

Functional assessment of the pelvic floor muscles by electromyography: is there a normalization in data analysis? A systematic review

Avaliação funcional dos músculos do assoalho pélvico pela eletromiografia: existe a normalização na análise de dados? Uma revisão sistemática

Evaluación funcional de los músculos del suelo pélvico por la electromiografía: ¿la normalización existe en el análisis de datos? Una revisión sistemática

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ABSTRACT | This study aims to evaluate the method of analysis of electromyographic data considering the functional assessment of pelvic floor muscles (PFM). We have included in our search strategy the following databases: Medline, PubMed, Cochrane Central Register of Controlled Trials and Cochrane Database of Systematic Reviews, PEDro, and IBECs, considering articles published in the last ten years (2004-2014). The identified articles were independently examined by two evaluators, according to these inclusion criteria: (1) population: female adults; (2) PFM assessment by electromyography (EMG) with vaginal/anal probe; and (3) description of how electromyographic data analysis is performed. The Newcastle-Ottawa Scale (NOS) was used to assess the risk of bias. We identified 508 articles, of which 23 were included in the review. The data showed differences between the collection protocols, and a significant number of studies did not normalize the electromyographic data. Physiotherapists are among the clinicians who most frequently use EMG to evaluate the function and dysfunction of the neuromuscular system. Although some previous studies have provided an overview to guide the evaluator in the assessment, few succeeding studies followed their recommendations.

Keywords | Pelvic Floor; Electromyography; Review.

RESUMO | Este estudo objetiva analisar o método de análise dos dados eletromiográficos na avaliação funcional dos músculos do assoalho pélvico (MAP). As bases de dados consultadas foram: Medline, PubMed, Cochrane Central Register of Controlled Trials e Cochrane Database of Systematic Reviews, PEDro e IBECs, considerando-se artigos publicados nos últimos dez anos (2004-2014). Os artigos identificados foram avaliados independentemente por dois avaliadores, de acordo com os critérios de inclusão: (1) população: mulheres adultas; (2) avaliação dos MAP utilizando a eletromiografia (EMG) com sonda vaginal ou anal; (3) descrição de como é feita a análise dos dados eletromiográficos. O instrumento Newcastle-Ottawa Scale (NOS) foi usado para avaliação da qualidade metodológica dos estudos. Foram identificados 508 artigos, dos quais 23 foram incluídos na revisão. Os dados mostraram diferenças entre os protocolos de coleta, e um número significativo de estudos não utilizaram a normalização na análise dos dados eletromiográficos. Os fisioterapeutas estão entre os profissionais que mais utilizam a EMG para avaliar a função e disfunção do sistema neuromuscular. Apesar de alguns estudos anteriores fornecerem uma visão geral para orientar o avaliador no uso deste instrumento, poucos estudos subsequentes seguiram suas recomendações.

Descritores | Diafragma da Pelve; Eletromiografia; Revisão.

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RESUMEN | Se evaluó, en este estudio, el método de análisis de los datos electromiográficos en la evaluación funcional de los músculos del suelo pélvico. Las bases de datos consultadas fueron: Medline, PubMed, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, PEDro y IBECS. La investigación fue refinada considerándose artículos publicados en los últimos diez años (2004 a 2014). Se evaluaron de forma independiente los artículos identificados por dos evaluadores, según los siguientes criterios de inclusión: (1) población: mujeres adultas; (2) evaluación de los músculos del suelo pélvico utilizándose la electromiografía (EMG) con sonda vaginal o anal; (3) descripción de cómo es el análisis de los datos electromiográficos. Se utilizó

el instrumento Newcastle-Ottawa Scale (NOS) para evaluar la calidad metodológica de los estudios. Se identificaron 508 artículos y 23 de estos fueron incluidos en la revisión. Los datos mostraron diferencias entre los protocolos de recolección y un número significativo de estudios no utilizaron la normalización en el análisis de los datos electromiográficos. Los fisioterapeutas están entre los profesionales que más utilizan la EMG para evaluar la función y disfunción del sistema neuromuscular. Aunque algunos estudios anteriores proporcionen una visión general para orientar el evaluador en el uso de este instrumento, pocos estudios posteriores han seguido sus recomendaciones.

Palabras clave | Diafragma de la Pelvis; Electromiografía; Revisión.

INTRODUCTION

The correlation between pelvic floor muscles (PFM) strength and dysfunctions in this region is still an open field of research, with few published data. Several functional PFM assessment methods are used in clinical practice and research, such as digital palpation, perineometry, surface electromyography (sEMG), dynamometry, and imaging modalities, such as ultrasonography and magnetic resonance imaging^{1,2}.

Among these assessment methods, electromyography (EMG) outstands as an alternative method to monitor muscle tone at rest, muscle strength, and muscular endurance, and to obtain data on the normal and abnormal physical functions of the PFM. EMG is indicated as a reliable and objective muscle evaluation method that causes no harm to patients^{3,4}.

