Conservative treatment of pelvic floor dysfunctions

A manuscript for students and practitioners

Studio IMPRESO

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of pelvic floor dysfunctions

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Abbreviations

PFD	pelvic floor dysfunction
PFM	pelvic floor muscles
PFMT	pelvic floor muscle training
SUI	stress urinary incontinence
MUI	mixed urinary incontinence
OAB	overactive bladder
ECM	extracellular matrix
UUI	urge urinary incontinence
CPP	chronic pelvic pain

Authors' note

According to DeLancey, the understanding of pelvic floor dysfunctions (PFD) is in a transition phase. A step is being taken from discussing hypotheses (based on general anatomy and physical examination) to testing them by comparing the structure and functioning of women with PFD through MRI, ultrasound, or functional tests (1). PFD refer to various symptoms and anatomical changes connected with disorders in pelvic floor muscle functions – their increased activity (hypertonia) or decreased activity (hypotonia) and their wrong nervous coordination (2). Scientific evidence confirms the effectiveness of conservative treatment strategy in PFD offered by physiotherapists and primary care providers (family doctors and nurses) (3). The short guide published in 2017 "Pelvic Physiotherapy Education Guideline" (4) and "An argument for competency-based training in pelvic floor physiotherapy practice," (5) published a year later, make it easier to plan education in the "Pelvic Physiotherapy" field and they highlight a significant role of Evidence-Based Practice during the choice of therapy methods (4). In the case of physiotherapists' job, this seems to be a very significant aspect – results of a study from 2019 on musculoskeletal disorders show that most physiotherapists choose methods that are not recommended in these disorders or ones for which there are no recommendations whatsoever (6). The need to develop and update various recommendations concerning particular physiotherapeutic procedures according to Evidence-Based Practice seems necessary and contributes to the search for new effective conservative treatment methods.

1.1. How to use this coursebook?

Dear reader,

The keynote of the manuscript is to present a new, broader perspective on the pelvic floor. The issue of conservative treatment in the form of physiotherapy is still investigated and updated by many researchers so while you read the text, look for tips, remarks, and suggestions that will help you expand your knowledge of the subject. When planning the scope of the manuscript's content, we followed the guidelines defined by the team of researchers from the International Continence Society (4) and the guidelines concerning the level 1 education of "pelvic floor physiotherapists" (4). In the text, you will also find coloured highlights (TIP/REMARK).

Special thanks to Prof. Carla Stecco from the University of Padua for allowing us to copy her figure and to put it in the text as well as Wouter H Lamers MD, PhD from the University of Amsterdam for agreeing to the inclusion of his pelvic floor figures from 3d atlas.

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1. Pelvic floor in women

1.1. Anatomy

Tip: For a better understanding of this text, we recommend a free 3D pelvis model by Wu et al. (7) which is available free of charge at: www.onlinelibrary.wiley.com/doi/full/10.1002/ca.23508

Note: This text supplementary to the basic knowledge of anatomy, physiology and neurology, especially of the pelvis and the torso, therefore, the skeletal structure of the pelvis was omitted, along with some other details. In order to avoid repeating the same content many times, there is a table at the end of this script where you will find recommended literature and links.

The pelvic floor consists of layers of muscles, ligaments and fascias which:

1. provide structural and functional support for the internal organs;
2. constitute the abdominal prelum along with the thoracic diaphragm;
3. close the lumen of the urethra;
4. narrow the transverse measurement of the vagina and urogenital hiatus;
5. together with the thoracic muscles, maintain posture and contribute to its stability;
6. participate in the sexual function (8,9,10).

The female pelvis can be divided into three areas: the urinary bladder and urethra are located in the anterior compartment, the uterus and vagina in the medial compartment while the rectum and anus are in the posterior compartment. Damage (due to various reasons) to the pelvic floor muscles, ligaments and fascias may lead to a number of functional abnormalities which often encompass all the above-mentioned compartments due to their proximity, innervation and vascularisation. Therefore, the knowledge of the normal anatomy of the pelvic floor is crucial for comprehensive assessment of pelvic floor dysfunctions (11).

Based on various reports, you can still notice discrepancies not only in the structure of the elements which constitute the pelvic floor, but also their nomenclature (12,13,14,15,16). Studies conducted in recent years, including MRI, ultrasonography as well as histological and histopathological examinations, allow to gain a better understanding of the structure of the pelvic floor. The use of this knowledge in the context of conservative treatment makes it easier to consider this body part in the aspect of the system's functioning as a whole (17), which is also confirmed by the myofascial continuity between the pelvis and torso, as described by Ramin et al. (18) It consists of: (18) (figure 1)

- Superficial fascia of the abdomen, which runs in the anterior-posterior direction as: Scarpa's fascia → Colles' fascia → external anal sphincter muscle → superficial fascia,
- the superficial part of the deep fascia, which runs in the anterior-posterior direction: external abdominal oblique muscle → ischiocavernosus and bulbospongiosus in relation to Gallaudet and Buck's fascia towards fascia lata → superficial transverse perineal muscle together with Gallaudet's fascia towards the perineal body → superficial external anal sphincter → superficial anococcygeal ligament → gluteus maximus + the lateral layer of the thoracolumbar fascia

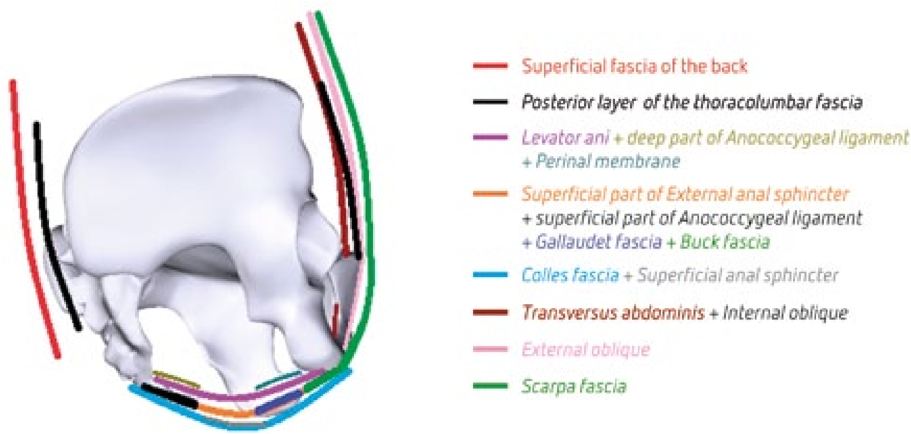


Figure 1. Myofascial continuity within the pelvis and torso (side view). The image is an interpretation of the text by Ramin et al. (18) Curtsey of Carla Stecco.

- the deep layer of the deep fascia in the anterior-posterior direction: internal oblique and transversus abdominis muscles, which overlap in the area of the pubic symphysis and create the urogenital diaphragm → perineal body → levator ani muscle → the deep layer of the anococcygeal ligament and presacral fascia → iliac fascia of iliopsoas. The deep fascia layer can be divided into two parts, if we assume that the levator ani is a kind of boundary which stretches from the urogenital triangle at the front, to the deep layer of the transverse perineal muscle. Therefore, we can describe the superficial layer as being: above the levator ani – created by the superior part of the pelvic diaphragm, which runs across, through the tendon of the arch of pelvic diaphragm with the obturator internus aponeurosis and the deep layer, which encompasses the inferior part of the pelvic diaphragm which is connected with the internal oblique aponeurosis.

The authors of the above-mentioned analysis emphasise that through a comparison of anatomical texts, they showed the existence of the so-called "fascial continuum", which could improve the understanding of the pathophysiology and mechanisms connected with pelvic floor dysfunctions, as well as the planned conservative treatment (18). The fascial continuum, with the pelvic floor as its part, is built of active and passive components of connective tissue which constitute an integrated system of layers, with the endopelvic fascia as the first layer, pelvic diaphragm as the second, the urogenital diaphragm as the third, and the perineum as the fourth one (8,19).

The first layer: The endopelvic fascia is an inhomogeneous collagen, elastin, nerve fibre, lymph vessel and smooth muscle fibre mesh, which stretches from the pubic symphysis to the sacral bone and ischial spines. In the lesser pelvis, it is divided into the parietal fascia (which covers its inner walls, the urogenital diaphragm and pelvic diaphragm, internal obturator muscles and piriformis muscles) and visceral fascia (which covers the bladder, rectum, and inferior part of the uterus and vagina) (16) and it constitutes a support system for the internal organs and muscle groups (20,21) described by DeLancey as:

- **Level I**, which refers to the interlacing fibres of the cardinal ligament / uterosacral ligament complex, which attaches the upper part of the vagina, cervix and lower part of the uterus to the obturator muscle/sacral bone, piriformis muscle and coccyx. Abnormal tone in this complex may lead to abnormal bladder emptying and uterine prolapse.
- **Level II** of the fascia attaches the central part of the vagina to the levator ani muscles, and it is a solid support for the neck of the urinary bladder and urethra. Loss of support on this level results in a cystic urethra, its hypermobility and stress urinary incontinence.

- **Level III** supports the distal part of the vagina to maintain the anatomical position of the vagina and urethra by connecting the vagina with the structures of the perineum. (22) It is worth remembering that the endopelvic fascia and its components are parts of the so-called visceral pelvic fascia, which stretches from the cranial base to the pelvic floor and lines all the body's cavities. (23)

The second layer of the pelvic floor, the pelvic diaphragm, is built of superior and interior fascias, which surround the levator ani muscle complex from above and below. (9) Fascias are connective tissue composed of irregularly arranged collagen and elastin fibres as well as a proteoglycan matrix, and their density depends on their location and inter-individual variability. Within the pelvis, they are thicker in the medial part. They also form channels for blood and lymph vessels, as well as the nerves running to particular organs. In women, they form the core of the broad ligament of the uterus. (23)

The pelvic floor is built of: (8,9,19,24)

- paired levator ani, which is characterised by continuous muscle tone – analogically to the tonic contraction of core muscles around the spine (25) and consists of both smooth and skeletal muscles (2/3 of the fibres are of type I) which is built of the:
  - pubococcygeus (which is sometimes referred to as pubovisceral muscle (25,26,27)), whose attachment is located on the posterior part of the pubis, the fascia of obturator internus and the lateral side of the coccyx (19). The muscle controls the urine stream during urination and with normal tension, it prevents leakage.
    It consists of the following muscles:
    - **puboperinealis**,
    - **pubovaginalis** – in women, it is the central part of the pubococcygeus. Its tension impacts the position of the baby's head during labour and participates in so-called postural stability.
    - **pubo-analis**,

> It must be mentioned here that in the levator ani muscle group, fibres of smooth muscles can be found (besides skeletal muscles fibres), mainly in the central and medial parts, which are innervated by the sympathetic nerves of the inferior hypogastric plexus (autonomous system) (28).

- **puborectalis**; its attachment is located on the superior and inferior part of the pubis, it is connected with the opposite puborectalis and forms a loop behind rectum and it is not attached to any bone structure (19). Together with the internal and external anal sphincters, it participates in the defecation process.
- **iliococcygeus**; it stretches from the obturator internus fascia to the lateral part of the coccyx, and it overlaps the fibres of the pubococcygeus. It forms a kind of a mediolateral raphe with the muscle fibres on the opposite side which, together with the anal ligament, provide an "anchoring" point for the pelvic floor.

- the paired **coccygeus** or **ischiococcygeus**; they form the posterior part of the pelvic diaphragm, as they stretch from the ischial spine through the posterior part of the obturator internus, the lateral side of the coccyx and sacral bone. The Coccygeus is not a part of the levator ani – it has a different function and origin (19).

As a whole, the levator ani supports the visceral organs of the abdomen and pelvis structurally, helps maintain intra-abdominal pressure, supports breathing and helps in the processes of defecation and urination. Apart from that, it helps control mechanical pressures (e.g., during increased intra-abdominal pressure) by distributing the loads during walking (or physical activity) and torso or limb movements. During breathing, the muscle is controlled by the upper parts of the respiratory system (during inhalation it relaxes and during exhalation it contracts). It is also directly connected to the gluteus maximus by connective tissue within the ischiorectal fossa (29).

In its function, the pelvic diaphragm is closely connected with the thoracic diaphragm, which reduces the pressure in the abdominal cavity during its lowering, or inhalation (28). During respiratory activity, the lowering of the diaphragm correlates with the lowering of the pelvic diaphragm, which was observed during examination with magnetic resonance imaging. Apart from that, bioelectric activity is observed in pelvic floor muscles, occurring right before inhalation (30,31), therefore its normal, physiological functioning seems to be a necessary condition for the so-called diaphragmatic respiration (32). Due to the low level of muscle spindles which form the diaphragm, described by Pickering and Jones (33), the diaphragm is not able to regulate the intra-abdominal pressure effectively on its own (33). However, it may rely on information coming from the muscle spindles of the abdominal cavity walls and pelvic floor, acting as feedback. Interestingly, in spite of the diaphragm muscles' great strength, the anatomical orientation of its fibres results in most of the contraction strength being transferred distally to the lower ribs instead of vertically downwards (23). While the rib part of the diaphragm expands the lower chest, the "central" diaphragm does not change its size significantly as it has a very small respiratory role, rather being more engaged in gastroesophageal functions like swallowing, vomiting or preventing reflux (34). The loss of mobility in the lower ribs, which results from trauma, incorrect posture or even emotional states, may be one of the causes of pelvic floor dysfunctions like stress urinary incontinence (32,34).

These theoretical analyses suggest that most of human body's skeletal muscles are directly connected by fascial connective tissue and form myofascial chains (35,36). To understand the origin of pelvic floor dysfunctions, a few simulation models have been developed, like the one according to Giraudet et al. (10) most of them are incomplete and only contain the analysis of the structure of the levator ani, separated from other muscles of the perineum. In 2018, this team of researchers developed the first 3D models of pelvic floor muscles obtained using MRI (10). Based on these images, it was noted that the pubococcygei and puborectalis form a distinctive "U" shape as they go from the inside of the pubic bone to the rectum, while the iliococcygeus provides support for the internal organs in the posterior part of the pelvis. (10) The iliococcygeus is located on the obturator internus and its fibres are directed towards the ischial spine, while the pubococcygeus and puborectalis were more difficult to visualise separately. The authors admit that identification of the three parts of the pubococcygeus was difficult, and for this reason it was presented as a single muscle (10). The pelvic diaphragm gets its innervation from sacral plexus S3-S5, and it provides structural support for the bladder and urethra during increased intra-abdominal pressure (37).

In spite of controversies on the terminology, the following may be included in the **third layer** of the pelvic floor (38) **perineal muscles** which some authors (39) also call **diaphragma urogenitalne** or perineal membrane - which is a fibromuscular three-layered structure located directly under the pelvic diaphragm (19). The urogenital diaphragm is the outermost layer and it consists of (40):

- **muscle of anal triangle**:
  - a single **external anal sphincter muscle –** a skeletal muscle under voluntary control, while relaxed it is tense, and during contraction it touches the wall of the rectum
- **muscles of urogenital triangle**:
  - **superficial perineal muscles** (superficial perineal pouch):

    - the single **superficial transverse perineal muscle -** it contracts the perineal body and the transversus perinei profundus
    - the single **bulbospongiosus,** the paired **ischiocavernosus** which is connected to the external anal sphincter
    - the paired ischiocavernosus, which is poorly developed in women is located on the crus of clitoris and affects its corpus cavernosum
- **perinei profundus muscles** (deep perineal pouch), which are located between the urogenital diaphragm's superior and inferior fascias,
    - the single **external urethral sphincter** - is the reinforcement of the internal sphincter.
    - single **sphincter urethrovaginalis** muscle
    - single **compressor urethrae** muscle,
    - the single **deep transverse perineal muscle -** stabilises the urethra.

The ischiocavernosus may well be separated from other muscles, while the bulbospongiosus is located close to the pubovaginalis and its boundaries are not that clear. This muscle is located on both sides of the vaginal orifice and urethra, just as the pubovaginalis, and it connects with perineal body at the bottom. The authors have separated the fibres of the external anal sphincter, but it was difficult for them to do the same with internal anal sphincter, whose fibres interpenetrate the fibres of the levator ani (10). There are scientific reports which confirm the anatomic continuity between the bulbospongiosi, superficial transverse perineal muscle and the external anal sphincter (41). The innervation of the muscles presented above comes, above all, from the pudendal nerve (37).

When writing about ligaments, it seems necessary to distinguish this term in reference to internal organs and the locomotor system, as both may be included in pelvic floor. In the case of the body's cavities and the internal organs, the ligaments are not as resistant or strong, and they form a rather loose area within the visceral fascia, which was often observed during autopsies (23). Their main function within the pelvis is to support the organs in their proper position and to protect blood vessels and nerves. Among the ligaments of the lesser pelvis in women, there are the ligaments which hold the uterus: the cardinal ligament, vesicouterine ligament, uterosacral ligament, round ligament and the aforementioned broad ligament; the ligaments which hold the bladder: pubovesical ligaments and the aforementioned vesicouterine ligament, and the ligaments which support the ovaries: suspensory ligaments of the ovaries and the ovarian ligaments (42,43,44).

