19$; Fig. 2). EMG of the OI was greater during moderate pelvic floor contraction, the brace and the Valsalva than during gentle pelvic floor contraction (all: $P<0.02$) and greater during brace than TrA and head lift tasks (all: $P<0.04$). There was no increase in the OE EMG ($P>0.22$) or in the RA EMG ($P>0.10$) in any task.

Figure 3 shows the relationship between bladder neck elevation, IAP and abdominal muscle activity. Normalised EMG values for all abdominal muscles were summed to provide a gross estimation of total EMG of the abdominal muscles, which all contribute to the increase in IAP. The EMG, IAP and kinematic data suggest that the bladder neck is elevated during contractions of the PFM although the IAP is increased. PFM activity is sufficient to overcome the pressure and leads to elevation. During the abdominal manoeuvres (except the TrA task), the bladder neck does not elevate. In these cases, IAP is increased (to the same level that was recorded during the PFM contractions) in association with abdominal muscle activity but without sufficient PFM EMG (less than during the PFM contractions) to overcome the downward pressure of the IAP on the PFM. During the TrA contraction, despite the increase in abdominal muscle activity, the IAP was associated with PFM elevation. In this case, IAP was lower than the other abdominal tasks, but PFM EMG was not different to that recorded during the PFM contractions.

There was no difference between the IAP increase during the maximal PFM contraction compared to the maximal RA, OE and OI contractions (all: $P>0.21$). The increase in IAP was greater during the maximal Valsalva ($P<0.025$) than all tasks except the maximal TrA muscle contraction ($P=0.40$).

During the maximal PFM contraction, activity of all of the abdominal muscles increased between 8.2% (7.1%; midTrA) and 32.8% (25.3%; lowTrA) of the maximal voluntary contraction (Fig. 4). As expected, the PFM were active to a greater percentage of maximum than the abdominal muscles during the PFM task (interaction: task × muscle—$P<0.0001$, post hoc: all—$P<0.02$). There was a trend for lowTrA to be more active than RA ($P=0.07$), and there was no difference between the other muscles ($P>0.09$).

The PFM were strongly active (between 28.4% (23.6%) MVC (maximal Valsalva) and 64.8% (24.3%) MVC (maximal OE contraction)) during all of the abdominal maximal voluntary contraction tasks (OE, OI, RA, TrA, IAP; Fig. 4). The PFM were more active during the maximal PFM and the OE contractions than during the maximal Valsalva. There was no significant difference between other tasks ($P>0.05$).

Discussion

The results of this study show that bladder neck elevation during a PFM contraction is influenced by the relationship between PFM activity and IAP. Bladder neck elevation occurred consistently only during PFM and gentle TrA contractions. The abdominal tasks gentle brace, gentle Valsalva and gentle head lift increased the IAP and prevented significant bladder neck elevation. When other muscles, such as the OI, the OE and the RA muscle contracted, the PFM activity was not sufficient to overcome the greater increase in IAP and the bladder neck was not elevated. Petros et al. [8] have presented an alternative view from X-ray observations that depression of the pelvic floor during straining may be due to contraction of a pelvic muscle other than puborectalis rather than pressure. Although our data cannot show whether IAP or some other muscle force causes the reduced depression, the tight relationship between IAP, pelvic floor activity and position change imply that bladder neck elevation occurs when PFM contraction is sufficient to counteract the bladder neck descent caused by downward force of the IAP [24]. Our study also showed that a co-contraction of PFM and TrA is already present with submaximal efforts.

Methodological considerations

A number of aspects require consideration for interpretation of the results of our study. First, superficial EMG recordings have the potential for crosstalk. For the vaginal probe, crosstalk from the hip rotator and abdominal muscles has

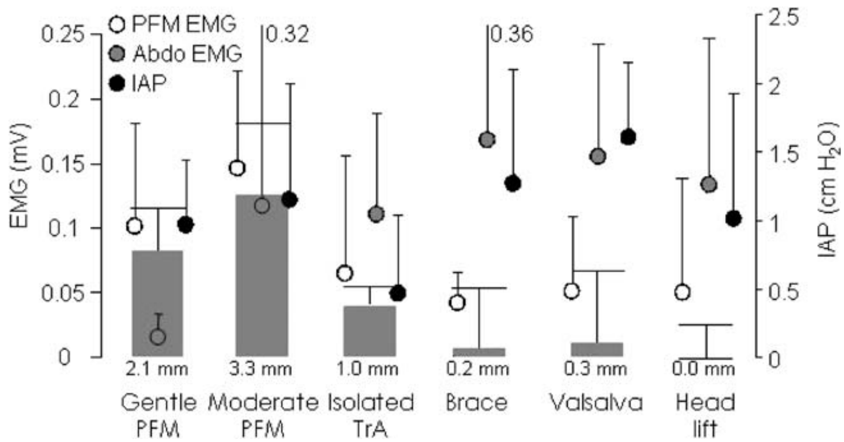

Fig. 3 Relationship between intra-abdominal pressure (*IAP*: *black dots*), pelvic floor muscle (*PFM*) EMG (*white dots*), abdominal muscle (*Abdo*) EMG (*grey dots*) and bladder neck displacement (*grey bars*) during the experimental tasks. Note that elevation of the bladder neck is related to adequate PFM activity relative to IAP. Mean and standard deviations are shown

been described [25, 26]. However, PFM recordings have been shown to be minimally affected by crosstalk during low and moderate levels of contraction similar to those used in this study [11]. Strong PFM contraction during the maximal trunk rotation tasks (OE and OI) with resistance to thigh and arms was unexpected as the IAP increase, and the associated demand on PFM activity was relatively small in these tasks. This could suggest that the high PFM activity