EMG monitors the electrical activity generated by the depolarization of muscle fibers, as a function of voltage effect over time. It is the algebraic sum of all the signals detected in a certain area and can be considered as an indirect measurement of muscle strength. The electrical activity can be collected either with surface or intramuscular electrodes^{1,5}. Because PFMs lie deep to the skin surface and the superficial and deep layers of PFMs have distinct functions, to use surface electrodes adhered to the perineum is not ideal to study the deep layer of the PFMs, as unwanted activity (crosstalk) would inevitably be recorded from the superficial PFMs and potentially from other nearby muscles including the anal sphincter, the gluteus, and the obturator hip musculature. Considering that deep PFMs lie adjacent to the vaginal walls, electrodes positioned against the

lateral vaginal walls are a convenient mean to record their EMG activity⁶.

Thus, in clinical practice, surface electrodes (vaginal and anal probes) are more widely used due to the high sensitivity of the perineal region and the skills required in using the needle or fine-wire electrodes^{2,7}.

The characteristics of the amplitude and frequency of EMG signal are sensible to intrinsic (type of muscle fiber, depth, diameter and amount of tissue between the muscle and electrode) and extrinsic factors (location, orientation and shape of the area of the electrodes). Therefore, the signal amplitude cannot be analyzed directly^{3,5,8}.

The “normalization” is required to analyze and compare EMG signals from different individuals, muscles and acquisition. It is a form of transforming the absolute amplitude values into relative values relating to an amplitude value characterized as 100%⁸. There are several forms of normalization of EMG signal. Among them, the most used is the normalization by maximum voluntary contraction (MVC), in which the reference to the standards is the highest value found among certain muscle contractions in question⁹.

Normalization prevents interference on the intensity of contraction, since they remove the effect of other factors that influence the signal capture. Thus, we can compare different muscles and individuals to the amount of energy produced during a certain contraction only after the process of normalization⁵.

However, no normal standards or references have been established for EMG or differences in the methodology, types of probe and collection protocols used. The way these data are analyzed can make the comparison of studies and systematic assessments of results found difficult.

Thus, the aim of this study was to evaluate the methods of analysis of EMG data in studies that encompass the PFM functional evaluation.

METHODOLOGY

Eligibility criteria

Inclusion and exclusion criteria are:

- Inclusion criteria:
 - Scientific articles published in the last ten years (2004–2014), which aimed to perform pelvic floor muscles (PFM) functional assessment using EMG;
 - Articles published in English and in full.
- Design
 - Full-text articles of cross-sectional studies.
- Participants
 - Female adult participants.
- PFM functional assessment
 - Performed using sEMG with a vaginal/anal probe;
 - With a description of how the analysis of EMG data is performed.
- Exclusion criteria:
 - Studies including children and adolescents;
 - Studies including men;
 - Animal experiments;
 - Treatment with EMG biofeedback, without EMG rating;
 - Other exams that included EMG (urodynamic, for example);
 - Modified custom probes;
 - Review articles, guidelines and other studies with different design.

Information sources and search

To select studies related to the topic investigated, we have performed a computer-aided and manual search between September 2013 and February 2014. The consulted databases included: Medline PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of Systematic Reviews, PEDro, and IBECs. We have limited the search to English-language manuscripts published

between 2004 and 2014. Articles published in full and available in the databases were included in this study. Our search strategy was broad, aiming to have as many manuscripts as possible to make a good triage. The following keyword was used: “pelvic floor electromyography”. Articles identified in the initial search strategy were selected according to the inclusion criteria.

This review followed the methodological quality parameters of systematic reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria were observed.

Data collection process

A standardized data extraction form was used to collect the following data: authors, year, publication, country of origin, study design, sample, age (years), probe used, data collection protocol and whether the normalization of electromyographic data was performed. This process was performed using two independent raters (AMR and ECLMV).

Risk of bias assessment

The risk of bias was assessed using the Newcastle-Ottawa Scale (NOS). The original NOS was developed to assess the quality of the observational studies; it contains eight items that analyze three dimensions: selection, comparability and outcome (in cohort studies) or exposure (case-control studies). There is a series of options for each item, which reflects the quality of the studies and is scored by a star: the higher the number of the star, the higher is the study quality¹⁰.

A study may receive a maximum of one star for each numbered item within the “selection” and “outcome” categories. A maximum of two stars may be given for “comparability”. The total score is nine: four stars in “selection”, two stars in “comparability” and three stars in “outcome”¹⁰.

Summary measures

The variables analyzed were: type of probe used in the collection of EMG data; collection protocol; and normalized EMG data. Data was summarized in tables. A qualitative analysis was undertaken due to trial heterogeneity and lack of standardized outcome measures. Therewith, a meta-analysis was not performed.