According to some authors, the ligaments of the locomotor system which remain in direct relation with the pelvic floor structures are (45,46) the ligaments of the sacro-iliac joint: the sacrotuberous ligament and the sacroiliac ligament. The sacrotuberous ligament is one of the ligaments which reinforces the sacro-iliac joint and has an impact on the position of the sacral bone. It is built of three tracts which run in a fan-like way, from the lateral surface of the sacral bone and partially the coccyx, to the ischial tuberosity. There is a direct connection between the nutation of the sacral bone and the tone of the sacrotuberous ligament. In the case of its excessive tension, the motion of the base of sacrum to the front is limited. The opposite situation of reduced tension in the ligament may lead to an increase in nutation and horizontal positioning of the sacral bone. Increased or reduced tension of this structure may result from a locked sacro-iliac joint, lumbar discopathy or pelvic muscles pain syndromes. In lumbar hyperlordosis, the ligament is stretched and in hypolordosis, there is contracture resulting from its attachments coming closer together (26,47). The long dorsal sacroiliac ligament is the antagonist of the sacrotuberous ligament. It is the most externally located in relation to the sacro-iliac joint, and has interesting anatomic relations to the erector spinae muscle (mainly the multifidus muscle), the thoracolumbar fascia or the sacrotuberous ligament, as well as the gluteus maximus and the latissimus dorsi. For this reason, it is an important structure which connects the lower limbs, the spine and the upper limbs, and pain is often felt within its boundaries. This ligament contracts in counternutation, and weakens in excessive nutation. The latter situation is balanced by the tension of the erector spinae and the sacrotuberous ligament (26).

Based on the analysis by Lee et al. (48), we know that the pelvic floor muscles, together with the transversus abdominis muscles, the multifidus muscles, the internal and external obliques, rectus abdominis, erector spinae in the lumbar spine and the diaphragm, form the so-called core, whose main job is to maintain body stability (48). Apart from these, other muscles which participate in the process are the: latissiumus dorsi, gluteus maximus (28) and trapezius. This is another important function of the PFM, besides providing proper support for the organs and, as a consequence, the function of the urethra (37). The coordinated work of the PFM and the other muscles which constitute the “core” is necessary for maintaining the proper functions of the urinary system (49). The latest research by Zhang et al. (50) conducted to determine the electromyographic activity of the abdominal muscles during micturition in mice and the assessment of the abdominal response’s contribution to effective urination shows that such a relation really exists (50). What is more, the normal function of the above-mentioned muscles may be lost in patients who manifest PFD. Thferefore, motor re-education in the form of learning motor control and posture re-education, which includes restoring the proper functions of the muscles connected with PFM, should be included in PFM exercise programmes (51,52). The literature review conducted in 2016 by Ferl et al. (53), on the other hand, shows that in healthy women, there is a synergy between the abdominal muscles and the pelvic floor. A better understanding of the combined work of pelvic floor muscles and other muscles may be favourable for developing more effective strategies for preventing and treating PFD (53). Based on the presented studies, it may be observed that the synergists of PFM play an important role in the proper urinary continence. However, there are reports which cast doubt on the role of the PFM synergists in PFD treatment (54,55,56). Based on electromyographic recordings, functional MRI and transcranial magnetic stimulation, it was shown that there are two patterns of muscle coordination for the pelvic floor in the cerebral cortex:

- an “isolated-pelvic pattern” in which the PFM contract independently of their synergists
- a “gluteal-pelvic pattern” which activates the PFM before gluteus maximus contraction and during it (57).

The results of the functional MRI in this experiment revealed that both patterns manifest the overlapping of two fields in the area of the supplementary motor area (SMA) and the primary motor cortex (M1). More importantly, in the aspect of pelvic floor physiotherapy, the cortical control of PFM functions in chronic pelvic pain and UI may provide bases for seeking new forms of therapy based on nervous system re-education (57). Therefore, it seems that it is necessary to conduct further research to assess the PFM as part of a kind of kinematic chain – some studies also show a co-occurrence of PFM dysfunctions with pain in the lumbar spine area, where interventions in the form of an improvement in the strength and endurance of the PFM and abdominal muscles significantly reduces pain and UI (58). The respiratory diaphragm and transversus abdominis are connected fascially through the pubic symphysis and sacral bone to the thoracolumbar fascia. The rectus abdominis is connected to the thigh adductor muscles through the pubic symphysis. In addition, the thigh adductor muscles are activated to contraction through the contraction of the pelvic floor muscles. Apart from that, the pelvic floor is connected fascially with the gluteus maximus, which is also involved in the activity of the pelvic floor muscles. What is more, this activity makes it possible to distribute the burdens coming from the trunk and upper limbs onto the lower limbs and vice versa, during walking or standing, thanks to the above-mentioned anatomic myofascial connections. There also are hypotheses that the position of the feet may impact the muscular tension of the pelvic floor, which also impacts the tension of the hip rotators (59).

1.2. Pelvic floor innervation

Reminder: The human nervous system consists of the central nervous system (brain and spinal cord), the afferent and efferent pathways, as well as the peripheral nervous system (the afferent and efferent nerve fibres transfer information between the central nervous system and the tissues). The peripheral nervous system and its fibres may be divided into the ones which constitute the somatic nervous system (which supplies the skeletal muscles) and the ones which form the autonomic nervous system (which supplies the smooth muscles, the myocardium and the organs). The autonomous nervous system is divided into the parasympathetic and sympathetic nervous systems.

We encourage you to download a complimentary fragment of the book edited by Kari Bo on the innervation of the pelvic floor: www.sciencedirect.com/science/article/pii/B9780702044434000042

On the pelvic level, the afferent and efferent fibres of the somatic nervous system come mainly from the lumbar plexus (L1-L4) and lumbosacral plexus (L4-L5 and S1-S4) where you can isolate the sacral nerve (L4-S3), pudendal nerve (S2-S4) and from which the following nerves branch: the motor nerves which innervate the gluteal muscles, internal obturators, gemellus superior muscles, gemellus inferior muscles, quadratus femoris muscles, piriformis muscles, levator ani muscles, as well as sensory nerves. The sacral nerve runs (in various configurations) within the piriformis muscle and comes out through the large sciatic foramen. Then, the nerve goes downwards and leans on the gemellus superior, obturator internus, gemellus inferior and quadratus femoris and it goes into the thigh, in the direction of the popliteal fossa, where it divides into its terminal branches: the tibial nerve and common fibular nerve. It provides the sensory innervation for the skin of the anterolateral posterior parts of lower limbs and feet. It also provides motor innervation for the posterior muscles of the thighs, legs and feet. The pudendal nerve, which runs along the piriformis muscle, comes out of the pelvic cavity through the greater sciatic foramen, looping around the ischial spine, going anteriorly towards the pubic symphysis, and it leans on the urogenital diaphragm. It is responsible for the sensory innervation of the skin of the perineum and the motor innervation of the pelvic floor muscles (60,61) (Table 1).

Table 1. Sensory and motor innervation of the pelvic area (51,61,62)

Plexus	Vertebrae	Nerves	Innervated area	Comments
Lumbar plexus	L1–L4	Iliohypogastric L1 (sensory)	The skin over the pubic symphysis and pyramidalis muscle	The second most frequent neuropathy after surgical intervention in gynaecology pertains to the damage of these nerves
		Ilioinguinal, L1 (sensory)	Labia majora, the medial side of the thigh, the skin between the transversus abdominis and internal oblique muscles	
		Lateral femoral cutaneous, L2-L3 (sensory)	Lateral side of the thigh	Has no motor component as the only one in the plexus
		Genitofemoral, L1-L2 (sensory)	Anterior side of the thigh, labia majora, medial side of the thigh	There is a risk of damage to the nerve during the application of TOT tapes = perineal neuralgia
		Femoral (sensory-motor)	Muscles and skin of the anterior side of the thighs, medial side of the leg, hip and knee joints	Possible femoral neuropathy during abdominal surgery
		Obturator L2-L4 (sensory-motor)	Adductors, hip and knee joints, skin of the medial side of the thigh	Possible damage during the application of TVT and TOT tapes
Lumbosacral plexus	L4–L5 and S1–S4	Sacral L4 and L5 + S1, S2 and S3	Sensory – the skin over the buttocks, the posterolateral side of the thigh, leg and foot. Motor - the thigh extensor, thigh abductors and rotators, leg flexors, feet muscles	
		Pudendal S2-S4: inferior rectal nerves, perineal nerves.	Sensory and motor pelvic floor	
Coccygeal	S4–S5	Annococcygeal	Skin over the coccyx	

The autonomic nervous system within the pelvis is composed of afferent and efferent nerve fibres which are directed to the organs and control the excretory and sexual functions (40): the parasympathetic nervous system serves the emptying function (miction + defecation + clitoral erection) while the sympathetic one has the storage function, among others of the intestines and bladder (vasomotor effects + inhibition of peristaltic contraction) (40) together with the somatic nervous system. The preganglionic sympathetic pathways come out of the lumbar spinal cord and transform into sympathetic chain ganglia and then pass through inferior splanchnic nerves to the inferior mesenteric ganglia. The preganglionic and postganglionic nerve fibres then go through the hypogastric nerve, to the pelvicalyceal plexus and the urogenital organs (63). The parasympathetic preganglionic fibres, which are formed in the lumbar spinal cord, go through the pelvic nerve to the ganglionic cells of the pelvic plexus and the distal plexuses in organs (63).

1.3. Pelvic floor biomechanics

The biomechanical properties of tissues may be active or passive, and they can be measured with the use of well-characterised ex vivo or in vivo techniques (64). Most of the studies on the tissues of the pelvic floor have revealed mainly their passive properties, which make the transmission of forces possible for them, or make them resistant to deformation or strains (physiological, such as age, labour, walking, jumping, breathing, or pathological, like vomiting, obesity, surgery, chronic cough). The knowledge of the changes in the biomechanical properties of the pelvic floor tissues and the strains on them facilitates the understanding of the development of PFD and helps identify those who are susceptible to it, or improve clinical practice as well as diagnostics, which leads to new methods of treatment (64). The soft tissues of the pelvic floor (muscles, fascias and ligaments) form a support resembling a hammock on the pelvic outlet floor, attached to the pelvic bones. They have two basic functions (which have also been mentioned in chapter 1): supporting the organs of the pelvis (bladder, vagina, uterus and rectum) and facilitating sexual intercourse, natural labour, stool storage and voluntary bowel evacuation, as well as urination. The function of organ support is fulfilled when the pelvic floor is able to resist external loads without causing pathological conditions (e.g., urinary incontinence, pelvic organ prolapse, faecal incontinence, etc.). Therefore, this function is dependent on the strains experienced by the pelvic floor during various activities and on the biomechanical properties of the tissues themselves. The presence of various factors which disturb the functions of the pelvic floor or its original biomechanical properties may expose some people to the occurrence of PFD (65).

For example, when pelvic floors are examined diagnostically in two women, during strain, one of them may not develop PFD, as her tissues are able to withstand mechanical loads (forces acting), while the other one has weaker tissues and develops PFD (64). Therefore, it is key to understand the environment which is the strain for the pelvic floor in detail, and characterise the biomechanical properties of its tissues. The pelvic floor is constantly burdened by intra-abdominal pressure due to its anatomical structure and the everyday activities it is involved in. Intra-abdominal pressure is a physiological load which is transferred from the lungs and diaphragm area, through the abdominal cavity, to the tissues of the pelvic floor. The load may change together with the active or passive compression of the abdominal wall, breathing, load transfer, cough, laughter, etc. The larger the loads, the higher the intra-abdominal pressure and the mechanical load. Changes in intra-abdominal pressure have been registered in the bladder, and they are considered to reflect the pressure received by the pelvic floor well. The maximum pressure in the bladder of healthy women who are not pregnant is 347 cmH2O during coughing and vomiting in a lying position. Defecation usually leads to the peak pressure of 100 cmH2O within a few seconds. Obesity may additionally increase the baseline by 19 cmH2O. These conditions (chronic cough, constipation, obesity) are connected with the well identified risk factors for PFD, and they are a serious mechanical load for the pelvic floor. Apart from that, pelvic organ prolapse and stress urinary incontinence are strongly connected to injuries sustained during labour. It is no wonder, as the maximum pressure on the pelvic floor muscles occurs during the second stage of labour, where a high baseline pressure resulting from the pregnancy itself may be further increased by another 194 cmH2O. Such pressure becomes higher than the elevated intra-abdominal pressure during cough and strain in women who are not pregnant, and may persist for even up to an hour. The combination of the increased pressures, the duration and the deformation of the tissues poses a serious risk of damage to the pelvic floor. Therefore, during recent years, the concept of pelvic floor biomechanics became the central point of understanding its dysfunctions (64).

1.3.1. Standing position and posture

The standing position results in a significant change in the tension of the gluteus maximus muscles as well as their constant synergy and antagonism with the abdominal muscles and the lumbar spine. Posture is an active, automatic and involuntary phenomenon which results from the tension, contraction and relaxation of the muscles which opposes gravity (66). The synergy between the PFM and the abdominal muscles contributes to increasing spine stability, by stiffening the spine and regulating intra-abdominal pressure. PFM function disorders alter the neuromuscular connection between the PFM and abdominal muscles, which results in an abnormal muscle synergy and, as a consequence, predestines people for bad posture, especially in the lumbar-pelvic area (67). To serve as a support, the pelvic floor muscles are constantly in the intermediate state between relaxation and contraction, and thanks to the proper work of the nervous system, there is no muscle fatigue (68,69). However, it must not be forgotten that the skeletal muscles of the pelvic floor, just like all skeletal muscles, consist of slow (type I) and fast twitch muscle fibres (type IIa or IIb). The combination of slow and fast fibres causes the phenomenon of fatigue in spite of better resilience, which is typical of type I fibres. Muscle fatigue is commonly defined as any decrease in the maximum capacity for generating strength or power (due to strain) (71). In 2019, pelvic and torso muscle (internal oblique, multifidus, tibialis anterior and gastrocnemius) bioelectric activity was evaluated in 61 healthy volunteers in 4 positions: standing position with dorsiflexion/plantarflexion of the feet and a long-lasting sitting position with dorsiflexion and plantarflexion of the feet. It was observed that while standing, the particular position of the lower limbs activates the pelvic floor muscles together with the muscles of the torso, which gave the author a base to claim that the information is useful in planning pelvic floor muscle training, especially in patients with urinary incontinence (71). The impact of the pelvis' position and movement in the sagittal plane on the bioelectric activity of pelvic floor muscles in women during menopause with urinary incontinence was evaluated by Ptaszkowski et al. (72). A higher action and resting bioelectric activity of pelvic floor muscles in the position of pelvic retroversion as well as backward movement itself in a standing position were observed. This seems important from the perspective of doing pelvic floor muscle exercises: the initial position with pelvic retroversion and the loss of lumbar lordosis may contribute to a better therapeutic effect. Similar results were received in the study by Capson et al. (73) where pelvic retroversion, also in the standing position, but this time in healthy women, was accompanied by higher resting bioelectric activity in pelvic floor muscles (73). Importantly, only the neutral position of the pelvis allowed to achieve higher bioelectric activity during maximal voluntary contraction or the Valsalva manoeuvre. The discussion included in this report brings interesting observations on postural disorders in women with symptoms of SUI, where therapeutic intervention in the form of re-education in maintaining proper posture could contribute to an improvement in the tonic and phase functions of the PFM. In 2019, another study was published. It confirmed higher bioelectric activity in the PFM with dorsiflexion of the ankle joints and the pelvis in anteversion (71,72). In the study by Manshadi et al. (74) on 160 women with urinary incontinence, a statistically significant difference in pelvic position asymmetry was shown compared to healthy women (74). The strength and endurance of the muscles underwent palpation too. In the case of the women from the study group, it was significantly reduced, which was a sign of muscle fatigue. Asymmetry in the position of the pelvis, understood as its lateral displacement in the coronal plane, which often is the effect of a difference in the length of the lower limbs, impacts resting PFM tension (51). The rotation of the wings of the ilium with respect to each other, is accompanied by the so-called "eight sign" (75), which, according to Rakowski (45) is one of the reasons for the development of an overstrained pelvis, which is characterised by low mobility of the sacro-iliac joint and a functional disorder of the pelvic floor structures (45). A literature review completed in 2017 by Zhoolideh et al. (76), which was done in order to define the relation between the maintained posture, the structure of the pelvis, as well as tonicity and pelvic floor dysfunctions, indicates that there is a need for further research in this direction (76).

1.3.2. Walking

The activity of pelvic floor muscles is extremely significant during walking, when their synergistic and antagonistic relations affect the function of the torso and the lower limbs. During movement, the pelvis is burdened significantly by constant changes in posture. There are noticeable gravitational loads on the pelvic bones, which would tend to move, but instead they remain immobilised. Therefore, pelvic floor muscles in synergy with the muscles in its external area and the muscles of the torso are of a crucial significance for opposing these forces and maintaining pelvic stability during walking. Biomechanical mapping of the response to the applied pressure or burden within the pelvic floor opens new possibilities for its biomechanical evaluation and the monitoring of its condition. The newly developed objective imaging allows for biomechanical mapping of the female pelvic floor, including the assessment of tissue elasticity, pelvic support and the function of the pelvic muscles in high resolution (65).