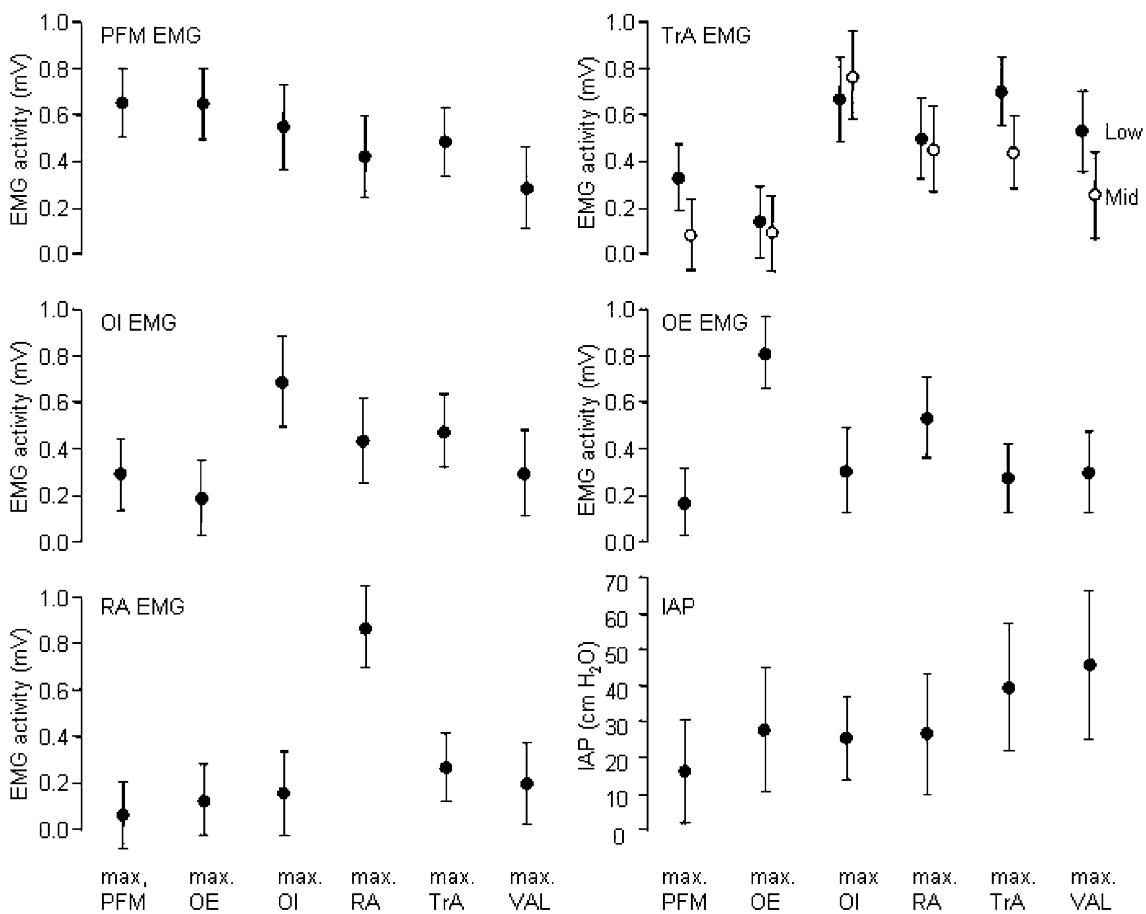

Fig. 4 Amplitude of electromyographic (*EMG*) activity and intra-abdominal pressure (*IAP*) during the standardised maximal voluntary contractions. Note the maximal activity of the target muscles and IAP during the appropriate task and the high pelvic floor muscle (PFM) activity during most tasks. Mean and standard deviation are shown. *TrA* transversus abdominis, *OI* obliquus internus abdominis, *OE* obliquus externus abdominis, *RA* rectus abdominis

in these tasks may be due to crosstalk from the hip rotator muscles.

Second, it is both an advantage and a disadvantage that fine-wire EMG electrodes record the activity from a specific area of a muscle. Fine-wire EMG is specific for a muscle but results do not necessarily apply to the whole muscle. For the purpose of this study, it was a requirement to selectively record activity of TrA, OI, OE and RA. As surface electrodes cannot differentiate between OI and TrA, fine-wire electrodes were the method of choice [19, 27].

Third, it was necessary to standardise the effort of contraction. A modified 15-point Borg scale was used for this purpose. A maximal contraction (perceived Borg scale 15) was performed at the beginning of the study which helped provide an anchor for the contractions at very gentle (2 out of 15) and moderate (8 out of 15) intensities.

Fourth, although a consistent bladder base elevation during a correct PFM contraction has been recorded using trans-abdominal ultrasound [28], this technique is affected by abdominal wall movement. Perineal ultrasound provides a more sensitive assessment of bladder neck displacement [29].

Fifth, we recruited a convenience sample of four nulliparous and five multiparous women. As they did not complain of any pelvic floor disorders and did not demonstrate pelvic organ prolapse or incontinence on ultrasound, we assumed that their motor control would be intact. For the same reason, however, we excluded women with back pain [30] and women who had undergone caesarean section.

Sixth, we chose to study tasks with submaximal effort. For comparisons and standardisation, maximal contractions were performed for each appropriate muscle and the IAP. We purposely omitted coughing, laughing, etc. because these are complex and very rapid actions requiring quick inspiration and then forced expiration involving all muscles of the abdominal capsule. As we were interested in the reaction of the pelvic floor and bladder neck when TrA, OI and OE are predominately contracted, effort and tasks with minimal interference of other muscles were selected.

Co-ordination between the pelvic floor and abdominal muscles

Although several studies have investigated activity of the PFM during abdominal muscle activation, the results have been variable. The findings of the present study may explain the discrepancies in some of the previous literature. Unlike the present study, Bø et al. [31] reported descent of the bladder measured using transabdominal ultrasound during activation of TrA and the PFM in some women. However, the present data show that when TrA muscle contractions are performed accurately with EMG confirmation, the bladder neck is elevated. Without precise concurrent measurement of abdominal muscle activity, differences in recruitment strategies may induce differences in PFM EMG, IAP and bladder neck position. Consistent with our data, Thompson et al. [32] hypothesised that different strategies for recruitment of the abdominal muscles could explain the bladder neck descent during PFM contraction. They showed that symptomatic women who depressed the bladder base during attempted PFM contraction had greater activity of abdominal muscles (recorded with surface electrodes) and less activity of PFM compared to asymptomatic women [33]. Asymptomatic women had more PFM activation and less abdominal activation. The data from our study confirm that bladder neck descent may be due to poor pattern and more exertion of abdominal muscles and therefore higher IAP with insufficient PFM contraction to prevent bladder neck descent. Nearly all previous studies have used maximal contraction of the PFM. Our data show that this involves co-activation of all abdominal muscles and increased IAP. With our intention to examine normal patterns of muscle recruitment, our participants performed standardised tasks with submaximal effort which are not as complex and rapid as coughing and laughing.

With regard to pelvic floor muscle training, some programmes focus on strength and randomised controlled trials have shown good outcomes [34]. However, these programmes have not examined whether the bladder neck is elevated or not. It was an aim of this study to examine which contractions and tasks lead to bladder neck elevation as we deem this essential for rehabilitation.

Several authors have suggested that PFM is accompanied by contraction of TrA [9, 10, 14]. All of the earlier studies involved higher efforts and therefore more co-contraction of other abdominal muscles. This is likely to explain the variation in patterns of activity that have been observed (e.g. activation of all of the abdominal muscles) [9, 33]. In some studies [10], it is unclear how much effort was used as no standardisation of a maximum contraction was reported.

Our study shows differences in the activation of the middle and lower regions of TrA when contractions of the PFM and TrA were performed. Previous work has identified morphological [35] and functional differences [20, 36–38] between regions of the abdominal wall. These differences in activity of the parts of TrA have clinical importance as TrA is usually palpated at the level of the anterior superior iliac spine. Our findings suggest that this is appropriate as the lower region of TrA was more active than the fibres in the more cranial middle region during PFM and gentle TrA contractions.