RESULTS

Study selection

A total of 213 publications were identified from MEDLINE, 221 from PubMed, 51 from CENTRAL and the Cochrane Database of Systematic Reviews, 18 from PEDro, and five from IBECS, resulting in 508 related

publications. Of the articles identified, 107 were selected after applying the established inclusion and exclusion criteria. Only 23 articles were included for this review (Figure 1).

Assessment of quality of manuscripts

Table 1 summarizes the results of the methodological quality assessment.

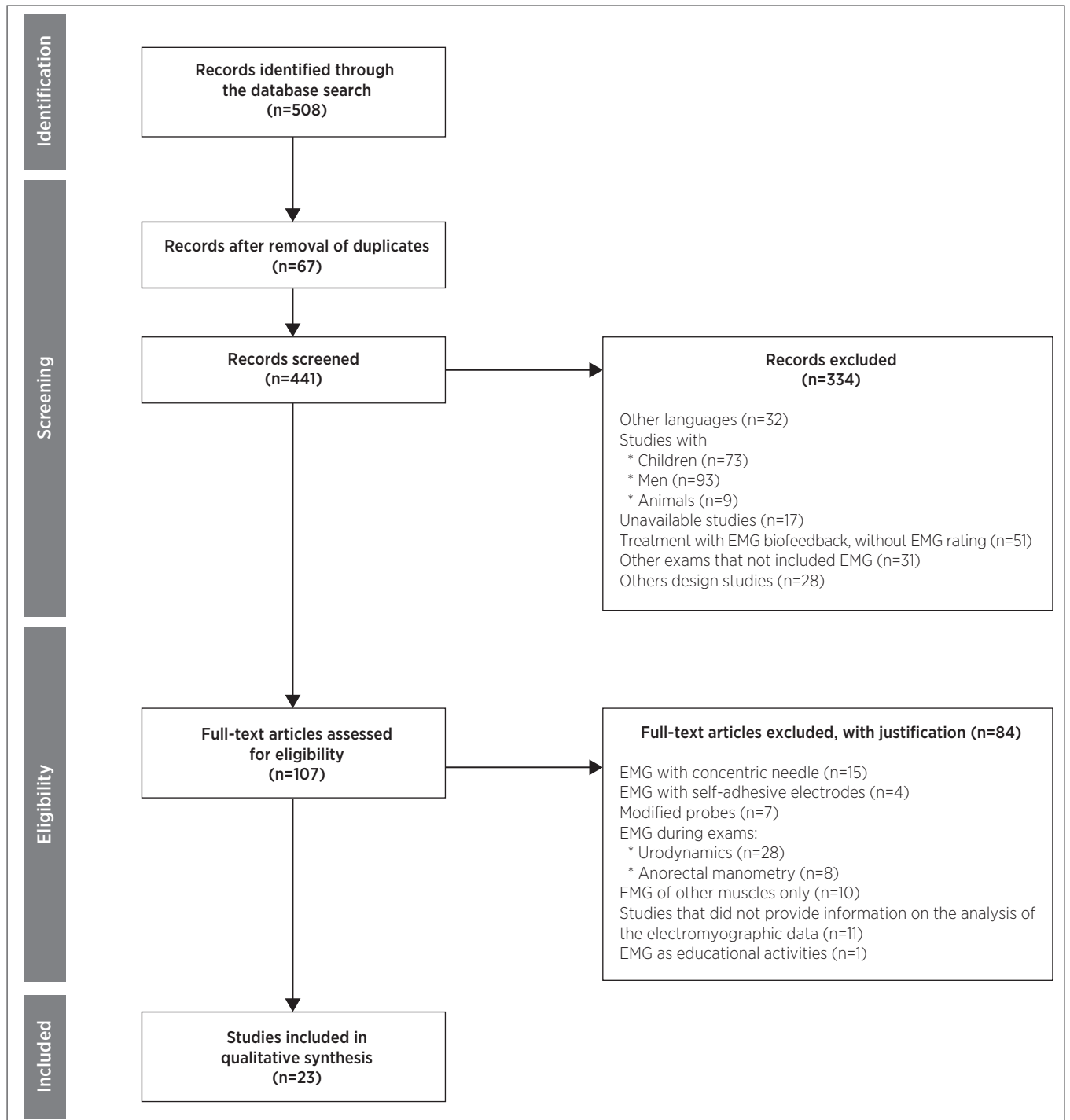


Figure 1. Flowchart with the numbers of articles identified, excluded, and included in the systematic review

Table 1. Evaluation of the methodological quality of selected studies.