2. Pelvic floor dysfunctions

In 2017, a survey was conducted to evaluate the awareness of pelvic floor dysfunctions (PFD) in 1092 women between the ages of 19 and 30. The results of the study showed that 33% of the participants would like to obtain more information on pelvic floor dysfunctions, particular at the same time as when information on the first menstruation or sexually transmitted diseases is provided at school. The authors claim that the education during pregnancy itself may not be sufficient, therefore the implementation of preventive practices and educational programmes for adolescents and young women (especially if they would result in a reduction of PFD) is necessary (77).

The connective tissue within the pelvic area is built of cells connected by the extracellular matrix (ECM). While cells serve biomechanical functions, the non-cellular ECM provides structural and mechanical support for the cellular components. ECM consists mainly of biopolymers' macroparticles, including elastin and collagen fibres and various amounts of adipose tissue and smooth muscles organised heterogeneously, creating a complex microstructure. On a structural level, the biomechanical properties of the ECM are dependent on the above-mentioned components: collagen is stiff (limited stretching), elastin is flexible, smooth muscles are capable of constant contractibility and the most delicate adipose tissue works as a "cushion" with much less stiffness than the rest of the components (22). Changes in the composition and mechanics of the ECM occur during all degenerative diseases, due to ageing or as a compensative attempt to maintain the functions of the tissues (78). The negative impact of ageing on the functions of skeletal muscles is associated with changes in the twitch muscle fibres (responsible for the active mechanical muscles' properties) as well as the non-contractible ECM (passive mechanical properties of skeletal muscles – stiffness) (79). The results of the work by Burnett et al. (79) show that the mechanism which underlines the base of increased pelvic floor muscle's (PFM) susceptibility to excessive muscle stiffness connected with age is currently unknown. Further research is needed, to investigate the potential role of hormonal balance and the regeneration potential in PFMs' vulnerability to the ageing process.

It is commonly believed that pelvic floor dysfunctions are caused by fatigue, excessive stretching or damage to the ligament structures, fascias, the organs themselves, or pelvic muscles. The impact of changed fascial properties as a result of proportional elastin and collagen reduction on the mobility of the pelvic organs is hard to depict with radiological techniques; therefore, they have never been examined. The results of the study have shown that it is the fascia inside the pelvis, which covers a larger part of the pelvic diaphragm (pelvic floor muscles), that transfers the induced intra-abdominal pressure and whose structural integrity is mainly responsible for limited mobility of the pelvic organs in relation to one another (22). Interestingly, some studies show a connection between lower back pain and pelvic floor dysfunction (80,81,82,83,84,85,86), i.e. the pelvic floor muscles' dysfunction symptoms were strongly connected to frequent back pains (58,82). The connection may be justified by physiological limitations in the function of postural muscles (including pelvic floor muscles), respiratory muscles, and torso muscles (40). According to Welk and Baverstock (87), one of the hypotheses explaining the relationship pertains to an increased tension in the torso muscles which causes lower back pain which in turn may increase the pressure in the abdominal cavity and, at the same time, deteriorate the PFM function (87). Apart from that, according to Rakowski (88), the sacrotuberous ligament is connected to the pudendal nerve through neighbouring tissue and it forms the path along which the nerve runs. Therefore the symptom in the form of excessive pain due to pressure within the ligament may, among others, result in disorders in urination because of hindered conduction in the pudendal nerve and the absence of the sphincter urethrae muscle (88). According to Welk and Baverstock (87), there is limited evidence that suggests therapeutic interventions within the pelvic floor are useful in low back pain treatment. Further research is necessary to determine whether there is an actual causal link between lower back pain and urinary incontinence.

Collagen is a protein that occurs in the human body most frequently and it is an important structural element of soft tissues. Among 20 different types, type I and II are significant building material of soft tissues. Together, they co-polymerise by building fibres with controlled diameters, which affects the biomechanical properties of a given tissue and its reactions to burdens. Type I collagen gives tissues mechanical resistance while type III provides elasticity and regulates the diameters of the collagen fibres during fibrillogenesis. Together with the onset of menopause, the level of oestrogens and progesterone gradually reduces which prevents tissue degeneration and is significant for maintaining tissue integrity. A significant decrease (68%) of total collagen was observed in patients with pelvic floor dysfunctions. Apart from that, an active tissue reconstruction also modifies smooth muscle cells, which reduces and disrupts the contents of smooth muscles. Contrary to this, no direct evidence of significant elastin metabolism or a reduction in elastin content or fibre size during tissue metabolism is observed. Therefore, a change in the biomechanical behaviour of a tissue manifesting as flaccidity or reduced stiffness is deeply connected with loosely arranged collagen fibres, a less dense extracellular matrix, and an impairment of smooth muscle cells (22).

2.1. Pathophysiology

Knowledge of pelvic floor anatomy allows one to better understand the pathophysiological mechanisms which are involved in pathologies in this area. The integral theory by Petros and Ulsten on urinary continence in women, which has existed since 1990, assumes a close connection between function and anatomy as well as the synergy of pubococcygeus muscles and levator ani muscles, the pubourethral ligaments and fascia as well as the lower part of the urogenital system. According to the authors of the theory, it is the failure and flaccidity of these structures which leads to a reduction of support for the pelvic floor organs and, as a consequence, their dysfunction (89). In 1997, the first transvaginal tension-free tape implantation operation was conducted in accordance with this theory. The tape replaced damaged pubourethral ligaments which play an important role in the mechanism of urethra closing and urinary continence. The restoration of normal anatomical and functional conditions in the pelvic floor and the lower part of the urogenital system is supposed to help regain bladder and urethra function, among others, in patients with stress urinary incontinence (90). The anatomical background of Petros and Ulmsten's integral theory with a strong emphasis on the role of the anterior vaginal wall and pelvic fascia confirms and supplements John DeLancey's hammock theory (91). In 1993, the author stated that as long as the pelvic floor muscles, mainly levator ani, function normally, the proper work of the pelvic floor as a whole shall be maintained. If the muscles are damaged or hypotonic, the internal organs must stay in their place only by the work of the ligaments and fascia. If the pelvic floor muscles cannot perform their function properly, the connective tissue will constantly be overloaded, stretched, and damaged (91). According to Wall and DeLancey (92), little success in pelvic floor dysfunctions results from too much "division" in this minor body part into jurisdictions of several medical experts. Each of the three parts of the pelvic floor is reflected in medicine. The urethra and bladder belong to urologists, vagina and reproductive organs to the gynaecologists, while the colon and rectum belong to the gastroenterologists and proctologists/surgeons. Therefore, it is much better to treat the three parts of the pelvis as a whole and, additionally, include PFM, ligaments, and fascia as an important support and integrative system (25,92). Norton reached the same conclusions in his publication. Both authors compared the pelvic floor to a ship floating on the water. In this case, the ship is an analogy for the pelvis' internal organs: the ligaments and fascias are ropes, while water is the PFM's support function (25,93). To sum up the above considerations, one could think that the physiological activity of the pelvic floor is necessary for urinary continence and damage to any structure which builds it may lead to:

- **Urinary incontinence**: stress urinary incontinence, mixed urinary incontinence, urge urinary incontinence
- **Pelvic organ prolapse**
- **Faecal incontinence**
- **Sensory disorders in the lower urinary tract**
- **Defecation disorders** (e.g. constipation)
- **Sexual dysfunctions** (e.g. dyspareunia)
- **Chronic pelvic and/or perineum pain** (25,94) → More in chapter 4.2.1 (see page 97).

The functioning of the pelvic floor is also impacted by the myofascial connections between the pelvic floor and other muscles in the human body. The Fascia Research Society appointed Fascia Nomenclature Committee for explaining the terminology connected with it. The committee proposed two definitions of fascia: an anatomical and functional one. The first one describes fascia as connective tissue in the form of a sheath which is formed under the skin to connect, close off, and separate muscles from internal organs (95,96). The functional definition is broader and describes fascia as a system that surrounds organs, bones, muscles, ligaments, tendons, joint capsules, nervous fibres as well as blood vessels and it provides the body with functional and structural integrity as it brings together the functions of all the body's systems (95,96). The research has shown that the fascial tissue is innervated by nociceptors and mechanoreceptors which provide information both on the somatic and the autonomous nervous system. It consists of smooth muscle fibres and a cellular structure of myofibroblasts and may change its shapes in response to mechanical stimulants (→ see chapter 4.2. and the definition of mechanotransduction (see page 93)) (97).

2.2. Symptoms of pelvic floor dysfunctions

2.2.1. Stress urinary incontinence

The prevalence of pelvic floor dysfunctions, like stress urinary incontinence (SUI), is estimated because of the intimate nature of the disease and, as a consequence, the data is difficult to obtain. It is estimated that 5-69% of women and 1-39% of men have at least one urinary incontinence or dribble incontinence incident occur in 12 months. In Poland, the problem of urinary incontinence may afflict 2.5 million people, but the number may be higher than in the published studies. Globally, the estimations of the prevalence of urinary incontinence in the entire population oscillate between 4-8%. However, it is estimated that in developed countries urinary incontinence afflicts at least 6% of society. In 2018, the estimated number of people with urinary incontinence problems globally was around 420-300 million women and 120 million men. It is worth mentioning that within the last decade, the number of people with urinary incontinence in the global population has grown successively – in 2008 it was 346 million and in 2013 it was 383 million (98,99,100,101). According to the definition by the International Continence Society and the International Urogynecological Association, urinary incontinence is an involuntary leakage that can be divided into stress, mixed, or urge urinary incontinence (102,103).

According to the International Continence Society (ICS) and the International Urogynecological Association (IUGA), stress urinary incontinence is the most frequently occurring incontinence and it is characterised by involuntary leakage during activities that increase the pressure in the abdominal cavity (cough, sneezing, physical effort). It is believed that there are two mechanisms that lead to SUI. One of them is the excessive mobility (hypermobility) of the urethra and bladder which results in the loss of anatomical support and the weakening of connective tissue which surrounds them, which is dependent on the amount of collagen in it. The above-mentioned hypermobility induces a change in the angle at which the neck of the urethra intersects the pelvic muscles, a change of over 30° from baseline, during increased pressure in the abdominal cavity. The changing conditions manifest dysfunctions of the urethral sphincter, the failure of the mechanism of urethra and neck of urinary bladder closing before the anterior vaginal wall, as the pressure increases in the abdominal cavity which leads to involuntary leakage of urine. In a urodynamic test, no detrusor instability is diagnosed in this case and the urine leakage may be minor or in the form of a urine stream (37,104,105).

2.2.2. Mixed urinary incontinence

Mixed urinary incontinence is defined as the involuntary leakage of urine connected with both the weakening of the mechanism of urethra closing during an increase of pressure in the abdominal cavity (effort) and an involuntary detrusor contraction (urinary urgency). In this case, it could be said that the bladder is hyperactive and the sphincter urethrae muscles are weakened or entirely non-functional. This kind of incontinence characterises one in three women, especially the middle-aged or elderly ones, and its aetiology is usually justified by a combination of exertional risk factors and urge urinary incontinence (106,107). In 2016, reports appeared about a significant difference between SUI and MUI different morphological defects for each kind of UI. They were evaluated with MRI. These observations allowed the authors to notice that the pathophysiology of MUI does not have to be the above-mentioned combination of SUI and UUI therefore the therapeutic approach should be adjusted to the particular sort of urinary incontinence, especially in elderly women (108). According to D'Ancon et al., patients who suffer from mixed urinary incontinence and urge urinary incontinence as adults manifested more frequent nocturnal enuresis in childhood (109). On the other hand, other reports indicate some people are prone to UI or POP due to a genetic factor. However, the significance of environmental factors cannot be ignored (110). To sum up, conservative treatment of MUI should be based on the most bothersome symptoms. They should be diagnosed before any invasive tests are conducted and the treatment should encompass a change in lifestyle, physiotherapy, and bladder training. A quality-of-life questionnaire is another indispensable element of MUI conservative treatment (111).

2.2.3. Urinary urgency

Urge urinary incontinence is also referred to as overactive bladder with urinary incontinence. It is an involuntary leakage that is accompanied by a sudden onset of the urge to urinate, which is impossible to hold in for a patient. This urgency might be caused by involuntary contraction of the detrusor which dominates the mechanism of the sphincter, or a small bladder's capacity for filling with urine which results from the loss of viscoelastic properties of the bladder's tissues. The cause of UUI may be neurogenic (damage to the spinal cord, multiple sclerosis, Parkinson's disease, or a stroke) or idiopathic (non-neurogenic aetiologies are usually processes that alter the bladder tissue, like radiation used in cancer treatment).

→ Look at the treatment algorithms in the case of urinary incontinence according to the guidelines of the European Urology Association accessible online: https://www.sciencedirect.com/science/article/pii/S0302283810010894#fig0005.

2.2.4. Pelvic organ prolapse

A pelvic organ prolapse occurs when one or more organs find themselves outside the pelvis; it could be the anterior vaginal wall together with the bladder or the posterior vaginal wall with the rectum, uterus, or the vaginal orifice. It is quite common – according to some data, about 50% of women over 40 might be experiencing pelvic organ prolapse. (112) The prolapse might lead to disturbance in everyday activities, physical activity, and sexual function. It has multiple causes (look below: risk factors (see page 37)). Clinically, pelvic organ prolapse may be connected with stress urinary incontinence, faecal incontinence and constipation, sexual dysfunctions, and the feeling of pressure in the vagina (29). It is estimated that the risk of an operation on a pelvic organ prolapse throughout the lifetime is from 7% to 11% and reoperations are frequent. Severe complications may occur after a mesh implant application, therefore early prophylaxis and conservative treatment are justified (113). Therefore, many physiotherapists who specialise in women's health offer so-called individualised pelvic floor muscle training. Its purpose is to improve pelvic floor muscle function – i.e. strength, endurance, and coordination – and ultimately, an increase in the structural support for the organs (more in chapter 4.1. (see page 73)). While Cochrane's review has shown that pelvic floor muscle training is effective in urinary incontinence treatment, the evidence concerning its use in the case of pelvic organ prolapse is less clear (114). Apart from exercise, in conservative treatment, vaginal pessaries are used too (112). POP-Q scale (Pelvic Organ Prolapse-Quantification) is used for the quantitative assessment of pelvic organ prolapse, Table 2 (115).

Table 2. The POP-Q scale is used for assessing in which stage the prolapsed pelvic organs are. (115)

Stage of pelvic organ prolapse POP-Q	Description
0	No prolapse
1	The most distal part of the prolapsed organs is over 1 cm above the level of the hymen
2	The prolapsed organs are between 1 cm above and 1 cm below the level of the hymen
3	The prolapsed organs are over 1 cm below the remnants of the hymen but not more than 2 cm less than the entire length of the vagina in cm
4	The organs come out of the vagina throughout its length

→ The current knowledge allows categorisation of risk factors that increase the probability of pelvic floor dysfunction occurrence. In the detailed division, predisposing factors can be distinguished. Among them, there are episodes of urinary incontinence among first-degree relatives, complications in patients with diabetes, neurodegenerative diseases, and anatomical factors (weakening of the urethra mechanism of contraction, various forms, and degrees of pelvic floor muscle flaccidity or small pelvic organ prolapse). Among the inducers, there are past pregnancies and childbirths (normal childbirth), operations, or possible nerve or muscle damage resulting from them (116–118). Another group are the decompensatory factors or, in other words, factors that accompany a natural process of body ageing and diseases of civilisation. Scientific research confirms that the number of cases of urinary incontinence of different kinds increase with age (119). The last group of risk factors are the favouring factors – the ones which affect urinary continence quality, for example through a change in patient's lifestyle. Among them are improper diet, chronic constipation, and excessive caffeine or alcohol intake (51,120–122). It was also noticed that in patients with high BMI, urinary incontinence episodes occurred more frequently and weight reduction moderated UI symptoms and restored control over urination. (123,124) The level of physical activity is one of the promoting factors as well – both too high, which burdens the system, and its lack are significant risk factors in urinary incontinence. In this group, there also is one of the frequently mentioned problems which lead to urinary incontinence – a deficiency of the female sex hormone, oestrogen, during menopause which is connected with changes in the density and structure of the collagen of the connective tissue which surrounds the neck of the urinary bladder (125). An overall list of the risk factors for pelvic floor muscle dysfunctions, among others urinary incontinence, was presented in Table 3.

The pelvic organs' direct contact with the pelvic floor muscles may also explain urinary incontinence symptoms: a full bladder is located on the obturator internus and levator ani muscles. Contact between them may lead to myofascial stimulation of trigger points which might be misinterpreted as urinary urgency. Significant correlations between the presence of trigger points in pelvic floor muscles and the level of the ailments reported by patients confirm the hypothesis that the presence of trigger points may underlie some pelvic floor dysfunction symptoms. If this was true, it would be an important non-pharmacological, non-surgical treatment strategy that would aim at reducing the symptoms of thousands of women and at the same time spare them the risk and side effects connected with medications or surgical procedures. However, further research is needed to explain this relationship (126).