The present study confirms previous data on activation of the PFM during the Valsalva manoeuvre even with submaximal effort [3, 39]. Using intraurethral pressure measurements, it has indirectly been demonstrated that there is an active component during increased abdominal pressure during coughing, e.g. [40, 41]. Although relaxation of the PFM is required to observe maximum bladder neck descent during clinical evaluation of the pelvic organ support including the condition of the connective tissue, this does not seem to be the natural tendency and is not achieved by all women [39, 42]. As the objective of the present study was to evaluate the automatic activation of PFM, no instruction for PFM relaxation was provided during the Valsalva task. It can be argued that a Valsalva manoeuvre is different from straining per definition. A Valsalva method is used to test the patency of the Eustachian tubes or to "equalise" pressure. Simultaneous contraction of the pelvic floor appears necessary to avoid any involuntary leakage of urine or flatus and stool. During straining, e.g. when evaluating the Valsalva leak point pressure or pelvic organ support, a contracted PFM acts as a confounder [42].

Implications for pelvic floor rehabilitation

Our findings have important clinical implications for PFM rehabilitation. First, the outcomes of our study suggest that maximal contraction of the PFM is associated with activity of all abdominal muscles which increases the IAP. As women with stress urinary incontinence have been shown to have greater activation of OE during voluntary PFM contractions [33] and during postural perturbations [18], the associated IAP increase during maximal PFM contractions should be considered in the rehabilitation. Attempts to normalise the co-ordination between abdominal and PFM may be an important step in rehabilitation. This requires multifaceted assessment of the pelvic floor with consideration of bladder neck position, IAP and activity of the PFM and abdominal muscles.

The second clinical implication is that the initial activation of the PFM could be achieved by gentle contraction of TrA in some women. This might be helpful in women who have problems with the perception of their PF and who are not able to contract their PFM because of decreased PF awareness. However, it would be necessary to confirm that the PF contracts during this task as it cannot be assumed and work is required with women with PFM dysfunction to ensure that the same relationship exists in that population. An early step in training such as this could then be followed by appropriate training of PFM contraction for strength and co-ordination which are likely to be important for control of continence.

Conclusion

In women without pelvic floor disorders, we demonstrated that, although there was co-contraction of the lower part of the TrA muscle and the pelvic floor muscle during all tasks, bladder neck elevation occurred only consistently during PFM and TrA contractions. When the OI was also recruited with Valsalva, head lift and brace, the PFM co-contraction was not sufficient to overcome the greater increase in IAP to elevate the bladder neck. Because maximal PFM contraction is associated with activity of all abdominal muscles and considerable increase of the IAP, we chose submaximal efforts and confirmed that PFM and TrA are recruited concomitantly.

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Conflicts of interest None.

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ORIGINAL ARTICLE

Submaximal pelvic floor muscle contractions: similar bladder-neck elevation, longer duration, less intra-abdominal pressure

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Abstract

Introduction and hypothesis An adequate pelvic floor muscle contraction (PFMC) elevates the bladder neck (BN) and stabilizes it during increased intra-abdominal pressure (IAP). A maximal PFMC may increase the IAP and thereby prevent BN elevation. The aim of this study was to assess BN elevation during submaximal and maximal PFMC and their achievable duration.

Methods We recruited 68 women with stress urinary incontinence and 14 vaginally nulliparous continent controls who were able to perform a PFMC on vaginal palpation. Women were upright and performed a maximal PFMC as long as possible, followed by a submaximal PFMC, controlled by vaginal electromyogram (EMG). BN position was measured with perineal ultrasound, IAP and urethral pressure with a microtip catheter, and breathing with a circular thorax sensor.

Results A submaximal PFMC elevated the bladder neck 4 mm in continent and incontinent women ($p = 0.655$) and 4.5 vs. 5 mm during maximal PFMC (0.528). Submaximal PFMC was maintained significantly longer than a maximal PFMC (33 vs 12 s) with no difference between groups. A maximal PFMC resulted in BN descent in 29% of continent and 28% of incontinent women, which was not observed during submaximal PFMC. Breathing was normal in 70% of continent and 71% of incontinent women during submaximal PFMC but stopped completely in 21 and 50%, respectively, during maximal PFMC ($p = 0.011$). IAP increase was significantly greater with maximal PFMC in both groups (24 vs. 9.6 cmH_2O and 17 vs. 9 cmH_2O, respectively).

Conclusion Submaximal PFMC are sufficient to elevate the bladder neck, can be maintained longer, and breathing was not influenced.

Keywords Pelvic floor muscle contraction · Maximal and submaximal · Bladder neck · Perineal ultrasound · Intra=abdominal pressure · Extended urodynamics

Introduction

Pelvic floor muscle training (PFMT) represents the mainstay of conservative treatment of urinary incontinence (UI) in women and is recommended as first-line treatment in many practice guidelines for UI and pelvic organ prolapse (POP) [1–3]. A prerequisite of successful PFMT is a correct pelvic floor muscle contraction (PFMC) that leads to elevation of the bladder neck (BN), which can be imaged with perineal pelvic floor ultrasound (PFU). In contrast, increased intra-abdominal pressure (IAP) during coughing or straining results in sonographically demonstrable BN descent [4–6] if a pelvic floor precontraction does not prevent this [6, 7]. Easy access, application, and comprehension of perineal PFU render it an excellent assessment and teaching tool. It can also serve as a visual biofeedback tool to teach women the effect of a PFMC [8].

In a study using PFU, it was shown that BN elevation during PFMC might be inhibited by an increased IAP generated by an increase in abdominal muscle activity, especially that of the internal oblique muscle [9]. As many PFM training programs teach maximal PFMC during exercise classes, including abdominal, hip, and low-back

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muscles, an excessively increased IAP resulting in loss of BN support [10] might be one component to preclude a successful outcome. The physiological muscle reaction to an increasing IAP would be an eccentric contraction that stabilizes urethra and BN during a cough [11]. However, muscle relaxation has been described during coughing in incontinent women [12], which would compromise BN support. Theoretically, a submaximal PFMC may also support the BN, with the possible advantage of a longer contraction, which would be helpful in urgency situations until reaching the toilet and may be a valuable aspect in pelvic floor reeducation and fitness classes.

Our research group assessed BN elevation dependent on the strength of a PFMC in continent and incontinent women and presented data at the International Urogynecological Association (IUGA) meeting in 2008 [13]. We found that BN elevation does not linearly increase with increasing PFMC intensity (Fig. 1) and that a perceived effort of only 25% of a maximal PFMC led to a significant elevation in most women. At ~50% of maximal PFMC strength, the BN was elevated sufficiently, especially in relation to the nearly exponentially increasing IAP. The IAP was as high as that produced by a moderate cough in many women, which seems to contradict the aim of a PFMC to elevate the BN. This study was criticized because we used a woman's subjective estimation only to assess the level of PFMC effort using electromyelographic (EMG) confirmation. Furthermore, data were obtained with women placed in the supine position. It therefore remained unclear how long a maximal PFMC could be maintained in contrast to submaximal PFMC.