References	Selection	Comparability	Outcome
Auchincloss and McLean ¹	***	-	*
Botelho et al. ³	***	-	*
Chen et al. ¹²	***	-	*
Devreese et al. ¹³	***	*	*
Frederice, Amaral and Ferreira ⁴	***	-	*
Grape, Dederig and Jonasson ¹⁵	***	-	*
Halski et al. ¹⁶	***	-	*
Halski, Ptaszkowski, Słupska and Dymarek ¹⁷	***	-	*
Junginger, Baessler, Sapsford and Hodges ¹⁸	***	-	*
Lauper, Kuhn, Gerber, Luginbühl and Radlinger ¹⁹	***	*	*
Luginbuehl et al. ²⁰	***	*	*
Pereira et al. ²¹	***	*	*
Petricelli et al. ²²	***	-	*
Resende et al. ²³	***	*	*
Resende et al. ²⁴	***	-	*
Sapsford, Richardson, Maher and Hodges ²⁵	***	*	*
Smith, Coppieters and Hodges ²⁶	***	*	*
Smith, Coppieters and Hodges ²⁷	***	*	*
Soljanik et al. ²⁸	***	-	*
Stüpp et al. ²⁹	***	-	*
Thompson, O'Sullivan, Briffa and Neumann ³⁰	***	-	*
Thompson, O'Sullivan, Briffa and Neumann ³¹	***	-	*
Zhang, Wang and Zheng ³²	***	*	*

General characteristics of the studies

The characteristics of the articles included in this study are listed in Table 2. The sample sizes ranged from nine

to 307 women (mean 50.0; median 30.0). The mean age of the participants was 35.2 years (median 30.4; range 22-63). Seven studies were performed in Brazil and six in Australia.

Table 2. General characteristics of the 23 selected studies.

Authors, year	Publication	Country	Study design	Subjects (age in years)	Objectives
Auchincloss and McLean, 2009 ¹¹	Journal of Neuroscience Methods	Canada	Cross-sectional	10 women (30.0±3.9)	To determine whether PFM activation amplitude changes when different vaginal probes are inserted into the vagina.
Botelho et al., 2013 ³	Neurourology and Urodynamics	Brazil	Cross-sectional	307 women (23.93±5.78)	To investigate if digital palpation of PFMs is correlated with its electromyographic activity.
Chen et al., 2009 ¹²	The Journal of Urology	Taiwan	Cross-sectional	31 women (46.48±7.24)	To examine the effects of passive and active ankle flexion on PFM activity during exercises.
Devreese et al., 2007 ¹³	The Journal of Urology	Belgium	Cross-sectional	82 women (32 continent, 52.38±9.68; 50 incontinent, 52.78±7.99)	To contribute to the understanding of the mechanisms we investigated, the contraction sequence of superficial versus deep PFM in six positions of continent and incontinent women.
Frederice et al., 2013 ¹⁴	Journal of Obstetrics and Gynaecology Research	Brazil	Cross-sectional	91 women (24.3±4.9)	To evaluate PFM function and its association with urinary symptoms in the third trimester of pregnancy.
Grape et al., 2009 ¹⁵	Neurourology and Urodynamics	Sweden	Cross-sectional	17 women (26, range 22-34)	To evaluate the retest reliability of repeated intravaginal EMG of the PFM in healthy women, who were able to correctly perform PFM contractions.

(continues)