Table 3. List of risk factors that affect the development of pelvic floor dysfunctions (105,120, 124,127–131)

Predisposing factor	Causing factor	Favouring factor	Accompanying factor
• Sex • Genes • Nervous system work • Anatomical conditionings • Amount of collagen in the tissues • Culture and environment • etc.	• Normal childbirth • Damage to nerves and muscles • Radiation • Operations • etc.	• Constipation • Obesity (body mass) • Operations • Lung diseases • Tobacco smoking • Menstrual cycle • Lower urinary tract infections • Medications taken • Menopause • Profession • Free time activities/overstraining physical activity • etc.	• Ageing process • Dementia • Concomitant diseases • Medications taken by the patient • Environment • etc.

2.3. Pelvic floor dysfunctions epidemiology

Many epidemiological studies on the incidence of PFD in women have been published in academic literature. There is a great diversity of studies and most frequently, they refer to the incidence of urinary incontinence symptoms. The range of UI incidence in the general female population is 5 to 72% and most studies are consistent with an incidence of about 30%. The divergence results from different definitions or the methodologies adopted in each study. Diversity among studies is observed both within a given country and between different countries. The studies on severe urinary incontinence defined as a urine leakage several times per week have a more consistent reported incidence of 6–10% both in Europe and in the USA (132).

The incidence of UI of any kind seems to rise exponentially until middle age, with a levelling or even a small decrease between the ages of 50 and 70 (133,134). The study conducted by Hannestad et al. reports an increase in the incidence during adulthood until 50 years old, when it ranges from 10 to 30% and a stabilisation or even a minor decrease until 70 when the incidence starts growing again (figure 2) (134).

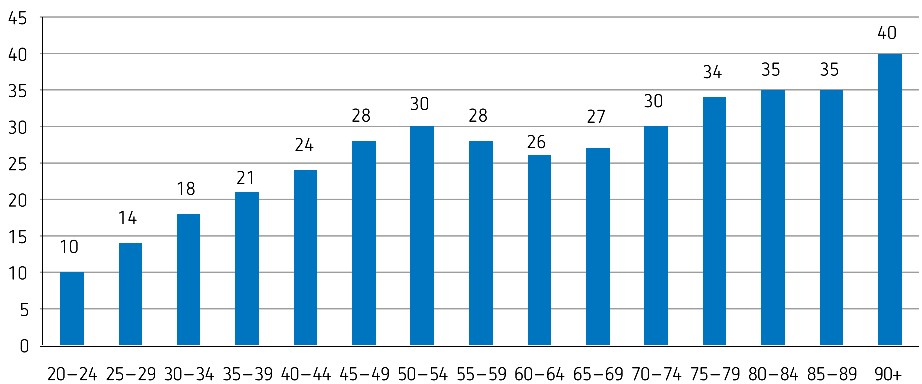


Figure 2. The incidence of UI in women aged between 20 and 90 years or more (134).

When referring to the European population (table 4) one may notice the incidence of UI is on a similar level. In the Hunskaar et al. study (135), 35% of women reported involuntary urination within the last 30 days. The incidence increases with age and between 50 and 79 years there is stabilisation, with a minor decrease between the age of 70 and 74.

Table 4. The incidence of urinary incontinence in European countries.

Author	Year of publication	UI incidence
Hunskaar et al. (135)	2004	**UI 35% in total** • Spain 23% • Germany 41% • France 44% • Great Britain 42%
Cerruto et al. (136)	2013 Systematic review (17 studies)	UI 14,1–68,8% • Austria, Denmark, Finland, France, Germany, Greece, Italy, Norway, Portugal, Spain, Sweden, the Netherlands, Great Britain, and Turkey
Milsom et al. (137)	2019	UI 30–60% POP 5–10% AI 11–15%

UI: Urinary incontinence; POP: Statics of genital organ disorder; AI: anal incontinence.

The studies by Cerruto et al. (136) also confirm the large variety in incidence estimations and the incidence of UI in Europe. One of the most significant UI risk factors observed by researchers was age. Apart from that, the study showed the main risk factors for UI occurred in pregnant women who were having their first child: the mother's age, an increased baseline body mass, and a previous occurrence of UI. In the case of all pregnant women (regardless of the number of past pregnancies) natural labour is an additional risk factor. The main postpartum UI risk factors are the mother's age, the kind of labour, if the mother is overweight, and UI during the pregnancy (138). In a study by Milsom et al. (137), the incidence of UI and adult women oscillated around 30–60%. The study evaluated the frequency of other pelvic floor dysfunctions, i.e. pelvic organ prolapse whose incidence was defined as 5-10% or anal incontinence – 11-15%. The incidence of one or more PFD is 46% and many women suffer from a combination of the diseases (137). Table 5 presents the results of the studies conducted independently in European countries (137).

Table 5. Incidence of urinary incontinence in particular European countries.

Author	Year/country	Incidence	Group size	Research method
Al-Mukhtar et al.	2016/Sweden	16,6% UI	9197	40 question online survey
Ebbesen et al.	2013/Norway	29% UI	14606	EPINCONT Study
Tahtinen et al.	2011/Finland	11,2% SUI 3,1 % UUI	2002	FINNO Study - Finnish National Nocturia and Overactive Bladder Study
Alvaro et al.	2010/Italy	15,3 % UI	1346	ICIQ Questionnaire
Driul et al.	2009/Italy	27,5% SUI 14,45% UUI 9,8% Mixed	602	Phone survey
Martínez-Agulló et al.	2010/Spain	4,01% UI	3090	EPICC study

UI: Urinary incontinence; SUI: Stress urinary incontinence; UUI: Urge urinary incontinence.

The data concerning UI incidence in various countries are presented in Table 5, where the reported UI incontinence is lower than in European countries. Among others, the table contains data from China and India which are the two Asian countries with the largest populations. The incidence in these countries is higher than in the USA. The results are closer to the European data. In Africa, on the other hand, incidence values are lower compared to other continents, which is also connected with the lowest number of studies conducted in this region. To sum up, the incidence of PFD varies depending on the country and the applied methods of recording.

Table 6. Studies on the global incidence of urinary incontinence.

Author	Year/country	Incidence	Group size	Research method
Dieter et al.	2015/US	17,1% UI 9,4% FI 2,9% POP	7924	National Health and Nutritional Examination Survey (NHANES) Questionnaire
Townsend et al.	2010/Mexico	14% UI	15,296	Potential UI risk factors reported by patients
Zhang et al.	2015/China	23,3% UUI 18,9%SUI	18 992	ICIQ-FLUTS Questionnaire
Islam et al.	2016/India	23,7% UI 5,3% FI 16,2% POP	1590	Reported by patients
Botlero et al.	2008/Australia /New Zeland	12,8–46,0% UI	Systematic review	No data
Wusu-Ansah et al.	2008/Ghana	12,07% POP	174	No data
Ojengbede et al.	2011/Nigeria	2,8% UI 2,3% SUI 1.05% UUI 0.6 %MUI	5000	Survey conducted by an interviewer

UI: Urinary incontinence; SUI: Stress urinary incontinence; UUI: Urge urinary incontinence; POP: Statics of genital organ disorder; AI: Anal incontinence.

3. Pelvic floor diagnostics

3.1. Subjective pelvic floor muscles' assessment methods

Palpation is the basic subjective method of PFM dysfunction assessment. However, it must be emphasised that before a therapist moves on to the clinical assessment of a patient, accurate urogynaecological history taking is a crucial element of the therapeutic process.

The interview conducted by a physiotherapist in the case of reported pelvic floor muscle dysfunctions may consist of the questions presented in table 7: (139)

Table 7. Physiotherapeutic history taking

No.	The physiotherapist's questions may refer to
1	Frequency of urination during the day
2	Waking up at night to urinate
3	Urine leakage during sleep
4	Feeling of urinary urgency
5	Incontinence during urinary urgency
6	Stress urinary incontinence
7	Characteristics of urine stream
8	Feeling of urinary retention
9	Pushing during miction
10	Number of used pantyliners
11	Fluid intake
12	Pain during urination (dysuria)
13	Urinary tract infections

Table 7. cont.

No.	The physiotherapist's questions may refer to
14	Quality of life
15	Constipations
16	Pelvic organ prolapse
17	Pain during intercourse (dyspareunia)
18	Physical activity
19	Gynaecological and obstetric history

3.1.1. "Red" and "yellow" flags reported during history taking (139)

In the case of patients who were not diagnosed by a doctor before visiting a physiotherapist, the physiotherapist should pay special attention to the symptoms defined as "red flags" and requires a referral to a doctor:

Table 8. "Red" flags

Symptoms requiring patient's referral to a doctor
• Unexplained urinary incontinence, e.g. constant urine leakage (which could mean a vesico-vaginal fistula) • Sudden onset of urinary incontinence in an elderly patient • Pain during urination • Haematuria • Urinary retention/incontinence due to overfilling • Symptoms of vaginitis / proctitis • (Chronic or recurring) urinary tract infections • Organ prolapse below vaginal introitus • Fever • Signs of being generally unwell • Significant weight loss • Fistula • Undiagnosed neurological disorders • Bleeding from the rectum

Apart from "red flags", the physiotherapist should focus on recognising the symptoms and identifying potential "yellow flags" which could also require medical consultation, especially before beginning palpation. They include mental/sexual traumas which hinder transvaginal examination. The identification of yellow flags is justified in the case of symptoms listed in Table 9.

Table 9. "Yellow" flags

Symptoms that may require medical consultation
• Cardiovascular diseases without medical supervision • Back, pelvis and / or hip pain • Diabetes • COPD • Sexual problems • Use of medications (diuretics, sympathomimetic drugs)

Lack of red or yellow flags make it possible to begin physiotherapeutic diagnostics

3.1.2. The patient's informed consent form

A patient should be informed orally and in writing about the physiotherapy methods and techniques used in the conservative treatment of pelvic floor dysfunctions, especially when (subjective and/or objective) transvaginal diagnostics is needed.

3.1.3. Palpation

Scientists who deal with PFD issues keep looking for a gold standard of PFM function assessment. In the case of subjective methods, palpation is a clinically useful PFM assessment tool that is also used for defining the goal and progress of the therapy (140).

Palpation may be conducted while the patient is in a supine position or standing. When the patient is lying down, her hips and knees should be bent and relaxed. Palpation may be conducted with a single finger as two fingers may stretch pelvic floor muscles which might cause the tissue to contraction. Clear and understandable instructions given to the examined patient are very important. Detailed instructions like "try to lift your muscles" or "tense your muscles" are helpful (140).

Reporting the position during the examination, the time of the day, the instructions given to the examined person as well as the exact way the palpation was conducted is very significant (141). This is connected with the limitations of palpation, its unreliable repeatability. Though the PERFECT scheme which is used simultaneously with palpation is characterised by acceptable reliability, it is not suitable for research purposes (142).

PERFECT is an acronym for the evaluation of main PFM contractibility components. The scheme by Laycock and Jerwood was developed to provide a simple PFM assessment method and it involves the elements presented in table 10.

Table 10. PERFECT scheme (143)

Parameter	Description	
P – power	Assessment of the muscles' reaction according to modified Oxford scale	0 – no palpable contraction 1 – flicker or pulsation 2 – weak tension with no vaginal wall lifting 3 – moderate tension with vaginal wall lifting 4 – tension which makes it possible to elevate the vaginal wall against resistance 5 – strong tension, vaginal wall elevation against stronger resistance
E – endurance	the time for which a maximum muscle contraction can be withheld;	
R – repetitions	the number of maximum contractions the patient is capable of;	
F – fast	the number of fast contractions a patient is capable of;	
E – elevation	Is there a contraction of all the muscles/only some of them? Observe the movement deficiencies;	
C – co-contraction	do pelvic floor muscles cooperate with other muscles;	
T – timing	Contraction time – is there an involuntary muscle activity, e.g. during cough	

When developing the PERFECT protocol, its authors emphasised the fact that before its use in the work with a patient both location and function of the pelvic floor muscles were described in enough detail to provide a proper understanding of the muscle group. PFM were examined with the index finger placed from 4 to 6 cm inside the vagina and directed at 4 at 8 o'clock, to monitor muscle activity. Apart from that, moderate pressure was applied on muscle mass to help initiate proper muscle contraction (144).

Power. Muscle strength is measured based on a 6-point modified Oxford scale (145) where grade 0 means no noticeable muscular contractions. Grade 1 twitching or pulsation felt under the finger of the person conducting the examination. Grade 2 is a palpable increase in the tension without a noticeable distinctive rising. In grade 3, the muscular tension is additionally increased and characterised by a lifted belly of the muscle as well as a lifted posterior vaginal wall. In grade 3 or stronger, drawn in perineum and anus may be observed. In grade 4, there is increased tension and good muscle contraction which are able to lift the posterior vaginal wall against resistance (pressure with a finger on the posterior vaginal wall). In grade 5, stronger resistance may be applied against the posterior vaginal wall lifting; the finger should be squeezed and drawn into the vagina. The assessment may be complemented by a + or - sign if it is needed (146). Apart from that, the description of the contraction according to ICS is another classification (table 11.) (141)

Table 11. Modified Oxford scale.

Modified Oxford scale.	ICS classification
0 – no contraction	no contraction
1 – flicker	weak
2 – weak contraction	
3 – moderate contraction with elevation	normal
4 – good contraction, with elevation	
5 – strong contraction, with elevation	strong

Endurance. Endurance is expressed in time, up to 10 seconds, through which a maximum voluntary contraction (MVC) may be held, before its strength decreases by 35% or more. In other words, the contraction is measured until the muscle starts getting tired. Another possible symptom of PFM fatigue may be simultaneous thigh adductor and buttock contraction and a stronger contraction of transversus abdominis. Attention should be paid to patients who hold their breath; if it is noticed that the patient is holding her breath, she should be instructed to perform a PFM contraction on exhale.

Repetitions. The number of repetitions (up to 10) of maximum contractions with a 4-second rest after each contraction.

Fast. Fast contractions. After a short rest (at least one minute), the number of one-second MVCs is evaluated. The patients are instructed to perform short, strong contractions with maximum relaxation after each contraction, until muscle fatigue occurs.

Elevation. It is observed whether there is a lift of all the pelvic floor muscles or only a part of them which could be connected with an innervation dysfunction on one side of the body, e.g. after natural birth.

Co-contraction. It is assessed whether the pelvic floor muscles and other muscles cooperate with remaining muscles, for example, buttock muscles, abdominal muscles, or lower limb muscles.

Timing. It is assessed whether there is an involuntary muscle activity, e.g. during cough.

> Tip! Normal muscle contraction must be felt by the examining person as circular (around a finger/two fingers) and elevating (towards the inside of the abdomen). According to The International Continence Society (ICS) terminology, a contraction may be evaluated as: absent, weak, normal, or strong. (102,141)

3.1.4. Relaxation assessment

Apart from assessing the possibility of PFM contraction, the muscles' ability to relax completely is a significant element during the examination. Pelvic floor muscle relaxation is a key factor in normal urination. PFM with a high passive tension that does not contract or relax normally may be the cause of urination dysfunction with the symptoms such as incomplete bladder emptying, recurrent bladder, and urinary tract infections. Dyspareunia is a less frequently reported symptom (147).