The aim of this study was to assess BN position during EMG-controlled submaximal and maximal PFMC and their achievable effective duration in continent and incontinent women in the standing position. We sought to assess the effects of submaximal and maximal PFMC on BN position, IAP, breathing, and PFMC duration with adequate BN support. We hypothesized that submaximal PFMC is sufficient to elevate the BN and can be maintained longer.

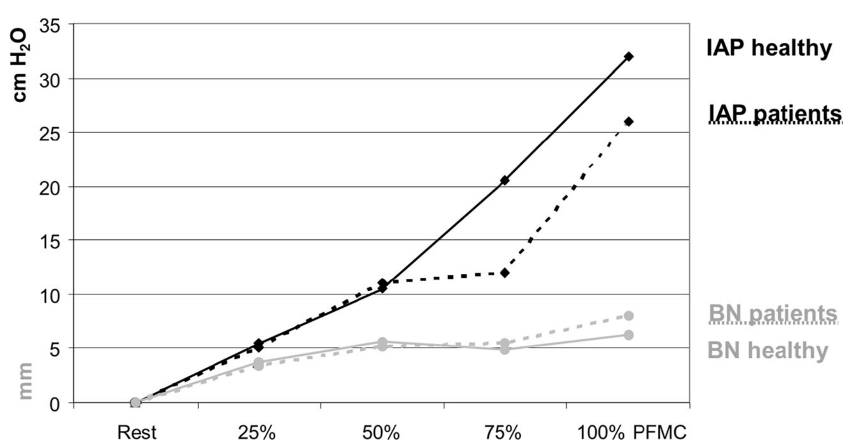
Methods

We recruited 68 consecutive women with dominant stress urinary incontinence (SUI) who were invited to take part in a randomized controlled trial comparing different pelvic floor rehabilitation regimes (clinical trial registration DRKS00004218). Fourteen continent women who had had no vaginal deliveries were recruited via advertisements and served as the healthy control group. All women completed a validated pelvic floor questionnaire (German version of the Australian Pelvic Floor Questionnaire) [14] and underwent Pelvic Organ Prolapse Quantification (POPQ) staging [15]. Both assessments were performed as a screening tool to include women with SUI with or without overactive bladder and to exclude women with prolapse beyond the hymenal remnants. The ability to perform a PFMC was checked by vaginal palpation. Exclusion criteria were age <18 years, inability to contract PFM, previous pelvic floor surgery, and POP beyond the hymen. The local Ethics Committee approved the study (EA1/297/10), and all women gave written informed consent.

A surface PFM-EMG electrode attached to a sponge (Disposable Vaginal Surface Electrode, Mediwatch, UK) was placed in the vagina at the level of the puborectalis muscle (PRM) to evaluate PFM activity and ensure that the submaximal PFMC was about half of maximal. In case of levator avulsion, the electrode was positioned higher, at the level of the pubo- or iliococcygeus muscle, or on the other side. No woman had complete loss of pelvic floor musculature strength. The sponge was soaked with lubricating gel and minimized in size to reduce interference with PFU.

BN and PRM position was assessed using perineal US. A curved-array (abdominal) probe (5 MHz, Voluson E8, GE) was placed on the perineum, with the cable vertical and the women in the standing position. A dual Microtip catheter (10 Ch) was inserted urethrally to measure the vesical/abdominal and urethral pressures [16, 17]. The transducers to measure the pressure in the urethra were placed at 3- or 9-o'clock positions, as recommended [18]. The location of the maximum urethral pressure was identified during a resting urethral

Fig. 1 Results of perceived pelvic floor muscle contractions (PFMC) with different intensities [13]. *Black* intra-abdominal pressure (cmH_2O), *gray* bladder-neck movement (mm), *dashed lines* patients, *solid lines* healthy women



pressure profile. The catheter was taped to the thigh at this position. A surface EMG electrode to record predominantly the external and internal obliquus muscles was placed just medial to the upper anterior iliac spine after cleaning the skin with an alcohol pad.

To monitor breathing, a sensor (Sleep Sense, S.L.P. Inc., USA) detecting stretching was placed around the thorax. Figure 2 shows the setting.

With a comfortably full bladder, between 150 and 300 ml, women were asked to stand relaxed and perform a maximal PFMC and maintain it as long as possible. After an appropriate rest, women were asked to perform a perceived submaximal PFMC at ~50% of their maximal and hold it for as long as they could. Women were not allowed to observe the measurement screen, thus avoiding visual feedback. Measurements were stopped when PFM-EMG decreased by ~50% or BN support was lost on perineal US.

IAP, EMG, breathing measurements, and US videos were recorded on one screen with one timeline and stored for later analyses using the software Tele Myo, Human Performance Measurements Solutions MR 3.0 (Noraxon, USA Inc.). Given the nature of the tasks it was not possible to blind the analyst regarding the task but regarding continence status. Position and height of the BN and PRM behind the rectum were measured from a horizontal line using the dorsal edge of the pubic symphysis as the reference point, as recommended by Dietz et al. [19]. The Noraxon software track points of interest (BN position and PRM) on-screen. This system is similar to the validated vector-based system [20] and allows correction of visible shifting of the probe in relation to the pubic bone during tasks, as described by Reddy et al. [20]. A ventrocranial displacement of the BN and PRM was considered a positive vector (BN elevation), whereas a dorsocaudal displacement was described as a negative vector (BN descent) [21–23]. EMG signals were filtered using a band pass between 30 and 1000 Hz [24]. To compare EMG amplitudes during maximal and submaximal PFMC, root mean squares (RMS) were computed over a period of 500 ms. Loss of BN support on perineal US was defined as visible BN descent of at least 3 mm (minimal detectable change) [25]. We considered a difference of 20 s between maximal and submaximal PFMC as clinically significant and calculated that ten women are necessary with a power of 80% and $\alpha = 0.05$ [two-sided, one-sample test, standard deviation (SD) 30 s]. To compare nonnormally distributed variables, we performed the nonparametric Wilcoxon test; for between-groups differences, the Mann–Whitney *U* test was used. SPSS 21 was employed.

Fig. 2 Measurement setting at rest. During pelvic floor muscle contraction (PFMC), women were asked not to look at the screens

Results

Incontinent women were a median age of 47 years (28–77), median BMI 24 (18-50), and parity ranged from 0 to 8 (median 1). Continent women were significantly younger (median 31 years, range 21–52; $p < 0.001$) and had a lower BMI (23, range 18–27). Parity was similar (median 1.5, range 0–3), although continent women had only cesarean sections. BN position at rest was significantly lower in incontinent women (1.9 vs 2.4 mm; $p = 0.001$). With a submaximal PFMC, it was significantly elevated to a median of 2.2 and 2.75 mm in continent and incontinent women, respectively ($p < 0.001$ for both groups, $p = 0.005$ between groups). During a maximal PFMC, BN height was marginally higher at 2.3 and 2.9 mm, respectively (fat rest, $p = 0.008$ and $p < 0.001$ in continent and incontinent women; $p = 0.002$ between groups). BN elevation (positive vector) was measured between 4 and 5 mm, showing no differences between continent and incontinent women or submaximal and maximal PFMC (Table 1).