Table 2. Continuation

Authors, year	Publication	Country	Study design	Subjects (age in years)	Objectives
Halski et al., 2013 ¹⁶	BioMed Research International	Poland	Cross-sectional	20 women (22.3±1.28)	To determine how the depth of probe placement affects functional and resting bioelectrical activity of the PFM and whether the recorded signal might be dependent on the direction in which the probe is rotated.
Halski et al., 2014 ¹⁷	BioMed Research International	Poland	Cross-sectional	16 women (63.1±4.1, range 55-70)	To evaluate resting and functional bioelectrical activity of the PFM and synergistic muscles, depending on the orientation of the pelvis, in anterior (P1) and posterior (P2) pelvic tilt.
Junginger et al., 2010 ¹⁸	International Urogynecology Journal	Australia	Cross-sectional	9 women (42, range 32-59)	To investigate the relationship between bladder neck displacement, EMG activity of the PFM and abdominal muscles and intra-abdominal pressure during different pelvic floor and abdominal contractions.
Lauper et al., 2009 ¹⁹	Neurourology and Urodynamics	Switzerland	Cross-sectional	38 women (21 control, 30.0±4.7; 17 post-partum, 31.7±3.4)	To determine if two different whole-body vibrations, sinusoidal vibration and SR-WBV, lead to a reactive activation of PFM when using various intensities.
Luginbuehl et al., 2012 ²⁰	Neurourology and Urodynamics	Switzerland	Cross-sectional	50 women (28 np/pp group, 47.0±9.6; 22 pp group 33.1±4.8)	To determine the SR-WBV load modality regarding PFM activity to complete the SR-WBV training methodology for future PFM training with SR-WBV.
Pereira et al., 2013 ²¹	Neurourology and Urodynamics	Brazil	Cross-sectional	81 women (20 nulliparous, 24.4±3.6; 25 pregnant, 24.6±5.6; 19 vaginal delivery, 21.8±3.1; 17 cesarean section, 23.1±5.9)	To simultaneously evaluate both transversus abdominis/internal oblique muscles and PFM during isometric exercises in nulliparous, pregnant, and postpartum women.
Petricelli et al., 2014 ²²	BioMed Research International	Brazil	Cross-sectional	60 women (26.06±5.58)	To compare the role of the PFM between nulliparous and multiparous women in the third trimester of pregnancy, analyzing the relationship between EMG, vaginal palpation (modified Oxford Grading Scale), and perineal distensibility (EPI-NO).
Resende et al., 2012 ²³	International Urogynecology Journal	Brazil	Cross-sectional	30 women (Group 1, 28.2±6.5; Group 2, 26.4±3.2)	To compare the MVC and strength of PFM of pregnant and non-pregnant women using sEMG.
Resende et al., 2011 ²⁴	International Urogynecology Journal	Brazil	Cross-sectional	34 women (28±5.9)	To determine whether Paula method of circular muscles contraction (those surrounding the eyes, mouth and fingers) can increase PFM activity.
Sapsford et al., 2008 ²⁵	Archives of Physical Medicine and Rehabilitation	Australia	Cross-sectional	17 women (9 asymptomatic, 45, range 32-66; 8 symptomatic, 41.8, range 33-55)	To determine whether resting activity of the PFM and abdominal muscles varied in different sitting postures in parous women with and without SUI.
Smith et al., 2007 ²⁶	Neurourology and Urodynamics	Australia	Cross-sectional	30 women (14 continent, 52.5±12.5; 16 incontinent, 49.8±12.0; 7 mild-incontinence, 48.1±12.2; 9 more severe incontinence, 51.0±12.4)	To determine whether activity of the PFM and abdominal muscles differs between continent and incontinent women in response to a postural perturbation with a moderately full or empty bladder.
Smith et al., 2008 ²⁷	Neurourology and Urodynamics	Australia	Cross-sectional	29 women (16 with SUI, 49.8±12.0; 13 controls, 53.1±12.7)	To investigate whether there are differences in center of pressure displacement, trunk motion, and trunk muscle activity in women with and without SUI during static balance tasks when the bladder is empty and moderately full.

(continues)

Table 2. Continuation

Authors, year	Publication	Country	Study design	Subjects (age in years)	Objectives
Soljanik et al., 2012 ²⁸	Archives of Gynecology and Obstetrics	Germany	Cross-sectional	23 women (22±3.7)	To evaluate the role of the ischioanal fossa in functional relations between the levator ani and gluteus maximus muscles in healthy female volunteers.
Stüpp et al., 2011 ²⁹	International Urogynecology Journal	Brazil	Cross-sectional	34 women (28.1±6.0)	To investigate PFM and transversus abdominis activation during the abdominal hypopressive technique through sEMG.
Thompson et al., 2006 ³⁰	Neurourology and Urodynamics	Australia	Cross-sectional	13 women (38±7)	To investigate the muscle activation patterns of the abdominopelvic region used by incontinent women during a PFM contraction and a Valsalva maneuver compared to healthy and asymptomatic subjects.
Thompson et al., 2006b ³¹	Neurourology and Urodynamics	Australia	Cross-sectional	13 women (37±9)	To investigate the different muscle activation patterns around the abdominopelvic cavity in continent women and their effect on pressure generation during a correct PFM contraction and a Valsalva maneuver.
Zhang et al., 2006 ³²	International Journal of Gynecology and Obstetrics	China	Cross-sectional	114 women (57 with SUI, 41.3±10.2; 57 controls, 38.8±11)	To obtain perineal electrophysiological data and assess the clinical usefulness of measuring the sEMG activity of the PFM in predicting and diagnosing SUI.

EMG: electromyography; MVC: maximal voluntary contraction; PFM: pelvic floor muscles; SR-WBV: stochastic resonance whole-body vibration; SUI: stress urinary incontinence; np: nulliparous; pp: primiparous

Characteristics of data collection and analysis of surface electromyography

The type of vaginal probe used varied between the studies. The most commonly used were FemiScan (n=4) and Periform (n=9). One study did not mention the type of vaginal probe used. The EMG data collection

protocols also varied. Only one study examined the evaluation of the two separate types of muscle fibers (types I and II). Six studies evaluated the PFM in other positions besides the supine position; and three, during effort (cough) or Valsalva maneuver. Only four studies reported a normalization of the sEMG data for analysis.