> Tip! The relaxation which occurs after contraction is the pelvic floor muscles returning to their passive tension state. According to ICS, it may be classified as: absent, partial, complete, or deleyed. (102,103)

3.1.5. Physical examination

It involves an examination at rest and during movement, through palpation and a functional examination:

1. General posture assessment in sitting and standing position:
   a) Spinal curves' assessment;
   b) Shoulder girdle symmetry;
   c) Rib position;
   d) Abdominal, neck and lower limb muscle tension;
   e) Pelvic statics assessment:
      i) Lumbar-pelvic complex assessment (148);
      ii) Lumbar spine assessment: location of the painful vertebrae;
      iii) Hip joint dysfunction assessment;
      iv) Sacroiliac joint dysfunction assessment;
   f) Inhalation and exhalation: diaphragm function and assessment of thoracolumbar junction: lower ribs mobility, accessory muscles of respiration activity;
   g) Abdominal muscles:
      i) Assessment of the ability to activate deep muscles without activating superficial muscles;
      ii) Assessment of deep muscle synergy during pelvic floor activation;
      iii) Deep muscle assessment (cough test);
      iv) Divarication of rectus abdominis assessment;
   h) Movement patterns;
   i) Soft tissue tension within pelvis and torso.
2. Urogynaecological examination (it is necessary to put on gloves):
   a) Visual examination:
      i) Observation of perineum skin, mucosa condition, and pigmentation when labia are parted, the examiner must watch for erythema, fungal infection, scars, perineum incisions, etc.
      ii) Urogenital diaphragm assessment:
         - Vulva opening: Usually the vulvar orifice should be closed. If it is not, it might indicate pelvic floor muscle hypotonia.
         - Anovulvar distance: The distance between the frenulum of the vulva and the anal sphincter should be around 3.5 cm. If the distance is larger, it might indicate PFM hypotonia.
         - Perineum and vaginal introitus: scars from tears or incisions (of the perineum), location of the urethral orifice, checking vaginal

introitus – any symptoms of vaginitis (red and dry instead of pink and moist), discharges with non-typical smell (leukorrhea) – fungal infection must be excluded.
- Vagina: organ prolapse, tissue quality (potential atrophy) + neurological examination (dermatomes and clitoral reflex), cough test.
- Anus: haemorrhoids + neurological examination (dermatomes and anal wink reflex)

b) Palpation and diagnostic assessment of pelvic floor muscles:
  i) Assessment of the tension in the central tendon of the perineum: the physiotherapist puts a finger on it and applies moderate pressure. If it meets no resistance and the finger sinks in a little, it may indicate PFM hypotonia. The sense of resilience and flexibility indicates normal tension. A sense of large stiffness may indicate hypertonia. Apart from the central tendon of the perineum, external palpation encompasses: ischiocavernosus, bulbospongiosus, and transverse perineal muscles. This evaluation is particularly significant in women with dyspareunia (149);
  ii) Vaginal walls: It is a very significant part of the assessment of pelvic floor organs and pelvic diaphragm muscles. The examination is always conducted with the observation of hygiene rules (gloves) and with respect for the dignity of the examined patient. The therapist may use a lubricant to facilitate the palpation. Major labia is separated from minor labia with one hand and the other hand inserts the index finger into the vagina, while the vagina's angle is maintained. If the tissue and the level of the patient's relaxation allows that, the middle finger may be inserted. The touch of the vagina should be delicate yet firm and progressive.
    - The finger's movement in the direction of the abdomen allows one to feel: urethra, the neck of the urinary bladder, and bladder.
    - The finger's movement towards the anus will allow one to assess the levator ani muscle. (figure 3).
    - Muscle examination with the PERFECT protocol → table 10.

The evaluated muscle tension may change if pain occurs → see chapter 4.2.1. (see page 97). The assessment is hindered by the fact that there is no single, generally accepted, or standardised way of measuring muscle tension. There also are no standard values for the terms normal-tension, hypertonus, and hypotonus (102,150). A physiotherapist may define hypertonus as an abnormally increased contractive activity and hypotonus as abnormally decreased contractive activity compared to the passive tension (102).

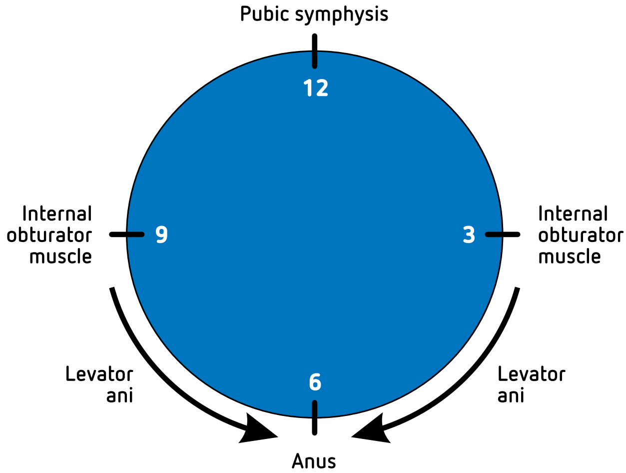


Figure 3. Palpation of the pelvic floor muscles and the location of the main muscles undergoing palpation: levator ani and obturator internus muscles.

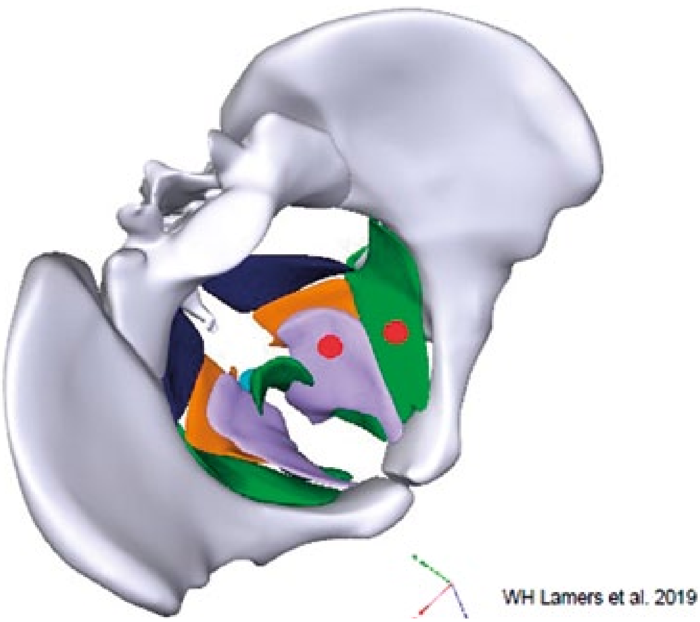


Figure 4. Transvaginal palpation of pelvic floor muscles: obturator internus muscles - marked in green - and the levator ani muscle - marked in purple and orange (layers of pubococcygeus muscles). The red points indicate the position of the index finger of the therapist's dominant hand in the middle of the muscle's' belly (150). *The illustration was used with the consent of Prof. W.H. Lamers*.

> Remember! Pelvic floor muscle exercise or training is beneficial only when the patient is able to perform both voluntary contraction and relaxation of the pelvic floor muscles. (141)

3.1.6. Muscular hypertonia

How to diagnose pelvic floor muscle hypertonicity? (149)

Table 12. Symptoms reported by the patient with hypertonic tension of pelvic floor muscles

The patient reports
• Flatulence, constipation, obstructed defecation, pushing during defecation, drop of the posterior part of the vagina, incomplete defecation. • Frequent urination, urinary urgency, painful urination, bladder pain, urge urinary incontinence • Superficial or deep dyspareunia, pain within the perineum after intercourse • Pain of the lower spine which radiates to the thighs or groins, lower abdomen pain, pelvic pain which is not connected with intercourse.

3.1.7. Subjective assessment questionnaire

> Additionally, standardised questionnaires may be used for the evaluation of urinary incontinence, for example, the ones coming from → www.iciq.net

International Consultation on Incontinence Questionnaire-Urinary Incontinence Short Form (ICIQ-UI SF) consists of six points where the first and the second points refer to the date of birth and sex and the following four concern UI symptoms. The maximum possible number of points is 21 and the number consists of the points from the questions: 3, 4, 5. A higher number of points indicates a higher severity of symptoms. In question 6, a person indicates particular situations in which he or she leaks urine (151). To use the questionnaire, in accordance with copyright, the form on the website should be filled in and the authors' consent should be obtained (usually in the form of an email).

3.2. Objective pelvic floor muscles' assessment methods

3.2.1. Surface electromyography

Proper diagnostics of the pelvic floor muscles are the basis of conservative treatment for various pelvic floor dysfunction symptoms. The assessment of strength and endurance of these muscles may be conducted through palpation, with the application of the Oxford scale or its modified version (→ see chapter 3.1. (see page 43)) d with the use of objective measuring devices like a perineometer (the results indicate a strong correlation between the perineometer and electromyograph in the functional assessment of pelvic floor in women who can recruit these muscles well) (152), dynamometer, or electromyograph (153). The kinesiologic, surface electromyography (sEMG) used in physiotherapy allows one to assess the neuromuscular activity (arousal) of the pelvic floor muscles at rest and when completing various tasks in the form of contractions and relaxations (allows to capture the sum of all the functional potentials of a motor unit – a larger number of activated motor units indicates recruitment of a larger number of muscles) (152,154).

In the case of sEMG, special anal, or transvaginal electrode probes are used the most frequently. Their use may require additional processing of the registered signal to eliminate artefacts (mainly filtering, e.g. 20-60Hz) which come, for example, from the muscles which are in direct contact with the pelvic floor muscles or vaginal walls. Lack of a permanent connection between the place where the signal is detected with the muscle surface makes it more difficult to eliminate artefacts (→described below (see page 55)). Electromyography is a measurement technique that consists of analysis and recording of electric activity – the depolarisation of muscle membranes. It is the sum of all the signals detected in a particular area of soft tissue and it may be considered an indirect measurement of muscle strength – there is a correlation between muscle strength and motor unit activity (155). The registered electromyographic signals, their amplitude and frequency are sensitive to internal and external factors which include: the depth of the analysed muscles, their diameter and the amount of the tissue between the muscles, the electrode location, its orientation, and the shape of its metal surfaces. Therefore, normalisation of the registered signal's amplitude is often required (156). In a study by Pereira-Baldon et al. (156), the credibility of various sEMG signal normalisation methods were evaluated in nonparous, healthy women. Perfect credibility was proven with the use of peak PRM, during a 5-second maximum voluntary contraction of pelvic floor muscles and the average or peak RMS during the Crunch test. High credibility was characterised by signal normalisation through peak RMS during a cough, average RMS during the Valsalva manoeuvre and average RMS during a 5 second maximum voluntary contraction (156). Most frequently, the measurement procedure is developed based on guidelines for non-invasive muscle assessment like SENIAM (→ www.seniam.org), ISEK (→ www.isek.org), and available academic publications. It is worth mentioning that until now, there have been no specific SENIAM guidelines for the pelvic floor (157). The applied transvaginal electrodes are usually bipolar, with two contact surfaces placed on one side – “true differential” (TD) – or with contact surfaces on opposite sides – “faux differential” (FD). At the moment, it cannot clearly be determined whether PFM should be assessed with ipsilateral or contralateral electrodes. Physiological bases for the ipsilateral innervation of PFM by the pudendal nerve is an argument for the use of TD as in the case of FD a large distance between the contact surfaces may lead to unnecessary additional CrossTalk and distort the normal sEMG signal registration. Apart from that, the pattern of PFM’s activation for contraction may differ in women with PFD and healthy women due to distorted nerve conduction on one side of the body. Based on the resent test results, it may be stated that there is no difference between the TD and FD electrodes (157,158).

Figure 5. The endovaginal electrode and the surface electrodes used in the project (photographs: the author’s own material).

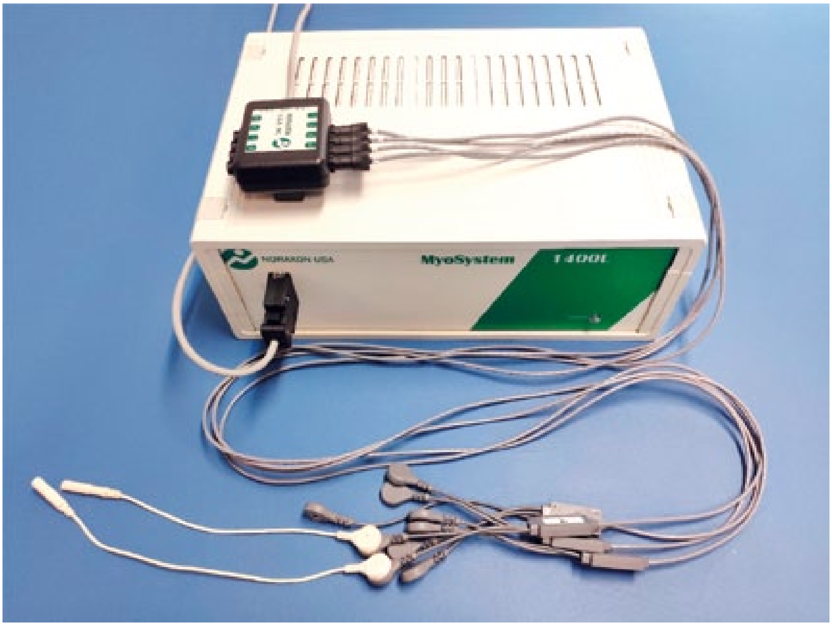


Figure 6. Eight-channel electromyograph MyoSystem 1400L used in the project (Noraxon, Scottsdale, Arizona, USA) (photograph: the author's own material).

Artefacts: During sEMG assessment, avoiding or reducing artefacts is the biggest challenge. The main sources of artefacts are (159,160):

- Electrodes.
- Movement: during functional body activity, like a cough or whole-body movement (running or jumping), the position of the electrodes may change and result in artefacts.
- Electromagnetic noise: noise from the surroundings, the patient's body and the devices' cables may overlap or block the signal registered from the muscle. Therefore, offline processing is necessary.
- In the case of sEMG signals coming from the neighbouring muscles (crosstalk). The phenomenon rarely exceeds 10%-15% of the entire signal but sometimes it results in an increase in electric activity. Depending on the parameters: the selectiveness of the EMG electrodes is determined by their location, the conducting surface, and the direction of the axis, with the muscle fibre orientation in mind. As a consequence, crosstalk may be minimised by choosing an appropriately sized electrode and maintain the distance between electrodes (usually 1–2 cm). The anal and transvaginal electrodes have a technical and practical advantage over skin electrodes.

During the pelvic floor muscle contraction, an increase in the pressure around the electrodes simultaneously increases the sEMG amplitude and decreases the crosstalk. The crosstalk phenomenon is often confused with a synergistic activation of co-activation of pelvic floor muscles (159).
- Internal noise: anatomical/biochemical/physiological abnormalities, blood flow rate, skin temperature, a larger amount of subcutaneous fat, or hormonal changes may impact sEMG activity. Thanks to high-pass spatial filtering, internal noise may be partially reduced.
- Active motor units and the mechanical interactions between the muscle fibres. The non-modifiable factors may alter the information registered in the EMG signal.

The protocol of pelvic floor muscle surface electromyographic (Glazer protocol): From the patient's perspective, the electromyographic measurement does not require any special preparation. The surface EMG is non-invasive and painless. However, the patient must be informed that before the electrodes are applied, it is necessary to remove body hair, de-grease the skin, and, in some cases, scrub the skin (161).

Assessment of patients with pelvic floor dysfunctions (162,163):

1. General examination conducted by a urologist, urogynecologist, or another doctor who has experience in this field in order to rule out a systemic disease (multiple sclerosis, diabetes, etc.) or a specific local disease (cancer, interstitial cystitis, tuberculosis etc.):
   a) Filling in a miction calendar: it contains the number of incidents connected with urinary incontinence, the activity connected with leaking urine, information about regular bowel movements, and fluid intake. The assessment will involve a review of the patients' medical history, a transvaginal and/or transrectal examination, the assessment of pelvic organ prolapse, muscle strength, and the patient's ability to control pelvic floor muscles. Depending on the history and the results of the physical examination, the urodynamic test, cystometry, cystoscopy, or uroflowmetry may be useful.
2. Before doing any recording the patient must be informed of the way the equipment is used, including the electrode and its proper placement in the body as well as the placement of the surface electrode:
   a) Instructions on the proper application of the endovaginal electrode.
   b) Bladder emptying, in order to eliminate any impact a bladder filled with urine might have on tonic PFM activity.

c) Instructions on the proper contraction and relaxation of PFM based on the anatomy and physiology of PFM and the observation of the sEMG graph on the display.
d) Evaluation and recording of the initial bioelectrical activity as well as passive and voluntary contractions. The suggested assessment protocol is as follows:
   i) A fully dressed patient in a supine position. This position allows one to move on to a more functional standing position and additionally increases the patient's proprioception in the target muscles thanks to contact with a hard surface. Then, the sensor is connected to EMG equipment.
   ii) The physiotherapist connects the electrodes which monitor the synergistic muscles according to SENIAM guidelines → www.seniam.org.
   iii) Placing a surface, self-adhesive reference electrode around the right anterior superior iliac spine and bipolar electrodes along the fibres of the right rectus abdominis, gluteus maximus, and thigh adductor muscles in order to observe their activity during maximum voluntary PFM contraction. After the EMG device is connected, the assessment may start. First, the basic information concerning the passive EMG level of pelvic floor muscles is collected. The levels of passive EMG must be measured at 1–3-minute intervals.
   iv) The registration of bioelectric PFM signals in the supine position with bent hips and knees, based on Glazer protocol consists of (figure):
      - Initial passive activity – 60 seconds of passive PFM activity measurement. The patient's task is to fully relax her pelvic floor muscles.
      - Fast contractions – 2 to 5 fast PFM contractions (within 10 seconds) after which a complete relaxation should come.
      - Functional activity – 5 ten-second contractions with a break (PFM relaxation) of 10 seconds between every two contractions.
      - Static contraction – lasting for 60 seconds.
      - End passive activity – 60 seconds of passive PFM activity measurement (164,165).
   v) Glazer protocol is often used in the software of devices for surface electromyography as a standard PFM assessment protocol, however, there still is a need to develop standards and normative values for particular phases of the protocol (165).