A submaximal PFMC was maintained significantly longer than a maximal PFMC (33 vs 12 s; $p < 0.001$) in both continent and incontinent women, with no differences between groups (Table 1). During a maximal PFMC, the BN descended in 19/68 (28%) of incontinent women and in 4/14 (29%) controls. During submaximal PFMC, no BN descent was observed in either group. Breathing was irregular or stopped completely in 55 and 21% of incontinent and 36 and 50% of continent women during a maximal PFMC, respectively ($p = 0.011$). In contrast, during a submaximal PFMC, a normal breathing pattern was observed in 70 and 71% in continent and incontinent women, respectively ($p = 0.4$). Breathing patterns differed significantly between maximal and submaximal PFMC ($p < 0.001$). IAP and abdominal muscle EMG increased significantly more with a maximal vs. a submaximal PFMC in both groups, without differences between groups, and urethral closure pressure increased

Table 1 Measurements taken at maximal and submaximal PFMC: median (range), Wilcoxon test. Comparisons between groups using Mann–Whitney *U* test

	Continent controls $n = 14$			Incontinent women $n = 68$			Continent vs. incontinent women	
	Max. PFMC	Submax. PFMC	*P*	Max. PFMC	Submax. PFMC	*P*	Max. PFMC, *P*	Submax. PFMC, *P*
Duration of PFMC (s)	10 (2–34)	46 (11–76)	0.002	11 (1–29)	33 (2–73)	<0.001	0.844	0.218
BN elevation (vector, mm)	4.5 (2.0–12)	4.0 (2–8)	0.243	5.0 (0–56)	4.0 (0–28)	<0.001	0.655	0.528
BN change in height (mm)	3 (1–6)	2 (1–5)	0.031	4 (−7–11)	3 (−1–8)	0.015	0.304	0.127
PR elevation (mm)	8 (3–19)	6 (4–9)	0.024	7 (0–36)	6 (1–46)	0.002	0.594	0.901
PFM EMG increase (μV)	11 (5–95)	7 (2–144)	0.033	11 (1–50)	6 (1–50)	<0.001	0.562	0.220
Abd. EMG increase (μV)	4.0 (0–51)	0.5 (−2–23)	0.001	9.0 (−1–157)	3.0 (−3–106)	<0.001	0.362	0.119
IAP increase (cmH_2O)	24.0 (0–110)	9.6 (0–35)	0.002	17.0 (0–113)	9.0 (8–68)	<0.001	0.467	0.907
UCP increase (cmH_2O)	66.6 (12.6–134)	48.0 (10.6–85)	0.008	55.0 (0–172)	36.0 (0.1–131)	<0.001	0.855	0.789

PFMC pelvic floor muscle contraction, *BN* bladder neck, *PR* puborectalis muscle, *UCP* urethra closure pressure, *EMG* electromyography, *IAP* intra-abdominal pressure, *Abd.* abdominal muscles (superficial EMG measurements)

adequately during maximal and submaximal PFMC, also without a difference between groups (Table 1). Age, BMI, and parity did not correlate with BN and PRM movement. Figure 3 demonstrates an example of recordings of maximal and submaximal contractions.

Discussion

When both incontinent women and continent controls perform a submaximal PFMC, adequate BN elevation can be maintained twice as long as with a maximal PFMC, which lasted ~12 s in our study. A maximal PFMC resulted in a statistically and clinically significant increase in IAP due to undue activation of the abdominal muscles. Subsequently, BN descent was observed in nearly a third of continent and incontinent women. Also, normal breathing stopped in most women during maximal PFMC but rarely during a submaximal PFMC. These advantages of a submaximal PFMC should be helpful in PF rehabilitation to oppose prolonged IAP increases during repetitive coughing, walking stairs, or gardening and during urgency episodes.

Our previous data (Fig. 1) showed that the BN is not elevated linearly with increasing PFMC strength. To use BN elevation as a surrogate parameter for PFMC strength is therefore limited. In our current and previous study, the abdominal

Fig. 3 Record of vesical/abdominal pressure (Pves), urethra pressure (Pura), pelvic floor (PFM) and abdominal (ABD) muscle electromyographic (EMG) activity and breathing pattern (Resp), as well as perineal ultrasound during maximal and submaximal PFM contraction (PFMC). Note the increase in intra-abdominal pressure and abdominal muscle activity simultaneously with a maximal PFMC (highest EMG values—dotted line) while breathing stops completely. During a submaximal PFMC, breathing appears regular and intra-abdominal pressure does not raise

muscles were recruited more intensively with a maximal PFMC (Fig. 3 and Table 1), which also increased the IAP [9]. We know that an increased IAP during straining results in BN descent [26, 27]. This might counteract BN elevation and was exhibited clearly by 28% of incontinent women in whom the BN became depressed during maximal PFMC. The amount of maximal BN elevation nearly matched the 6.4 mm demonstrated by Peschers et al. [28]. Hypothetically, a submaximal 50% PFMC would lead to only a 3-mm elevation. This was already achieved with 25% of effort in our previous study (Fig. 1). A recent study showed that PRM movement highly correlated with PFM-EMG but that BN movement was more variable [29]. In agreement with our study, there was greater elevation of PRM on perineal US (PUS) than of the BN. In contrast to the directly assessed PFM action, the BN is only indirectly elevated by the endopelvic fascia and does not represent direct muscle action. Perineal US represents an excellent assessment tool with which to observe BN mobility and PFM function during coughing, straining, or PFMC [26, 30]. Women can be taught the different phases of PFM action during a contraction before IAP increases and how to maintain that contraction while expiring intensively during the cough. PFU can serve as a visual biofeedback instrument because women can easily follow instructions on the US screen. While we would encourage physiotherapists to use US during rehabilitation, it might not be essential. However, in a randomized controlled trial comparing selective activation of multifidi muscles during the motor-learning process in back pain, US implementation as a biofeedback tool was superior to explanation alone regarding selective activations [31].

BN support is an important factor in maintaining continence [6, 7, 26, 32]. Submaximal PFMC also elevates the BN and might be sufficient during coughing. Although incontinent women started with a lower BN position, they achieved a comparable BN elevation with continent women. Interestingly, the elevated BN position was similar to the resting position in continent women. Whether this BN position is sufficient to prevent urinary leakage during coughing in incontinent women remains open. Further studies will be necessary to prove the effectiveness of submaximal PFMC for treating UI.