Table 3. Characteristics of the probe used, collection protocol and other data on EMG

Authors, year	Probe used	Data collection protocol	Frequencies and approaches to filter the signal	Normalization?
Auchincloss and McLean, 2009 ¹¹	Vaginal: Periform and FemiScan	One MVC and maximal effort cough.	The signals were preamplified using a Delsys™ DE-2.1 Sensor for active electrode amplifiers (200×) before final amplification using Delsys™ AMT-8 amplifiers [common mode rejection ratio (CMRR)=90 dB at 60 Hz, bandwidth of 20-450 Hz, input impedance>10 ¹⁵ Ω] to produce an overall gain of 1000.	No
Botelho et al., 2013 ³	Vaginal: PhysioMed Services	Three 5-s MVCs with 10-s rest.	Band-pass filter with cutoff frequencies at 20-500 Hz, an amplifier gain of 1,000 times and a CMRR>120 dB. A 12-bit A/D signal converter plate was used, to convert analog signals into digital ones with a 2.0 kHz anti-aliasing filter sampling frequency, with an input range of 5 mN.	No
Chen et al., 2009 ¹²	Vaginal: FemiScan	One contraction standing and one contraction in eight different positions of the ankle joint.	No description.	No
Devreese et al., 2007 ¹³	Vaginal: No description	Supine + knees flexed, supine + knees straight, sit leaning forward, sit upright, stand leaning forward and stand upright: 2-min rest preceded by a MVC for 6 s. The onset of increased activity was defined as any muscle activity with a minimum amplitude of a sliding window of 25 ms exceeding resting EMG by 2 SD.	Band-pass filter of 10 to 500 Hz. Data were sampled by a 12-bit analog-to-digital converter at a rate of 1,000 samples per second, stored on a computer, full-wave rectified and low-pass filtered at 50 Hz to smooth the data.	No

(continues)

Table 3. Continuation

Authors, year	Probe used	Data collection protocol	Frequencies and approaches to filter the signal	Normalization?
Frederice et al., 2013 ¹⁴	Vaginal: Miotec	Basal tone at rest, one contraction with 1-min rest, MVC (highest of 3 contractions), and one 10-s contraction.	No description.	No
Grape et al., 2009 ¹⁵	Vaginal: FemiScan	Three series of contractions with 10-s sustenance and 10-s rest.	A band-pass filter of 8 to 500 Hz (3 dB points) and a low-pass filter of 500 Hz was used. The signal was sampled at 10 Hz after full-wave rectification.	No
Halski et al., 2013 ¹⁶	Vaginal: Periprobe Optima 3	Standing position: five contractions with 5-s rest between each contraction (resting activity).	This device is characterized by a continuous amplitude of 0.2-2000 μ V _{RMS} in the frequency band of 2-100 Hz and pulse-width modulation from 50-450 μ s for signals recorded generated by muscles. Device sensitivity is established at a level of 0.1 μ V (4% accuracy; readings \pm 0.3 mV at 200 Hz), with selectable band-pass filter (3 dB bandwidth) and 50 Hz notch filter (33 dB; 0.1% accuracy).	No
Halski et al., 2014 ¹⁷	Vaginal: Lifecare PR-Q2 Vaginal Probe	EMG activity was recorded with the pelvis rotated forward (P1) and backward (P2) around the transverse axis. In P1 and P2, the participants made five 5-s MVCs (functional sEMG activity) with a 5-s rest (resting sEMG activity). They took 60 s of rest between trials.	Analog output gain: x1000 standard (5000 selected units); minimum CMRR: 100 dB at 50-60 Hz; input impedance >100 M Ω on sEMG channels (isolated to >3000 V; sEMG amplifier performance: 1 μ V sensitivity and <1 μ V _{RMS} baseline noise; data acquisition: 8 channels of 12-bit resolution, and USB update to PC every millisecond; cutoff of high-pass filter: 10 Hz first-order filter on sEMG channels; selectable low-pass cutoff of 500 or 1000 Hz on sEMG channels.	No
Junginger et al., 2010 ¹⁸	Vaginal: Perform	One 5-s MVC with 30- to 120-s rest.	EMG data were amplified 2,000 times, bandpass-filtered between 10 Hz to 1 kHz and sampled at 2 kHz.	Yes
Lauper et al., 2009 ¹⁹	Vaginal: Perform	PFM activity at rest and in 5-s MVC.	The EMG was sampled at a rate of 1 kHz, the cutoff frequency of the low-pass filter (Butterworth, 24dB/Oct.) was set at 500 Hz. Expecting vibration artifacts in the EMG, no high-pass filter was applied to detect the fundamental frequency of vibration as well as the harmonic content in the EMG signal.	Yes
Luginbuehl et al., 2012 ²⁰	Vaginal: Perform	Orthostatism: PFM activity at rest and two 5-s MVCs with 60-s rest.	The EMG signal was transmitted to a measurement amplifier (UMVE, uk-labs). The cutoff frequency of the low-pass filter was set at 500 Hz to avoid aliasing in accordance with the Nyquist-Shannon sampling theorem.	Yes
Pereira et al., 2013 ²¹	Vaginal: PHYSIOMED Services	Three 5-s MVCs with 10-s rest	Band-pass filter with cutoff frequencies at 20-500 Hz, an amplifier gain of 1,000 and a CMRR>120 dB. A 12-bit A/D signal converting plate was used to convert analog signals to digital ones with a 2.0 kHz anti-aliasing filter sampling frequency, with an input range of 5 mn.	No
Petricelli et al., 2014 ²²	Vaginal: Cone-shaped intravaginal sensor (Chattanooga Group)	Three MVCs followed by relaxation (10 s). The best of the three contractions was selected for the study.	This is a signal processor with band-pass filters, cutoff frequencies of 20-500 Hz, instrumentation preamplifier (20-fold gain), differential amplifier with bipolar input, and CMRR>100 dB.	No
Resende et al., 2012 ²³	Vaginal: Chattanooga Group	Two contractions sustained for 5 s with 30-s rest. The best of the contractions was considered as the MVC.	Band-pass filter with cutoff frequencies at 20-500 Hz, an amplifier gain of 1,000, and a CMRR>120 dB and a 12-bit analog-to-digital signal converting plate with a 2.0 kHz anti-aliasing filter sampling frequency for each channel was used.	No
Resende et al., 2011 ²⁴	Vaginal: Chattanooga Group	Three 30-s MVCs. The best of the 3 contractions was used for the analysis.	Band-pass filter with cutoff frequencies at 20-500 Hz, an amplifier gain of 1,000 and a CMRR>120 dB and an A/D 12-bit analog-to-digital signal converting plate with a 2.0 kHz anti-aliasing filter for each channel and an input range of 5 mV was used.	No
Sapsford et al., 2008 ²⁵	Vaginal: Perform	PFM activity was conducted for 10 s in 3 different sitting postures: slump supported, upright unsupported, and very tall unsupported.	EMG data were bandpass-filtered between 20 and 1000 Hz and sampled at 2 kHz using an AMLAB-based data acquisition system.	No