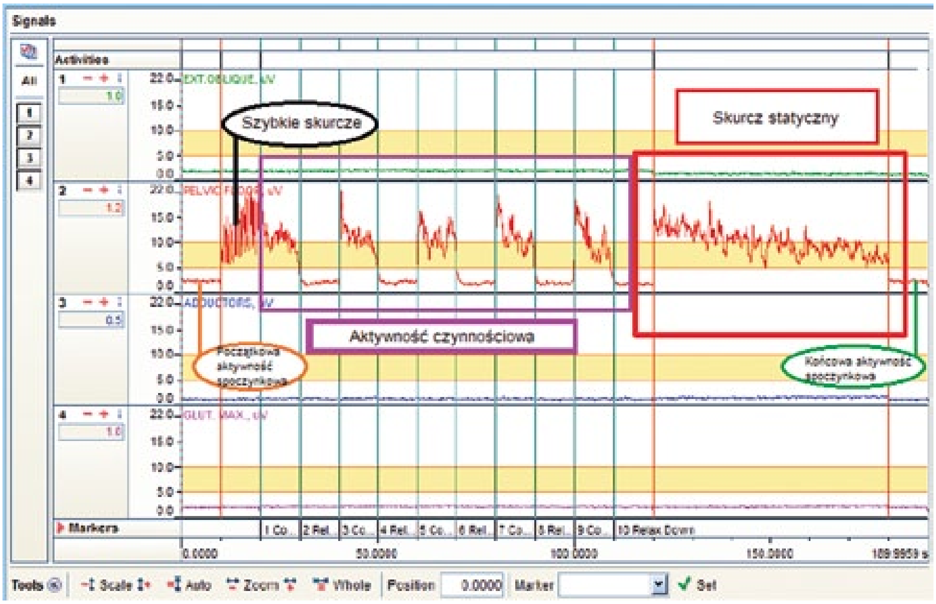


Figure 7. A model record of pelvic floor muscles' bioelectric activity according to Glazer protocol.

vi) There is no "magic" signal amplitude value during contraction and no evidence has been found to support any particular amplitude which would be necessary for urinary continence function. Patients may be monitored individually. In spite of the different protocols and electrode configurations, there is a clear connection between the characteristics of the sEMG signal and PFD (166). The results of the study by Ptaszkowski et al. from 2020 confirm sEMG as a useful measuring tool for assessing urinary incontinence and that the recordings are characterised by lower values than healthy individuals. However, to define proper reference values (norms) for the assessment of data on the sEMG activity of pelvic floor muscles, it is necessary to conduct multicentre studies on a larger population which would account for factors like a uniform methodology of studies as well as participant age and condition (167).

vii) After a pelvic floor muscle contraction, there should be a period of relaxation. It is important to isolate the pelvic floor muscles during registration and not to additionally contract muscles of the legs, abdomen, and buttocks. The voluntary contractions should be observed with the maximum amplitude, average amplitude, muscle recruitment, and fatigue in mind. The passive levels must be observed with the focus on any symptoms of muscle contractions, like abnormally high passive level or excessive activity at lower amplitudes. The relaxation time or the degree of "delay" may be defined by registering the time needed for the EMG signal to move from rest to work and from work to rest. The measurements usually are 0.5 second for the contraction and 1.0 second for relaxation. A series of five quick, strong contractions sometimes referred to as "fast movements" is a good indicator of fast-twitch fibres of the pelvic floor. The ability to perform 5 rapid contractions of this kind within ten seconds is the goal of the patients' training so that they are able to use their muscles in a functional manner, like "squeezing" during a cough or sneezing.

It is worth knowing that the sEMG signal registrations are influenced by a woman's menstrual cycle – hormones impact the perfusion of fluids in the muscles, the properties of the skin and body temperature, which could impact sEMG signal (e.g. electrical conductivity, the electrical resistance of the tissues). Therefore, in the planning phase of research experiments, it is recommended to consider the phases of the participants' menstrual cycles. (158)

3.2.1.1. sEMG Biofeedback

One of the applications of sEMG is its inclusion in conservative treatment, for example in the case of urinary incontinence. The registered sEMG signal is processed into sound or visual feedback, which helps a patient understand the functional condition of the pelvic floor muscles. It seems that it could improve the PFM awareness and the capability of selective muscle contraction. Though a limited number of well-designed, randomised controlled studies confirm this therapeutic choice, in the latest papers a close correlation was noticed between the patterns of pelvic floor muscle activation and the kind of verbal instructions needed to be given. The results of a 2019 systematic review did not show proof that PFMT combined with biofeedback brings any therapeutic benefits compared to other kinds of interventions (no training, only PFMT or pelvic floor muscles' electric stimulation) or that adding biofeedback to other interventions would be more effective than the interventions themselves. There is also no particular protocol for using BF (168).

For the purpose of this script, in July 2019, we conducted a so-called Umbrella Review - a review of systematic reviews and meta-analyses on the use of biofeedback and vaginal cones in the conservative treatment of urinary incontinence (based on the Joanna Brigg Institute reviewer's manual (169)).

Publication inclusion and exclusion criteria: I) Systematic reviews and analyses, II) publication within the last ten years, III) the intervention was not performed on pregnant women or women after childbirth, IV) biofeedback (BF) or vaginal cones constituted the intervention.

Participants: Women with urinary incontinence. Women with overactive bladders, sexual dysfunctions, and faecal incontinence were excluded.

Interventions: BF and/or VC for the improvement of pelvic floor muscles' function (as repetitive, functional pelvic floor muscles' contractions together with the monitoring conducted by a specialist).

Comparators: I) BF+ PFMT/Behavioural training vs PFMT/only behavioural training in urinary incontinence; II) VC vs no intervention, conservative treatment (PFMT, electric stimulation), or placebo effect in urinary incontinence.

Measurements: I) Number of urinary incontinence episodes and the amount of the urine, II) quality of life, III) pelvic floor muscles' strength (perineometer), IV) patient's engagement and recovery as well as V) adverse effects.

Search strategy:

- Biofeedback: ((“Pelvic Floor Disorders”[Mesh] OR “Pelvic Floor Disorders”[Title/Abstract]) OR (“Pelvic Floor”[Mesh] OR “Pelvic Floor”[Title/Abstract])) AND ((“Abdominal Muscles”[Mesh] OR “Abdominal Muscles”[Title/Abstract]) OR (“Abdominal Oblique Muscles”[Mesh] OR “Abdominal Oblique Muscles”[Title/Abstract]) OR (“Musculoskeletal System”[Mesh] OR “Musculoskeletal System”[Title/Abstract]) OR (“Rectus Abdominis”[Mesh] OR “Rectus Abdominis” [Title/Abstract])) AND ((“Pelvic floor muscle training”[Title/Abstract]) OR (“Pelvic floor muscle activation”[Title/Abstract]) OR (“Pelvic floor muscle exercise”[Title/Abstract]) OR (“Pelvic floor muscle fatigue”[Title/Abstract])) AND ((Biofeedback [Title/Abstract]) OR (*feedback [Title/Abstract]))
- Vaginal Cones: “Vaginal Cones” [Title/Abstract]

The quality assessment of the papers included in the review was completed with the use of the 16-point Amstar scale (*A Measurement Tool to Assess Systematic Reviews*) (170). Four quality levels were defined: high, moderate, low, and critically low. Two reviewers assessed the quality of the studies included in the review independently. If there was divergence, the reviewers had to reach a consensus.

Data abstraction: The information on the main results analysed in randomised clinical trials included in the systematic reviews were abstracted. All the documents were grouped according to the kind of intervention. The data abstracted from each study encompassed the kind of intervention, review ID, title, kind of review, the purpose of the review, kinds of evidence, and follow-up (table 13).

Based on the above guidelines, 37 randomised clinical studies and 64 meta-analyses were selected. Only 16 of them were in accordance with our further guidelines. Then, the titles were reviewed in-depth and 10 documents were ultimately included in the collective review. The Rayyan online platform (→ https://rayyan.qcri.org) was used by three independent reviewers for the process of paper selection.

Analysis and discussion: After the process of search and selection was conducted, significant information on the scientific evidence concerning PFMT with the use of biofeedback and vaginal cones may be observed. Ten systematic reviews or meta-analyses complied with the guidelines adopted by our team (table 9). There are 3 Cochrane reviews, 4 systematic reviews, 2 systematic reviews and meta-analyses, and 1 quantitative systematic review. The studies were published in 2009-2019.

As it was shown in tables 10 and 11, for both interventions the result with the highest number of randomised clinical studies is “urine leaking” with 19 articles connected with the use of biofeedback and 12 with the use of vaginal cones. Lack of side effects is the only result with sufficient evidence for BF supported by numerous high quality randomised clinical studies. Based on the remaining results in both interventions, positive effects were noted for “leaking” and “pelvic floor muscle strength” (perineometer), and only for “quality of life” with the use of vaginal cones. However, the quality of evidence confirming most of the results is low for biofeedback and average for vaginal cones. The most frequent cause for low study quality was a serious risk of a systematic error and lack of coherence in the methods used in the clinical trials. The conclusion is the following: **A larger number of well-designed and well-conducted randomised clinical studies are needed (e.g. According to CONSORT guidelines which you will find here: http://www.consort-statement.org/).**

Table 13. Systematic reviews and meta-analyses compliant with the adopted guidelines

Inter-vention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year published	Funding/ COI	AMSTAR score
PFMT VC	Onwude JL. (171) 2009	Stress Urinary Incontinence	Systematic Review	To answer the following clinical questions: What are the effects of non-surgical treatments and surgical treatments for women with stress incontinence?	Pelvic floor electrical stimulation (PFES) versus no treatment or sham treatment: one systematic review, three additional RCTs and two subsequent RCTs (n=392)	• Medline (1966-June 2008). • Embase (1980-June 2008). • The Cochrane Database from 1966.	No funding/no apparent COI	Critically low-quality review
PFMT VC BF	Greer JA. et al. (172) 2012	Pelvic floor muscle training for urgency UI in women: a systematic review.	Systematic Review	To summarise the available data on the effectiveness of existing physiotherapy modalities for the treatment of female Urgency UI.	The total number of RCTs included in the final analysis was 13. Ten of the included 13 RCTs were also listed in the PEDro database with PEDro scores ranging from 4 of 10 to 7 of 10. Four RCTs involving 283 women with UUI and MUI evaluated the efficacy of pelvic floor muscle exercises.	From January 1996 to August 2010	No funding/no apparent COI	Moderate quality review
BF	Herderschee et al.(173) 2013	Feedback or Biofeedback to Augment Pelvic Floor Muscle Training for UI in Women: Shortened Version of a Cochrane Systematic Review	Shortened version of a Cochrane Systematic Review	To determine whether feedback or BF add benefit to PFMT for women with UI.	Randomised or quasi-randomised (e.g., alternation) trials in women with stress, urgency or mixed UI regardless of the cause: • 24 trials were included, and many were at moderate to high risk of bias (1583 women). • 14 recruited women with stress UI only. • 5 included women with stress or mixed UI. • 2 included stress, urgency or mixed UI. • 1 urgency and mixed UI. • 2 urgency UI only.	The date of the last search was 13 May 2010 and there were no restrictions on language of publication.	No funding/no apparent COI	Moderate quality review

Inter-vention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year published	Funding/ COI	AMSTAR score
VC	Herbison et al.(174) 2013	Weighted vaginal cones for UI (Review)	Cochrane systematic review	To determine the effectiveness of vaginal cones in the management of female urinary stress incontinence	Randomised or quasi-RCTs comparing weighted vaginal cones with alternative treatments or no treatment. 23 trials involving 1806 women, of whom 717 received cones	MEDLINE (January 1966 to March 2013), EMBASE (January 1988 to March 2013)	No funding/apparent COI	Low quality review
PFMT VC BF	Mørkved and Bø (175) 2014	Effect of pelvic floor muscle training during pregnancy and after childbirth on prevention and treatment of UI: a systematic review.	Systematic review	To address the effect of pelvic floor muscle training during pregnancy and after delivery in the prevention and treatment of UI.	The database searches resulted in 117 references after deduplication. In addition to the studies included in the Cochrane Systematic Review 2008, eight new RCTs and one quasi-experimental study were found. Eight were short-term original studies and one was a 7-year follow-up study.	Reports published up to June 12 2012	No funding/no apparent COI	Low quality review
PFMT VC	Ayeleke et al. (176) 2015	Pelvic floor muscle training added to another active treatment versus the same active treatment alone for UI in women.	Cochrane systematic review	To compare the effects of pelvic floor muscle training combined with another active treatment versus the same active treatment alone in the management of women with UI.	They included a total of 13 trials in 33 reports in the current updated version. The trials included a total of 1164 women, 585 of whom received some form of PFMT added to another active treatment, while 579 received comparator treatments, which were the other active treatment alone.	May 2015	No funding/no apparent COI	High quality review

Table 13. cont.

Inter-vention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year published	Funding/ COI	AMSTAR score
VC	Oblasser et al. (177) 2015	Vaginal cones or balls to improve pelvic floor muscle performance and UI in women postpartum: A quantitative systematic review.	Quantitative systematic review.	To compare the effectiveness of vaginal cones or balls for improvement of PFM performance and UI in the postpartum period to no treatment, placebo, sham treatment or active controls.	• RCTs. • 2 parallel study arms (1 arm with 3 subgroups) with women who had incontinence 3 months postpartum 230 women with symptoms of incontinence 3 months post-partum.	There was no language, publication period or publication status restrictions.	The review is part of a PhD research project by Claudia Oblasser, funded by a City University London Scholarship.	Moderate quality review
PFMT BF VC	Moroni et al. (178) 2016	Conservative Treatment of Stress UI: A Systematic Review with Meta-analysis of RCTs.	Systematic review and Meta-Analysis	Studied the conservative management of stress UI.	Three eligible studies studied such a comparison, which included a total of 122 patients, 59 in the PFMT groups and 66 in the control groups. Incontinence-specific quality of life two studies reported this outcome. A meta-analysis demonstrated a moderate to large effect of PFMT toward a better score in incontinence-specific scales.	May 2016	Not reported	Moderate quality review
VC BF	Mateus-Vasconcelos ECL et al. (179) 2017	Physiotherapy methods to facilitate pelvic floor muscle contraction: A systematic review.	Systematic Review	To undertake a systematic review of the literature on physical therapy methods to facilitate voluntary pelvic floor muscles (PFM) contraction.	• 2 RCTs. • 1 Single-blinded RCT. • 2 Single group Pre-Postest. • 1 Cross-sectional and interventional study N=207 women (18-65 years old)	1987–2012	No funding/no apparent COI.	Critically low-quality review

Inter-vention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year published	Funding/ COI	AMSTAR score
BF	Nunes (180) 2019	Biofeedback for pelvic floor muscle training in women with stress UI: a systematic review with meta-analysis	Systematic Review and Meta-analysis	To determine whether BF is more effective than other interventions for women with stress UI in terms of quantification of urine leakage, episodes of urinary loss, quality of life and muscle strength.	11 included. RCTs involving individuals with stress UI were considered for inclusion. The total simple of the studies was 649, with an average of 59 participants per study	Between January 2000 and February 2017	Universidade Estadual do Estado do Pará (UEPA) and Brazilian fostering agencies Fundacão de Ampar Pesquisa do Estado do Pará (FAPESPA: process number 16993. UNI413. 16204. 29112014).	Moderate quality review

BF: Biofeedback; COI: Conflicts of interest; PFMT:Pelvic Floor Muscle Training; RCT: Randomised clinical trial; UI: Urinary Incontinence; VC: Vaginal Cones.

Table 14. Randomised clinical trials selected based on the adopted guidelines regarding the biofeedback

Interven-tion	Urine leaking	Quality of life	Muscle strength (Perineom-eter)	Adjust-ment	Expected effect	Side effects
Biofeed-back	19 RCTs	3 RCTs	6 RCTs	1 RCT	7 RCTs	15 RCTs
Results	Positive ef-fect PFMT+BF vs PFMT (no statistical significance)	Ambigu-ous effect	Positive effect vs Control (no statistical significance vs PFMT)	No change	Positive ef-fect PFMT+BF vs PFMT (no statistical significance)	No adverse events
Quality of evidence	Low	Average	Low	Low	Low	Average
Conclusion	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence

BF: BioFeedback PMMT: Pelvic Floor Muscles Training. Quality of evidence: Overall, the quality of evidence ranged from 'very low' to 'high'. The most common reasons for downgrading the quality of evidence was a serious risk of bias and serious inconsistency. Common sources of bias included poor or unreported compliance and inappropriate treatment of missing data when the attrition rate was high. When possible to examine, no evidence of publication bias was observed.

Table 15. Randomised clinical trials selected based on the adopted guidelines regarding the vaginal cones

Interven-tion	Urine leaking	Quality of life	Muscle strength (Perineom-eter)	Adjust-ment	Expected effect	Side effects
VC	12 RCTs	7 RCTs	3 RCTs	3 RCTs	2 RCTs	2 RCTs
Results	Positive effect vs Control (no statistical significance vs PFMT)	Positive effect vs Control (no statistical significance vs PFMT)	Positive effect vs Control (no statistical significance vs PFMT)	Very High Dropout Rate	Not enough precision to dis-tinguish better, worse or indif-ferent results	Lower in PFMT vs VC
Quality of evidence	Low quality	Medium quality	Medium quality	Medium quality	Low quality	Medium quality
Conclu-sions	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence	Insufficient evidence

PFMT: Pelvic Floor Muscles Training. VC: Vaginal Cones. Quality of evidence: Overall, the quality of evidence ranged from 'very low' to 'high'. The most common reasons for downgrading the quality of evidence was a serious risk of bias and serious inconsistency. Common sources of bias included poor or unreported compliance and inappropriate treatment of missing data when the attrition rate was high. When possible to examine, no evidence of publication bias was observed.