Clinical implication

Submaximal PFMC significantly elevates the BN and can be maintained much longer without increasing IAP. High IAP might counteract BN elevation and lead to BN descent. Especially for women with OAB, it might be beneficial to practice submaximal PFMC so they have more time to reach the toilet without increasing pressure on the bladder and urethra. While we demonstrated that submaximal PFMC elevates the BN and can be held longer, it is not meant to substitute maximal PFMC with the intention to improve PFM strength and size. although formal PFM strength training did not seem to improve BN position at rest and during coughing in a study by Hung et al. [33].

Preactivation of PFM during coughing has been integrated into pelvic floor rehabilitation programs and is known as the "Knack" [34] . Sonographically, it was demonstrated that the BN descends less with a PF precontraction [4, 7]. Our data show that the BN can be sufficiently elevated with a submaximal PFMC, providing the advantages of not unduly increasing IAP and women's ability to maintain it during breathing [9]. Continent and incontinent women demonstrated similar patterns, with no differences between groups. It appears encouraging that both continent and incontinent women can activate their PFM, resulting in similar effects on BN support between them.

Common urge strategies include performing five maximal PFMC [35]. Well-maintained submaximal PFMC might be more effective, which has to be proven in randomized controlled trials. In a follow-up study, we previously showed that 79% of women improved after PFM rehabilitation with advice to perform a submaximal PFMC as an urge strategy [8].

One aim of PF strength exercises is muscle hypertrophy [36], which results in a reduction in hiatal area when the PFM are at rest, most likely due to muscle thickness increase [37]. This might not be achieved with submaximal contractions. However, hypertrophy can only be maintained with regular life-long exercises with protocols following strength-training programs.

Strengths and limitations of the study

The strengths of this study include validated measurement and assessment tools in a physiological standing position. The digitalized assessment of BN and PRM on PFU was indispensable and had been validated previously [20]. The required sample size was reached in both continent and incontinent women. Furthermore, the person analyzing the measurements offline was blinded to continence status. PFMC strength was controlled by pelvic floor EMG. The study is limited by the lack of an age-, BMI-, and parity-matched control group. Also, selection of vaginally nulliparous controls resulted, ase expected, in a higher BN resting position [28]. Further limitations are that blinding the assessor to maximal or submaximal PFMC was impossible. It remains unclear how BN and PRM are influenced in women who cannot contract their PFM. IAP was measured intravesically to avoid insertion of a rectal line, and equal pressure distribution can be expected [38].

Concluding message

Submaximal PFMC significantly elevates the BN and can be maintained for more than twice as long as maximal PFMC.

Maximal PFMC does not elevate the BN much further and has the disadvantage of considerably increasing the IAP. Especially in women with pelvic floor disorders, this might offset the initial functional BN elevation and result in increased urgency. Implementation of submaximal PFMC training might therefore be beneficial in incontinent women. Submaximal PFMC might not replace PFM strengthening programs if muscle power and augmentation is required to improve PF symptoms.

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Compliance with ethical standards

Conflicts of interest None.

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Bladder-neck effective, integrative pelvic floor rehabilitation program: follow-up investigation

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ABSTRACT

Objectives: To evaluate the effectiveness of a pelvic floor rehabilitation program consisting of pelvic floor (PF) and transverse abdominal muscle (TrA) pre-contraction, coordination training and sustained submaximal contractions employing a validated pelvic floor questionnaire.

Study design: Fifty-five consecutive women with stress urinary incontinence ($n = 9$), overactive bladder ($n = 9$) or mixed symptoms ($n = 37$) were invited to participate. The German version of the Australian pelvic floor questionnaire was completed by all women before and after treatment, and additional validated improvement and satisfaction scales assessed patient-centered outcome. Individual treatment programs were selected according to the dysfunction evaluated by vaginal palpation and perineal ultrasound. Bladder-neck effective pelvic floor contraction was ensured using perineal ultrasound. Co-contraction of TrA was incorporated. Active integration of the pelvic floor contraction into daily life and individual incontinence triggering activities was practiced (duration, submaximal contraction, maintenance, pre-contraction before breathing, getting up and urgency).

Results: Of 46 women with stress urinary incontinence symptoms, 67% and of 46 women with OAB symptoms 78% were improved or cured. Bladder, bowel and sexual function domain scales improved significantly after 1–6 sessions (median 2). Pre-contraction of PF and TrA was routinely performed by 39 of 55 women (71%) resulting in less incontinence.

Conclusion: The bladder-neck effective, integrative pelvic floor rehabilitation program is highly effective for SUI and OAB. Although PF strengthening with maximal contractions was omitted, these results are comparable with strength programs in the literature. Due to the integration of submaximal PF contractions into daily life and individual incontinence situations, life-long strength training might be unnecessary, and this has to be studied further.

1. Introduction

There is no doubt that pelvic floor rehabilitation should be offered to most patients complaining of urinary and/or anal incontinence [1,2]. The best treatment regime, however, is not known [1]. Most treatment programs consist of pelvic floor muscle (PFM) strengthening and many do not involve integration of pelvic floor (PF) activity into daily life [1]. These programs are based on principles of regular skeletal muscle strength training resulting in an increased cross-sectional area (hypertrophy) of muscles with type II muscle fibers [3]. Up to 80% of the PFM, however, consists of type I muscle fibers (slow-twitch fibers) [4] mainly responsible for tonic activity and endurance. The PFM is part of the abdominal capsule, a muscle cylinder that stabilizes the trunk, together with the transverse abdominal muscle (TrA), the multifidi muscles and the diaphragm [5]. In healthy women, the TrA co-contracts with a PFM contraction [6–8]. There is also a PFM pre-contraction as a postural response before trunk perturbation [9], but this pre-contraction might get lost in incontinent women [9]. In a clinical study it has been demonstrated that teaching a PFM pre-contraction (the so-called "Knack") [10], e.g. in advance of a cough, can prevent urinary leakage [10] and reduces bladder neck (BN) descent [11]. Significant reductions in urine loss were achieved within one week, which is too early to be a result of PFM strength increase and hypertrophy [12].

Taking the above findings into account, we developed a specific pelvic floor rehabilitation program. Perineal ultrasound is used to assess PFM function, to teach a BN effective PFM contraction and especially a pre-contraction ("Knack"). Abdominal ultrasound is employed to ensure the physiological co-contraction of the TrA and to avoid pathological co-activity of the oblique abdominal muscles. Maximal PFM contractions are omitted to prevent undue increases

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in intra-abdominal pressure (IAP) [8] and to allow for longer PFM contractions. Finally integration of correct PFM activity into daily life is practiced.

The aim of this study was to prospectively evaluate the effectiveness of this pelvic floor rehabilitation program with focus on motor control and integration into daily life, employing ultrasound as a visual biofeedback method and a self-administered validated pelvic floor questionnaire [13].