(continues)

Table 3. Continuation

Authors, year	Probe used	Data collection protocol	Frequencies and approaches to filter the signal	Normalization?
Smith et al., 2007 ²⁶	Vaginal: Periform	EMG activity was recorded prior and subsequent to a postural perturbation in which a 1-kg weight was dropped 30 cm into a bucket held. Subjects were instructed to remain relaxed before loading and to catch the load when it contacted the bucket. In the first ten repetitions the subject held the switch and controlled the timing of the drop of the weight (expected condition). In the subsequent ten trials, subjects wore a blindfold and earplugs and the weight release was controlled by the researcher (unexpected condition).	EMG data were amplified 2,000 times, band-pass filtered between 30 and 1,000 Hz, and sampled at 2,000 Hz.	Yes
Smith et al., 2008 ²⁷	Vaginal: Periform	Subjects stood on a force plate during six static balance conditions: eyes open, eyes closed, standing on foam with eyes open, standing on foam with eyes closed, tandem stance, and standing on a short base.	EMG data were amplified 2,000 times, band-pass filtered between 30 and 1,000 Hz and sampled at 2,000 Hz.	Yes
Soljanik et al., 2012 ²⁸	Vaginal: VSO 2000, Haynl-Elektronik Corp.	Six body positions: MVC sustained for 5 s and rest for 10 s, with 10-min rest between positions.	The sEMG signal-processing unit consists of one portable analog-to-digital channel of an EMG unit operating at voltage between 0 and 100 V, band-pass filtered at 50 Hz.	No
Stüpp et al., 2011 ²⁹	Vaginal: Chattanooga Group	Three 30-s MVCs. The best of the three contractions was used for the analysis.	Band-pass filter with cutoff frequencies at 20-500 Hz, an amplifier gain of 1,000 and a CMRR>120 dB. An A/D 12-bit analog-to-digital signal converting plate with a 2.0 kHz anti-aliasing filter sampling frequency for each channel was used. The plate had an input range of 5 mV.	No
Thompson et al., 2006 ³⁰	Vaginal: Periform	One contraction for 3 s and a maximal straining Valsalva maneuver. The EMG activity was recorded for 3 s and repeated three times with 1-min rest.	The gain setting was 2,000, and the signal was sampled at 1,000 Hz. The EMG raw data was reduced, rectified, band-pass filtered at 4-400 Hz using a fourth-order zero-lag Butterworth filter (National Instruments).	Yes
Thompson et al., 2006 ³¹	Vaginal: Periform	One contraction for 3 s and a maximal straining Valsalva maneuver. The EMG activity was recorded for 3 s and repeated three times with 1-min rest.	The amplifier gain was 2,000, and the signal was sampled at 1,000 Hz. The EMG raw data was reduced, rectified, band-pass filtered at 4-400 Hz using a fourth-order zero-lag Butterworth filter (National Instruments).	Yes
Zhang, 2006 ³²	Vaginal: FemiScan	Four 5-s contractions preceded by 10-s relaxation.	No description.	No

EMG: electromyography; MVC: maximal voluntary contraction; PFM: pelvic floor muscles; sEMG: surface electromyography

DISCUSSION

This systematic review aimed to determine how EMG data are analyzed in the functional assessment of PFM. Only seven studies normalized the data, according to the recommendations proposed in the *Guide for Use and Interpretation of Kinesiologic Electromyographic Data*³³.