3.2.1.2. Implications for clinical practice/Summary

→ Though BF and VC are used in clinical practice, there still are many unanswered questions. One of the priorities when conducting the projects is to monitor whether the therapeutic recommendations are being followed and a potential assessment of the applied intervention's correlation (for example vaginal cones) with the occurrence of possible adverse effects (181). As every kind of treatment has advantages and disadvantages, the women need to be offered support to help them express what they want to achieve through their therapy (124), as well, it is important to account for their preferences (182,183) when each method is considered during the physiotherapy programme.

→ The effectiveness of PFMT depends on the patient's adherence to the proposed treatment and in the case of BF and VC, more extensive supervision by the physiotherapist is needed. For example in the case of BF with electric stimulation which a patient may use on his or her own, a more extensive education programme during the physiotherapeutic treatment is necessary to optimise muscle training with no BF, showing the clinical advantage of PFMT with EMG-BF (180). Though there are more ways to facilitate such contractions, it is hard to reach a consensus as to the hierarchy of their use (179) because, as it was mentioned above, a patient's preference, assessment methods, and a therapist's clinical experience need to be taken into account (184). Therefore, standard assessment protocols and special training is recommended for specialised physiotherapists who assess these deficiencies.

3.2.2. Myotonometry

A device called Myotone may also be used for objective evaluation of pelvic floor muscles. It is a manual device for the assessment of the soft tissues' viscoelastic properties. MyotonPRO's work is based on a short external (15 ms) mechanical low-intensity impulse (0,58 N) applied on the skin. The tissue's oscillatory response is registered by the device. Internal software calculates the tissue's passive tension, its flexibility (elasticity), and stiffness with the use of an acceleration graph (185). In the case of the pelvic floor, the diagnostic measurement of the pelvic floor muscles is conducted from the outside (it does not require transvaginal insertion) (186). Good or perfect credibility may be observed in cohort studies that assess pelvic floor muscle stiffness in women with vulvodynia who had a higher level of stiffness compared to the control group without symptoms. This could result from abnormalities in the local morphology or viscoelastic properties of the tissues or from cortical disorders (which will obviously result in the choice of different therapeutic procedures) (187).

Table 16. Characteristics of the parameters measured with Myoton-Pro (188–190).

Parameter	Definition
Tone – oscillation frequency [Hz]	Muscle tone is the baseline, involuntary tension. An increased tone (hypertonia) is often connected with muscle pain, trauma, or spasticity. Decreased tone (hypotonia) is characterised by tissue atrophy and reduced muscle strength for contraction.
Elasticity – logarithmic decrement [arbitrary unit]	Elasticity is a muscle's ability to return to the normal shape after mechanical changes and it is an indication of a muscle's condition. The higher the elasticity, the higher the muscle's ability to perform a movement and circulate blood to the fibres during physical activity. The lower the value of this parameter, the lower the blood supply in the muscles and, as a consequence, the lower the capacity for work, early fatigue and longer regeneration.
Muscle Stiffness [N/m]	Stiffness is a muscle's ability to resist changes in the shape caused by external forces and it is connected with resistance caused by antagonistic muscles. If muscle stiffness is increased, performing a movement at the same speed will require more energy than with normal values.

At the moment there is only one article (186) in which the results concerning the credibility of Myoton-Pro use on small muscle groups was published. The participants were lying in a supine position with bent and properly supported lower limbs (to make sure that legs were relaxed symmetrically during the measurement). A measurement of pelvic floor muscles was performed externally: On both sides of the perineal body (figure 8), within the superficial transverse perineal muscles and bulbospongiosus muscles. The points for measurement were chosen based on visual observation and palpation of the largest area of muscle mass during pelvic floor contraction (186). Based on the measurements in 43 healthy women and 32 women with PFD from 18 to 50 years of age, it was noticed that the small muscle group stiffness assessment is a credible and repetitive measurement process. Based on a systematic review by Mateus et al. (183) in which various methods of PFM contraction assessment were evaluated, an important aspect of discomfort and embarrassment during transvaginal palpatory PFM diagnostics was highlighted. More importantly, there is no sufficient scientific evidence that would guarantee that a transvaginal examination would provide better results than an external one (183). It seems that this statement is another good reason for searching for other external diagnostic methods, like myotonometry.

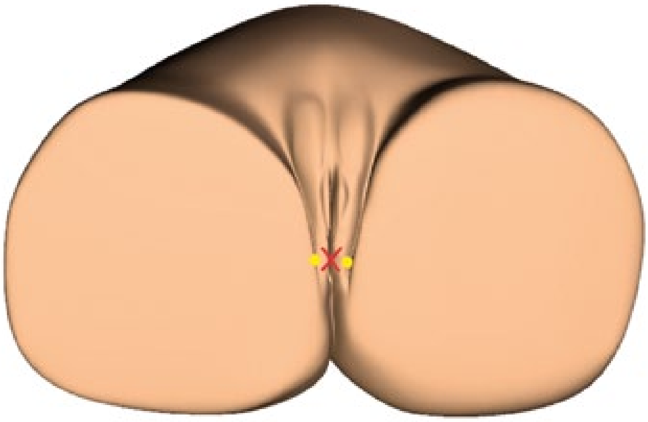


Figure 8. Location of the points where the measurements were conducted within the pelvic floor, with Myoton-Pro, from outside.

In the studies by Paolucci et al. (190) (→ see chapter 4.3. (see page 102)) and Barassi et al. (191) Myoton-pro was used for the assessment of the tension, stiffness, and elasticity of the soft tissues within the pelvic floor. In both studies, after an intervention in the form of a physical factor was applied, a decrease of the assessed parameters was observed (normalisation) which was supposed to also have an impact on the pelvic floor symptoms reported by the patients through the "fascial continuum".

3.2.3. Elastography

Shear wave elastography (SWE) is a new pelvic floor dysfunction diagnostic technique that uses ultrasound for visualising the viscoelastic properties of soft tissues, including muscles, nerves, and ligaments. SWE might be an effective method for examining weakened components of the small pelvis which may contribute to the occurrence of pathological symptoms connected with the decrease of their function (192).

Damage to the muscles and connective tissue structures as a result of many natural childbirths is a frequent cause of pelvic floor dysfunctions (122,193). Connective tissue serves an important function within the pelvis as both ligaments and fascia are largely responsible for stabilising the structures located in it. Restoring normal properties to connective tissue after childbirth is often connected with replacing type I collagen with weaker type III collagen which leads to loss of elasticity in these structures (194–196). Therefore, proper diagnostics and therapeutic procedures play a key role in preventing and mitigate the discussed dysfunctions. Elastography makes it possible to visualise and assess the stiffness of the tissue in real-time, in a credible and repetitive way (197,198).

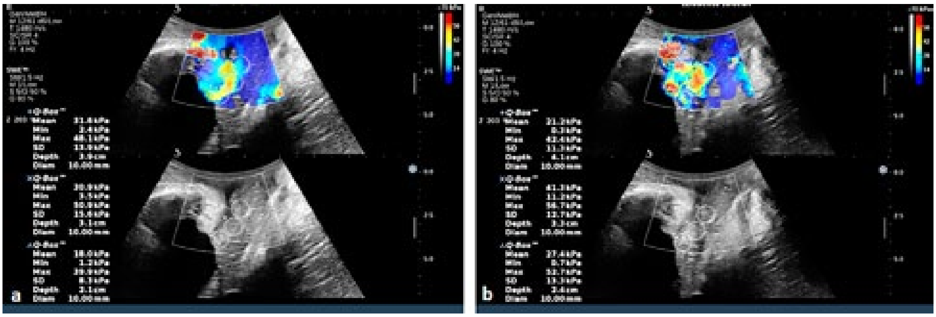


Figure 9. Image from PFM elastography a. during relaxation b. during PFM contraction. Source of photographs: the author's own archive.

4. Physiotherapy as conservative treatment

According to the Agency for Health Care Policy and Research as well as the European Association of Urology (199,200)**, pelvic floor dysfunction treatment should, primarily, be a conservative treatment**. Above all, broadly understood pelvic floor rehabilitation encompasses a change in health behaviour, the use of electrical stimulation, biofeedback, or exercise. The latter undergoes a kind of re-education on proper contraction and relaxation of pelvic floor muscles (201). Pelvic floor muscles were first described by an American gynaecologist, Arnold Kegel, in 1948. This form of therapy seems to be the most beneficial method of conservative treatment. One of the reasons for this is the fact that patients can do it at home, on their own. However, for the exercise to be effective, the patients need to be taught proper pelvic floor muscle contraction (202,203). During their proper contraction, it is advisable to maintain relaxed thigh adductors, abdomen, buttock, or erector spinae muscles (204). Bø and Mørkved emphasise that an inability to perform the so-called isolated contraction of these muscles (without engaging their synergists) might obscure the awareness of this muscle group and its strength which, in turn, translates into lower effectiveness of the proposed exercises. According to other authors, the order of different muscle groups' activation during a pelvic floor contraction correlates with urinary incontinence symptoms (205). The results of the study, on the effectiveness of the pelvic floor muscles, differ depending on whether patients exercise pelvic floor muscles after identifying them, how they exercise, and how engaged they are in the exercises (202,206). Various studies show (207,208) that about 30% of the women who participated in them were not able to perform an isolated pelvic floor muscle contraction without previous written or oral instructions. What's more, the amount increases to about 70 % in the case of women with pelvic floor dysfunctions (209). The study by Henderson et al. (210) shows that healthy women or women with mild pelvic floor dysfunctions perform pelvic floor muscle contraction properly after receiving verbal instructions which suggest that preventive exercises may be done without contact with, e.g., a physiotherapist (210). Therefore, it seems that in the case of some women, verbal and/or non-verbal instructions are important, especially during the attempt to perform a pelvic floor muscle contraction the patient holds her breath or contracts her abdominal muscles. Both activities lead to an increase of pressure in the abdominal cavity and lowering of the pelvic floor, which does not lead to an improvement in its strength (211). Apart from that, the use of auxiliary techniques in teaching the patients a voluntary pelvic floor muscle contraction may be significant, as the sole exercises might not bring the expected results (212).

Table 17. Physiotherapy's potential in pelvic floor dysfunctions treatment (213,214)

Physiotherapy method	Intervention
Physical therapy	• Thermotherapy: Warmth/coldness • Electrotherapy: Electrical stimulation of pelvic floor muscles • Laser treatment • Pelvic floor muscle biofeedback • Magnet therapy
Manual therapy/ massage	• Soft tissue mobilisation to reduce restrictions and improve mobility • Joint mobilisation in order to improve the range of motion • Dry needling
Kinesiotherapy/ exercise	• Pelvic floor muscle exercise • Positional inversion • Core stability • Functional exercises • Relaxation techniques
Patient's education:	• Posture/body mechanics • Bladder training • Diet modification • Change of bathroom habits

4.1. Exercises

The therapeutic programme which involves exercises is based on the concept of motor learning and may be divided into phases:

- **Phase 1:** Understanding: the patients must understand the location and functions of the pelvic floor muscles.
- **Phase 2:** The "Where is my pelvic floor?" search. Patients need time to apply what they learnt from understanding their bodies and often need feedback as well as improvement in proprioception. Taking into account the imbalance and postural defects as well as lack of proper pelvic floor muscle activation time in women with stress urinary incontinence, the role of proprioception improvement in motor control seems essential. However, further research is needed in this field. (215)
- **Phase 3:** Learning (automation) – patients must learn to perform a contraction and relaxation of pelvic floor muscles properly and feedback from a physiotherapist is recommended at this point (216,217).

Learning to perform a contraction and relaxation of pelvic floor muscles

Patient's starting position: lying in the supine position with bent hip and knee joints

Therapist: provides verbal instructions "tighten your muscles around the electrode/the therapist's finger which is inside your body as hard as you can (as if you wanted to stop a urine stream) and then fully relax them" (218). If it is impossible to use a transvaginal electrode or palpation, according to Ami and Dar (219),

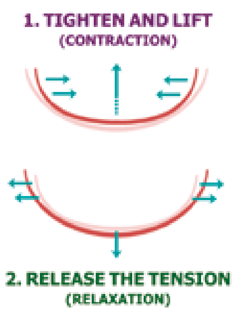


Figure 10. Pelvic floor muscles during contraction and relaxation. Source: the author's own materials

the verbal instruction: "Tighten the sphincter muscles around your anus" activates the pelvic floor muscles the most. The activities have the characteristics of an isolated contraction: thigh adductors, abdomen, buttock, or erector spinae muscles remain relaxed. According to Bø and Mørkved (25), an inability to perform the so-called isolated contraction (without engaging the synergists) might obscure awareness of this muscle group and its strength which, in turn, translates into lower effectiveness of the proposed exercises.

- **Phase 4:** Monitoring – most patients will still have to work on performing voluntary and coordinated contractions as well as recruitment of the motor units during each contraction. In the rehabilitation process, and in fact the prevention process too, patients are an active and irreplaceable part (220).

How long should the exercise programme last?

According to a systematic review of 2018 (221), the shortest duration of the exercise programme proposed by some researchers is 6 weeks and the biggest changes are observed during short exercise sessions (10–45 min.) with a frequency of 3-7 days a week. (222)

Other pelvic floor exercise possibilities proposed by various specialists:

- Hypopressive exercises: They consist of performing movements and positions which increase negative pressure in the abdominal cavity, which causes activation and reprogramming in the work of the diaphragm, transversus abdominis, and obliques as well as pelvic floor (involuntary activation). The exercises are recommended in posture correction, postnatal physiotherapy, and PFD treatment (pregnancy and hypertension are contraindications). As the exercises are difficult to do, one on one sessions are often necessary. (223) In 1980, Caufriez suggested a hypothesis that since the pelvic floor muscles consist of tonic muscle fibres (type I), they can benefit from training through autonomous and tonic activation but not maximum contraction. Study results from 2018 do not confirm the recommendation of hypopressive exercises for strengthening the pelvic floor neither in the postpartum period nor outside it. According to the authors, pelvic floor muscle training remains the first-line treatment in the case of pelvic floor dysfunctions. There still is a shortage of high-quality clinical trials which would assess the effectiveness of this form of exercise in PFD. (224)
- Pilates: The main purpose of this method is to improve the general posture and balance the tension in the muscles which surround the lumbar-pelvic

area. It is based on the strength and stability of the muscles which form the core (→ see chapter 1.1. (see page 13)), posture, and breathing (225). According to Chmielewska et al. (164), knowledge on the impact of Pilates on PFM is still minor. Several elements of Pilates training may increase the pressure in the abdominal cavity and therefore increase the compression of the lesser pelvis which ultimately leads to an escalation of the urinary incontinence symptoms. This team's research shows that neither the sEMG biofeedback exercises nor the Pilates exercises resulted in a significant increase in PFM's bioelectric activity during contractions. (164) The results of the study published in 2020 are different though – in healthy women, in some positions, especially "core" and "plank", a higher pelvic floor muscle activity was observed. (226) Therefore, it seems that when choosing an additional physical activity, the current functional condition of the exercising patient's pelvic floor and the way the pelvic floor reacts to the proposed exercises is crucial. (227)

Siff et al. (228) proposed the comparison between Kegel's exercises and 10 popular exercises: bird dog, bridge, clam, crunch, tucked squat, untucked squat, leg lift, plank, plié, and thigh adduction, assuming that, among others, they would increase PFM strength and decrease the levator hiatus area. The authors observed that exercises like bird-dog, plank, and leg-lift might serve as an alternative to the traditional PFM exercises. (228)

Bø describes two possibilities and opposing hypotheses which concern physical activity's impact on the pelvic floor (127):

1. Exercises strengthen the pelvic floor. During general physical activity, a co-contraction of pelvic floor muscles (indirect effect) may occur. This could decrease the levator hiatus area which causes its hypertrophy and shortening which, in turn, elevates the pelvic floor and internal organs. Theoretically, such morphological changes may decrease the risk of urinary incontinence, faecal incontinence, or pelvic organ prolapse. On the other hand, it is also possible that the changes may have a negative impact on childbirth, by making it more difficult for the foetus to descend during pushing.
2. General training causes overburdening, stretching, and weakening of the pelvic floor. Physical activity increases intra-abdominal pressure and if pelvic floor muscles are not able to co-contract quickly or with sufficient strength to counteract the increased pressure or to withstand the ground reaction force, the levator hiatus area may expand, stretch, and weaken the muscles. According to this theory, pelvic floor muscle overburdening may increase the risk of urinary/faecal incontinence

and pelvic organ prolapse but, on the other hand, it should result in easier labour.