2. Materials and methods

Terminology conforms to the standardization of the International Urogynecological Association (IUGA) and International Continence Society (ICS) [14]. Initial assessment was performed by one physiotherapist, experienced in the rehabilitation of TrA, multifidus and PFM and in the use of ultrasound for rehabilitation. Follow-up assessment was performed by one independent health care provider, (E.S.), registrar in urology. This study was approved by the Institutional Ethics Committee and conformed to the Declaration of Helsinki. Informed written consent was obtained.

Women with stress urinary incontinence (SUI) or overactive bladder symptoms (OAB) who were referred by gynecologists, urologists or general practitioners were consecutively invited to participate. Exclusion criteria were neurogenic bladder dysfunction, pelvic organ prolapse stage II or more [14], previous pelvic floor surgery, or inability to voluntarily contract the PFM on vaginal palpation (Oxford = 0) [15].

The validated German version of the Australian pelvic floor questionnaire [16] was completed by all patients at their first consultation to assess bladder, bowel, prolapse and sexual symptoms with severity scores, bothersomeness and quality of life. After the rehabilitation program, it was completed again by all women including a validated post-treatment module with improvement scales for all domains (much better, a little better, no change, a little worse, much worse) and a visual analog scales (VAS) from 0 (not at all satisfied) to 100 (very satisfied) to assess satisfaction with care and with treatment [13]. Additional questions evaluated the patient' compliance and self-judged integration of the PFM into daily-life.

SUI, urgency and urge incontinence were defined according to the validated PF questionnaire. OAB symptoms included urgency with or without urge incontinence. Mixed incontinence was assumed when SUI and OAB were present concomitantly. Cure was defined when symptoms ceased after rehabilitation, and improvement when frequency of symptoms was reduced according to the PF questionnaire [13].

A vaginal examination of the pelvic floor muscle was performed at rest and during contraction. Functional aspects were palpable contraction, maintained contraction during inspiration and during consecutive breaths (co-ordination and endurance) and pre-contraction before a cough. Insufficiencies were noted and guided the individual rehabilitation.

Perineal ultrasound was applied to evaluate pelvic floor activity and BN position at rest, during breathing, speaking, coughing and during a voluntary PFM (SonoSite 180 plus, C60 curved transducer with 5–2 MHz).

Abdominal palpation and ultrasound were used to assess transverse abdominal and internal and external oblique muscle activation [17]. Ultrasound was performed medial to the anterior superior iliac spine, standing or supine as convenient (SonoSite 180 plus, L25 linear transducer with 10–5 MHz). This probe position corresponds to the lower part of the TrA [18] which specifically co-contracts with submaximal PFM contractions [8].

A specific PF rehabilitation program was devised according to motor learning principles and to the individual dysfunction identified on palpation and ultrasound. Goals included a bladder neck effective contraction on perineal ultrasound with submaximal contractions, a PFM contraction before an increase in abdominal pressure (pre-contraction, e.g. before coughing), a PFM contraction that can be maintained during breathing and coughing, a co-contraction of the TrA evaluated by palpation and with ultrasound, and integration of PFM pre-contractions into daily life, especially in individual situations that lead to urinary incontinence.

Fig. 1. Use of perineal ultrasound as a visual biofeedback instrument for assessing, teaching and controlling movements of the bladder neck.
Full consent has been given to publish this photo.

Elimination of internal and external oblique muscle activation was sought and maximal PFM contractions were avoided to omit undue increases of abdominal pressure [8]. Treatment included instructions to maintain a submaximal PFM contraction during breathing, urgency, and on the way to the toilet, e.g., and to pre-contract before coughing, lifting, blowing the nose, etc.

Responses to the instructions were checked on vaginal palpation and ultrasound. Patients were shown the effects of their PFM contraction on the BN position and their TrA co-contraction on the ultrasound screen (visual biofeedback). Visible bladder neck elevation was practiced employing perineal ultrasound during breathing and coughing and individual symptoms (Fig. 1). Whenever feasible, perineal ultrasound was used as a biofeedback instrument, e.g. standing, bending over or lifting.

Behavioral advice was given when OAB symptoms were present. This included instructions on submaximal PFM contractions with the urge sensation and to maintain the contraction until the urge subsides. The same applied to fecal urgency. Women were also advised to perform a gentle PFM contraction before a typical urge trigger, e.g. before the key is inserted into the lock or before the tap is opened. If appropriate, recommendations on voiding and defecation were given. No formal strength training or standardized home-training was added. Finally, patients were encouraged to integrate all components of the program into their daily life, sports activities and incontinence situations. The initial treatment session lasted approximately 60 min. Further appointments were scheduled as necessary.

SPSS 19.0 was used for statistical analyses. Descriptive methods as well as *t*-tests and non-parametric tests according to the distribution of the variables were employed. Chi-square or Fisher's exact test as appropriate were used for assessment of risk factors (like age or BMI).

3. Results

Fifty-five consecutive women were included: no one declined participation. Four women were excluded before inclusion because

Table 1
Median domain scores (range) of the Pelvic floor questionnaire before and after treatment (Wilcoxon test).

	Before treatment	After treatment	p
Bladder function	2.6 (0.7–5.1)	1.3 (0–3.1)	<0.001
Bowel function	1.8 (0–1.8)	1.2 (0–7.1)	<0.001
Prolapse symptoms	0.9 (0–6)	0.7 (0–7.3)	0.072
Sexual function	1.2 (0–5.2)	0.7 (0–4.3)	0.006
Global PF dysfunction score	6.5 (2.0–11.4)	3.9 (0.4–11.8)	<0.001

they were unable to contract the PF (Oxford = 0). According to the PF questionnaire, nine women had pure SUI, 9 pure OAB symptoms and 37 mixed OAB and SUI. Patients had 0–4 children (median 2). The body mass index ranged between 16.9 and 32.0 kg/m^2 (median 23.5.). The specific PF rehabilitation program consisted of 1–6 sessions (median 2) lasting 15–90 min each, with a total of 60–240 min treatment time (median 120 min, mean 133 min) during a period of 4–6 weeks. Follow-up ranged from 1 to 16 months (median 7, mean 7.6). Nearly two-thirds of women (63%) had a follow-up of more than 6 months.

All included women were able to contract the PFM on palpation. Visible BN elevation and maintenance of the PF contraction on ultrasound was achieved by all women in the program. Of 46 women with SUI (pure or mixed), 31 (67%) were cured ($n = 17$) or improved ($n = 14$) after rehabilitation ($p = 0.001$; Wilcoxon test). OAB symptoms ceased ($n = 25$) or improved ($n = 11$) in 36 of 46 (78%) women ($p = 0.002$; Wilcoxon test). Subjective improvement of bladder function was reported by 91% (50 of 55) (a little better = 22; much better = 28). Five women (9%) considered themselves as unchanged. Bladder, bowel and sexual function domain scales improved significantly after treatment (Table 1). No woman reported deteriorating symptoms. Reduced frequency of pad use was associated with bladder domain score and subjective improvements ($p = 0.032$). Improvement of symptoms did not depend on length of follow-up or number of appointments and did not decline over time ($p > 0.05$). Median satisfaction with outcome was 80 (15–100) and satisfaction with care was 90 (40–100) ($p < 0.001$).