The characteristics of the amplitude and frequency of the electromyography signal are sensitive to intrinsic (muscle fiber type, depth, diameter, and amount of tissue between the muscle and electrode) and extrinsic factors (location, orientation, and shape of the area

of the electrodes). Thus, the signal amplitude cannot be analyzed directly^{3,5,8}. To analyze and compare electromyography signals from different individuals, muscles, and acquisition modes, it is necessary to “normalize” them, which is a form of transforming the absolute values of the amplitude into relative values related to an amplitude value characterized at 100%⁸.

Normalization methods impede any interference on the intensity of the contraction, as they remove the effect of other factors that influence on signal capture. Thus, it is only after the standardization process that we can compare different muscles and individuals considering the amount of energy produced during a given contraction⁵.

We have several ways to normalize the electromyographic signal. Usually, it is performed by dividing the obtained values by a reference point. The most referenced point in the literature is the normalization by the maximum voluntary contraction (MVC); in this point, a reference is attributed to the highest value found among certain contractions from that muscle. In general, patients are oriented to perform three MVCs and the highest value is recorded. The other contractions of the collected protocol will be percentages of the MVC⁹. Some authors use the mean between two or three MVC as reference value⁸. Another possibility of normalization is to use the maximum peak of the electromyographic signal. Similarly, the value of 100% is attributed to the maximum peak, and all the electromyographic signal is normalized using this value⁸.

In this systematic review, only seven studies performed the normalization of the electromyographic signal using the MVC^{18-20,26,27,30,31}.

As aforementioned, the most common method for the normalization of the amplitude of the EMG signal is to use the MVC. This method quantifies more precisely the relative effort of muscular groups, allowing the comparison between patients with and without neuromuscular dysfunction. It may also be defined as the Muscular Utilization Ratio (%), characterized by the ratio between the mechanic demand imposed during the motor activity and the maximum capacity of the muscular group to perform the activity. This ratio is multiplied by one hundred to obtain a percentage (%) based on the MVC to develop a specific motor task³³.

According to Soderberg and Knutson³⁴, the decision to normalize or not is based on the type of description and whether one of the research objectives is to compare data. If comparisons are made between subjects, days, muscle, or studies, the normalization is required³⁵. Meanwhile, if the subjects act independently and the collection is held on the same day, assessing the same muscle without electrode removal, the normalization is not considered necessary. However, we recommend normalization of data, because this step is required in case the results are compared with similar data from other studies in the future.

Besides depending on physiological properties, sEMG is also influenced by non-physiological properties, such as probe configuration (size, shape, how it is applied, and type of filter used for signal detection)⁸. Some studies have assessed the reliability of the comparison between

different probes; however, few studies have evaluated this aspect in Brazil.

Ten different probes were used in the studies included in this review, except for those that did not mention the type of vaginal probe used. Data collection protocols also varied, and patients were evaluated in different positions. These are limiting factors for a systematic review of literature that seeks to evaluate the contribution of sEMG in the functional assessment of PFM in a given population. The heterogeneity of the studies hampered their comparison and systematization of data. However, positively, our study opens space for reflection and discussions on the subject to move toward a standardization of the technique used in the PFM functional assessment.

Another important factor worth mentioning is the sample heterogeneity between studies. Functional assessment of PFM of nulliparous, primiparous, and multiparous women; patients with PFM disorders, such as urinary incontinence and pelvic organ prolapse; and women in menopause and postmenopause contribute to the differences in results due to the effects of delivery, mode of delivery, and hormone changes related to aging, for example, on the PFM function. Variations in sample size and study design are also relevant factors that limit the systematization of data due to the distinct methodologies between studies.

The strength of this review is the originality and the analysis of the risk of bias with a specific tool for cohort studies¹⁰.

As weaknesses of the study we can mention the low methodological quality of the included studies. A considerable amount of the NOS scoring was lost when we analyzed the “comparability” item due to the lack of a control group for comparisons. “Outcome” was another item with a reduced score due to the lack of information on blinding and/or a follow-up long enough so that results may occur. Unfortunately, this was not found for most of the selected results.

The research question within this systematic review is very important. EMG studies are central to evaluate studies on pelvic floor training efficacy, and, as such, comparison across studies with heterogeneity in the methods used to capture sEMG activity is important.

Thus, standardization of guidelines for sEMG data collection, management, analysis, and interpretation of results in the PFM functional assessment is essential. We hope that this review alerts physiotherapists about PFM disorders regarding these issues.

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