After the rehabilitation, 39/55 (71%) women reported they routinely contracted their PFM before coughing, lifting, etc. (pre-contraction). Women who performed pre-contractions were more likely to report fewer SUI symptoms (Chi-square test; $p = 0.021$). There was a significant correlation between frequency of pre-contractions (3-never, 0-always) and patient satisfaction with treatment (Spearman −0.36; $p = 0.006$). During the follow-up period women did not request further treatment (pelvic floor physiotherapy, pelvic floor surgery and anticholinergic drugs).

4. Comments

This study showed that a specific PF rehabilitation program employing pre-contraction, coordination training, vaginal palpation and perineal ultrasound as an assessment and biofeedback tool is feasible and effective for SUI and OAB, with improvement/cure rates of 67% and 78%, respectively. These results are comparable with PFM strength programs in the literature [1,19]. PFM strengthening programs require life-long training and adherence, and long-term results are discouraging [20]. In our study, SUI and OAB improved after approximately 2–3 sessions within 4–6 weeks of commencement of the program and persisted for more than 6 months without further supervised PFM training. An important component of our treatment program was the coordination of sustained submaximal pre-contractions and their routine integration into daily life, sports activities and urge episodes. We believe that these features were responsible for the excellent success rate for OAB.

To our knowledge, this is the first study that did not focus on PFM strength. In contrast it relied on PF awareness, coordination, and visualization of the BN effective PFM contraction and sustained submaximal PFM contraction. The biological rationale was not hypertrophy [2] but a retraining of known physiological continence mechanisms [9,10,21], such as the "Knack".

That specific rehabilitation might be more efficient than strength training was shown in a randomized controlled trial of a specific multifidus and TrA muscle rehabilitation program vs. standard treatment in patients with lumbar back pain. Pain recurrence rates at 1 and 3 years were significantly lower after only four treatment sessions [22,23]. The cross-sectional area of the muscle recovered after 4 weeks, which is too early to be a result of hypertrophy. The specific rehabilitation involved selective contraction of multifidus muscle without other extensors of the spine, selective contraction of TrA without other abdominal muscles, and co-contraction and a pre-contraction of both muscles before postural movements and loads. The postural load represents a similar challenge for stabilization of the spine as the increase in IAP for the PFM and the bladder neck.

In patients with an acute first episode of lumbar back pain [22], the deep multifidus muscle was observed to decrease in size within 24 h and displayed signs of denervation and atrophy. This cannot be a "real" atrophy in this short time period, and the term "pain inhibition" was first used by these authors. The muscle was restored and symptoms alleviated by a specific muscle rehabilitation, similar to those used here in the present study, resulting in a cross-sectional area that was similar to the uninjured side [22].

The principles of the BN effective, integrative rehabilitation program are: correct and selective muscle contractions that elevate the BN, physiologic coordination of muscle recruitment, and specifically the integration of PFM pre- and co- contraction. Of course, the patient' compliance and mental health are fundamental prerequisites. This is also very important for the integration of PFM activity into daily life. Our patients were taught BN-effective pre-contractions before lifting, getting up, coughing and other activities which increase the IAP. Those 71% of our patients who reported routine pre-contractions also reported fewer incontinence symptoms and more satisfaction with treatment. Whether there will be a change from a voluntary pre-contraction to an automatic one remains unclear. Following the basics of motor learning, automatism is the goal of integration of pre-contractions into daily life. As "staying dry" is an immediate positive feedback and gratification of a pre-contraction, adherence to this strategy is encouraged and may result in a restored automatism. Life-long PFM strengthening exercises might therefore not be necessary. However, the long-term efficacy of our rehabilitation program has yet to be assessed.

Perineal ultrasound is the instrument of choice to measure BN mobility [24]. It can facilitate teaching of a correct PFM contraction that elevates the BN and is therefore useful as a biofeedback instrument. In a recent study it has been shown sonographically that even gentle PFM contractions elevate the BN [8]. Although a maximal PFM contraction also elevated the bladder neck, it considerably increased the IAP to levels seen during nose blowing or a moderate cough [8]. The fast results (4–6 weeks after beginning and with only 2–3 treatment sessions) are perhaps a result of the visual biofeedback that increased patients' awareness and knowledge on their PF function. Whether our results can be achieved without ultrasound remains unclear. Once a bladder-neck effective PFM contraction is assured, however, rehabilitation might proceed without ultrasound.

Ultrasound was also used to teach and control correct TrA-contraction without internal oblique activity. The position of the ultrasound transducer referred to the lower part of the TrA that is activated already with gentle PFM contractions [8].

There was a wide range in the number of treatment sessions from 1 to 6 and treatment duration from 15 to 90 min in our study. Patients with difficulties in relaxing their PFM or reduced awareness needed more time until they were able to perform a correct contraction. Furthermore, women with OAB and bowel symptoms required more attention. Short treatment sessions of only 15 min were sometimes necessary to supervise a patient and to help with perception and with correct performance.

Urge coping strategies are established and successful [25]. One strategy is to immediately contract the PFM to inhibit the detrusor contraction [26]. Our rehabilitation program improved OAB in 78%. This excellent result may be due to a submaximal PFM contraction that can be maintained longer, e.g. until the toilet is reached. Furthermore, a submaximal contraction does not increase the IAP as much as a maximal PFM contraction [8], which might result in BN descent and funneling of the proximal urethra.

We also noted significant improvement in the bowel and sexual domains of the PF questionnaire. Although we did not specifically recruit women with concomitant anal incontinence or sexual problems, these results are encouraging. Very few women reported prolapse symptoms which subsequently did not improve significantly. Whether our PF rehabilitation program can also reduce prolapse symptoms remains open.

We explicitly assessed satisfaction with treatment outcomes and satisfaction with care. Satisfaction with care was significantly higher. Women might be absolutely content with the care given by the physiotherapist although treatment results might not have been as satisfactory. This shows that women are able to differentiate between good care and good treatment, and satisfaction rates should distinguish between them. During the validation process of the PF questionnaire including the post-therapeutic module [13], the questionnaire correlated well with pad use reduction and subjective measures. We therefore chose not to add tests, e.g. a pad test, to keep patients as compliant as possible.

The strengths of the study are that validated assessment tools like the perineal and abdominal muscle ultrasound and PF questionnaire with improvement and satisfaction scales were used and that follow up assessment was performed by an independent examiner. The limitations include the lack of a control group or randomization to standard or specific treatment as well as a non-scheduled follow up. A randomized controlled trial is currently in progress to compare this specific PFM rehabilitation with standard electromyograph (EMG)-biofeedback training.

Pre-contraction and coordination training of the PF with BN-effective submaximal contractions and subsequent integration into daily life is a suitable treatment regime in women with PF disorders. Obviously further studies are needed to prove the long-term efficiency of this program.

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