The hypothesis that strenuous exercise may contribute to PFD occurrence (though still minor) has more evidence than the hypothesis that regular exercise is beneficial for PFM functions. Sportspeople with pelvic floors functioning in an optimum manner probably manifest both positive and negative pelvic floor reactions to burdening, e.g., the pelvic floor of a gymnast may withstand the forces generated during landing on an exercise mat but it does not have to withstand the forces during landing on a beam. Individual predispositions may be very significant (127).

4.1.1. Effectiveness of pelvic floor muscle training as well as abdominal muscle training, Pilates, and yoga

As it was mentioned above, in 1948, Dr Arnold Kegel described the impact of regular, particular strength training of pelvic floor muscles on urinary incontinence and pelvic organ prolapse in women (229). However, there are several aspects that require clarifying: for example, whether the exercises should be performed under supervision or not, with vaginal cones or without them, with biofeedback or electrical stimulation? The Cochrane reviews define the effectiveness of the pelvic floor muscles' training (PFMT) as a first-line conservative treatment (230,231) and the best results are received with supervised personal training and patient monitoring (231). In 2011 and 2015, Dumoulin et al. (230) conducted a systematic review to evaluate the effectiveness of pelvic floor muscle exercise in women with stress urinary incontinence and they received the highest level of scientific evidence – A, based on a meta-analysis of numerous randomised studies which was also confirmed in publications by other authors. (203,232,233) There also are other studies that analyse not only the use of the traditional PFMT but also exercise forms like yoga or Pilates. The main purpose of our review was to define the effectiveness of pelvic floor muscle exercises which are isolated or combined with transversus abdominis (TrA) exercises, Pilates, or yoga training in preventing or treating urinary incontinence. Apart from that, we present a review of current exercises used for urinary incontinence and define the fields in which additional evidence is still needed.

What publications were included in the review? Systematic reviews and meta-analyses which describe the effectiveness of pelvic floor muscle exercises, transversus abdominis exercises, yoga, and Pilates (a so-called umbrella review).

Publication inclusion and exclusion criteria: i) systematic reviews and meta-analyses, ii) published within the last 10 years, iii) the intervention was not performed in pregnant or post-partum women and iv) the intervention is based on PFMT, TrA, yoga, or Pilates. The studies which analysed therapy combined with biofeedback, electrical stimulation, etc. were excluded.

Search details: The short review was performed in July 2019 in the PubMed and Cochrane medical databases. The search strategy was the following: ((“Pelvic Floor Disorders”[Mesh] OR “Pelvic Floor Disorders”[Title/Abstract]) OR (“Pelvic Floor”[Mesh] OR “Pelvic Floor”[Title/Abstract])) AND ((“Abdominal Muscles”[Mesh] OR “Abdominal Muscles”[Title/Abstract]) OR (“Abdominal Oblique Muscles”[Mesh] OR “Abdominal Oblique Muscles”[Title/Abstract]) OR (“Musculoskeletal System”[Mesh] OR “Musculoskeletal System”[Title/Abstract]) OR (“Rectus Abdominis”[Mesh] OR “Rectus Abdominis” [Title/Abstract]. In total, we found 989 systematic reviews and meta-analyses (umbrella reviews) but 37 publications were selected for further analysis. They underwent critical evaluation after which 9 articles were ultimately selected for further review. The Rayyan Online Platform (https://rayyan.qcri.org/) was used for independent assessment and their ultimate inclusion into further analysis.

How did we evaluate the article quality? We used the AMSTAR – *A MeaSurement Tool to Assess Systematic Reviews* (AMSTAR 2) scale for evaluating the quality of the articles (170).

Data clustering: All the publications included in the review were grouped according to the evaluated intervention.

Nine systematic reviews or meta-analyses complied with our guidelines (Table 8). There are 2 reviews in the Cochrane base, 4 systematic reviews, 2 systematic reviews and meta-analyses, and 1 review (scoping review). The studies were published between 2009 and 2019. In Table 9, we can see that the largest number of randomised clinical trials are connected with the use of PFMT and the assessment of urine leakage in 24 hours. The remaining results brought positive effects when it comes to quality of life and the urinary incontinence questionnaire (IMQUI). However, the quality of the evidence confirming all the results is low and a larger amount of randomised clinical trials is needed. When it comes to interventions involving transversus abdominis exercises (Table 10), the quality of RCT is low and the evidence is insufficient to justify an intervention in the form of isolated TrA training or combined with PFMT in the case of urinary incontinence.

Table 18. The characteristics of the reviews on pelvic floor muscles' exercises, transversus abdominis exercises, yoga and Pilates in urinary incontinence.

Intervention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year studies were published	Funding/COI	AMSTAR score
Pelvic floor muscle training, PFMT	Hay-Smith EJC et al. 2011 (231)	Comparisons of approaches to pelvic floor muscle training for urinary incontinence in women (Review)	Cochrane Systematic Review	To compare the effects of different approaches to pelvic floor muscle training for women with urinary incontinence.	21 trials were included in the review. The 21 trials randomised 1490 women. Nearly two-thirds (13 of 21 trials) had more than 20 and fewer than 50 participants per comparison group. Four trials were small, with fewer than 20 per comparison group.	17 May 2011	Declared internal sources of funding with apparent COI	Moderate quality review
PFMT	Dumoulin et al. 2018 (230)	Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women	Cochrane Systematic Review	To assess the effects of pelvic floor muscle training for women with urinary incontinence in comparison to no treatment, placebo or sham treatments, or other inactive control treatments; and summarise the findings of relevant economic evaluations.	All included trials were RCTs except one, which was considered to be quasi-randomised. Sample size ranged from 15 to 143 participants per study (n=2632)	12 February 2018	No funding/ apparent COI	High-quality review
PFMT+ Transversus abdominis training+ Pilates	Kari Bø et al. 2013 (234)	There is not yet strong evidence that exercise regimens other than pelvic floor muscle training can reduce stress urinary incontinence in women: a systematic review	Systematic Review	What evidence is there for alternative exercises to specific pelvic floor muscle training for treatment of female stress urinary incontinence?	Among the seven randomised controlled trials that were included, three assessed abdominal training, two assessed the Paula method, and two assessed Pilates exercise.	4 January 2013	No funding/ apparent COI	Low-quality review

Intervention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year studies were published	Funding/ COI	AMSTAR score
PFMT	Paiva et al. 2017 (235)	Pelvic floor muscle training in groups versus individual or home treatment of women with urinary incontinence: systematic review and meta-analysis.	Systematic review and Meta-Analysis	To perform a systematic review comparing the effects of group pelvic floor muscle training vs individual or home training in the treatment of women with urinary incontinence.	Ten studies were found to fit all the inclusion and eligibility criteria and were included in the review. Of the 10 selected studies, 5 compared PFMT in groups vs individuals; 3 studies compared PFMT in groups vs at home; and 2 compared PFMT in groups vs individuals vs controls. The exercise protocols used in the selected studies were very different. The total number of participants in the 10 selected studies was 927 women and the mean ages in the studies ranged from 42-60 years old.	June 2016	No funding/no apparent COI	Moderate quality review
PFMT	Onwude 2009 (236)	Stress incontinence	Systematic Review	To answer the following clinical questions: What are the effects of non-surgical treatments and surgical treatments for women with stress incontinence?	Pelvic floor Muscle Exercise: one systematic review (search date 2004, 3 RCTs), and one subsequent RCT. (n=389)	Medline: 1966–June 2008, Embase: 1980–June 2008, CDRS i CENTRAL: 1966–2008	No funding/no apparent COI	Critically low-quality review
PFMT	Greer JA. et al. 2012 (172)	Pelvic floor muscle training for urgency urinary incontinence in women: a systematic review.	Systematic Review	To summarise the available data on the effectiveness of existing physiotherapy modalities for treatment of female Urgency Urinary Incontinence.	13 RCTs. Ten of the included 13 randomised controlled trials were also listed in the PEDro database with PEDro scores ranging from 4 of 10 to 7 of 10. Four randomised controlled trials involving 283 women with UUI and MUI evaluated the efficacy of pelvic floor muscle exercises.	From January 1996 to August 2010	No funding/no apparent COI	Moderate quality review

Table 18. cont.

Intervention	Authors	Title	Type of review	Purpose of the review	Types of evidence and sample size reported	Year studies were published	Funding/ COI	AMSTAR score
PFMT+ Abdominal muscles' training	Moroni et al. 2016 (237)	Conservative Treatment of Stress Urinary Incontinence: A Systematic Review with Meta-analysis of Randomized Controlled Trials.	Systematic review and Meta-Analysis	Studied the conservative management of stress urinary incontinence (SUI).	Three eligible studies studied such a comparison, which included a total of 122 patients, 59 in the PFMT groups and 66 in the control groups. Incontinence-specific quality of life two studies reported this outcome. Meta-analysis showed a moderate to large effect of PFMT toward a better score in incontinence-specific scales.	10 May 2016	Not reported	Moderate quality review
PFMT+ Abdominal muscles' training	Radzimińska et al. 2018 (238)	The impact of pelvic floor muscle training on the quality of life of women with urinary incontinence: a systematic literature review	Systematic Review	The purpose of this review was to assess the effectiveness of pelvic floor muscle training in the treatment of urinary incontinence in women, with a focus on the impact of this form of therapy on the patients' quality of life.	Twenty-four articles were included in the final review. There were between 30 and 446 women (a total of 2,394 patients), aged 40–85 years old in each study group. The Jadad scale showed that 19 research findings were randomised and additionally 5 of them were blinded.	November 2017	No funding/no apparent COI	Critically low-quality review
Joga	Sha et al. 2019 (239)	Yoga's Biophysiological Effects on Lower Urinary Tract Symptoms: A Scoping Review	Scoping Review	Regard to the evidence for the effects of yoga on lower urinary tract symptoms and factors that may mediate yoga's effects on lower urinary tract symptom with the goal to find gaps in knowledge about the relationship between yoga practice and lower urinary tract symptom	The eight articles included 186 men and women. Seven of the eight studies used an integrated yoga program that included physical postures, breathing exercises, relaxation, and meditation as the intervention. Three randomised trials, four nonrandomised pilot studies and one case report.	2012 to 2017	No funding/no apparent COI	Critically low-quality review

COI: Conflicts of interest; PFMT: Pelvic floor muscle training; TrA: Transversus Abdominis; RCT: Randomised clinical trial; CDRS: The Cochrane Database of Systematic Reviews; CENTRAL: Cochrane Central Register of Controlled Clinical Trials.

Table 19. The main conclusions and the quality of the evidence in the treatment of urinary incontinence through pelvic floor training.

Intervention	Nocturia	Pad test (1h)	Pad test (24h)	Urination frequency	Quality of life	Urine leakage (24h)	IMQUI Questionnaire	KHQ /functional limitations	KHQ /impact	KHQ /severity	Expected recovery	Additional effect
PFMT	5 studies (5 RCT)	6 studies (6 RCT)	3 studies (3 RCT)	5 studies (5 RCT)	5 studies (5 RCT)	12 studies (12 RCT)	3 studies (3 RCT)	3 studies (3 RCT)	3 studies (3 RCT)	3 studies (3 RCT)	5 studies (5 RCT)	1 RCT (1 RCT)
Results	No effect	Mixed effect	No effect	Mixed effect	Positive effect	Positive effect	Positive effect	Mixed effect	Mixed effect	Mixed effect	Mixed effects	1 RCT reported pain
Quality of the studies	Low	Low	Low	Low	Average	High	Medium quality	Low quality	Low quality	Low quality	Low quality	Medium quality
Conclu-sions	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence	Insuf-ficient evidence

KHQ: King's Health Questionnaire IMQUI: Incontinence Modular Questionnaire Urinary Incontinence Quality of evidence: Overall, the quality of evidence ranged from 'very low' to 'high'. The most common reasons for downgrading the quality of evidence were serious risk of bias and serious inconsistency. Common sources of bias included poor or unreported compliance and inappropriate treatment of missing data when the attrition rate was high. When possible to examine, no evidence of publication bias was observed.

Table 20. The main conclusions and the quality of the evidence in the treatment of urinary incontinence through pelvic floor training.

Intervention	Quality of life
TrA and PFMT vs PFM with no exercise	RCT 1
Results	No difference
Quality of evidence	Low
Conclusions	Insufficient evidence

Quality of evidence: Overall, the quality of evidence ranged from 'very low' to 'high'. The most common reasons for downgrading the quality of evidence were serious risk of bias and serious inconsistency. Common sources of bias included poor or unreported compliance and inappropriate treatment of missing data when the attrition rate was high. When possible to examine, no evidence of publication bias was observed.

Tables 21 and 22 present the conclusions concerning the interventions with the use of two particular training methods: yoga and Pilates. There is insufficient evidence concerning all the assessed parameters, as only 1 RCT confirmed the results, however, it is of low methodological quality so it should not be used as basis in therapy planning. Frequency is the result with positive effects, when the intervention involves yoga but as it was mentioned before, RCT is of low quality, and we cannot base our clinical practice on so little evidence. Therefore, in the interventions of this type, we need more RCT with well-conducted examinations.

Table 21. The main conclusions and the quality of the evidence in the treatment of urinary incontinence with yoga exercises. (239)

Intervention	Nocturia	Urination frequency
Yoga	1 study (1 RCT)	1 study (1 RCT)
Results	No effect	Positive effect
Quality of evidence	Low	Low
Conclusions	Insufficient evidence	Insufficient evidence

Table 22. The main conclusions and the quality of the evidence in the treatment of urinary incontinence through Pilates exercises.

Intervention	PFDI-20 questionnaire	PFQ-7 questionnaire
Pilates	RCT 1	RCT 1
Results	No effect	No effect
Quality of evidence	Low	Low
Conclusions	Insufficient evidence	Insufficient evidence

PFDI-20: Pelvic Floor Stress Inventory Short Form PFIQ-7: Pelvic Floor Impact Questionnaire Quality of evidence: Overall, the quality of evidence ranged from 'very low' to 'high'. The most common reasons for downgrading the quality of evidence were serious risk of bias and serious inconsistency. Common sources of bias included poor or unreported compliance and inappropriate treatment of missing data when the attrition rate was high. When possible to examine, no evidence of publication bias was observed.

Generally, the quality of the evidence confirming the interventions based on particular exercises is low. The most frequent cause for lowered data quality was a serious risk of systematic error and lack of coherence in the methods used in the clinical trials. We could state that PFMTs enjoy the highest quality of evidence, however, it does not indicate strong support in most of the measured results.

4.1.2. Implications for clinical practice

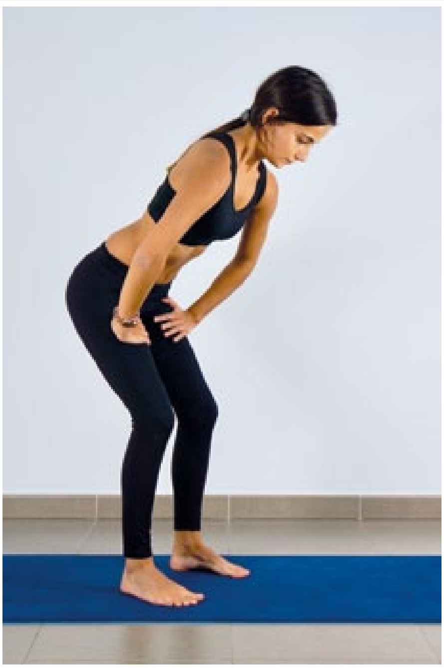
- → Though the interventions based on pelvic floor muscle training are often used in clinical practice, researchers are still looking for a more definite answer when it comes to the effectiveness of exercises focused on the pelvic floor.
- → PFMT is currently one of the main strategies used by physiotherapists in the treatment of urinary incontinence. Its use is also applied in a number of articles that analyse the impact of exercises which strengthen pelvic floor muscles. Currently, the best evidence is focused on preventing urine leakage and the impact on the quality of life and IMQUI.
- → The application of isolated abdominal muscle training or abdominal muscle training combined with PFMT lacks sufficient evidence. As Bø et al. said (234), a TrA co-contraction occurs during PFM contraction but the PFM co-contraction occurs during TrA contraction may be lost or weakened when a patient suffers from UI. The use of this type of exercise is not well-supported by scientific evidence.
- → Yoga or Pilates, as unique training methods, seem to impact the improvement of PFM strength, regulation of the autonomic nervous system, and activation of the central nervous system (239), however, currently there is no evidence to confirm this hypothesis. The theory on the use of Pilates suggests that a PFM co-contraction, which appears by coincidence when the exercises are being performed, counteracts increasing pressure in the abdominal cavity which prevents urine leakage and strengthens PFM. However, there is no sufficient evidence to support this hypothesis. **Therefore, such an approach could be used as a complement to PFMT.**

Our umbrella review confirms that PFMT is the first choice in conservative treatment for all types of urinary incontinence. The conclusions are our challenge for the future – to create a solid framework for the protocols of clinical interventions concerning physical activity and PFM. The current, extensive review on PFMT shows that women with abnormal function of pelvic floor muscle contraction and relaxation (motor control disorder) are usually excluded from the projects which assess PFMT's impact on PFM (240) – women in the postpartum period are a good example. (241)

Table 23. Sample functional exercise set for PFM (242)

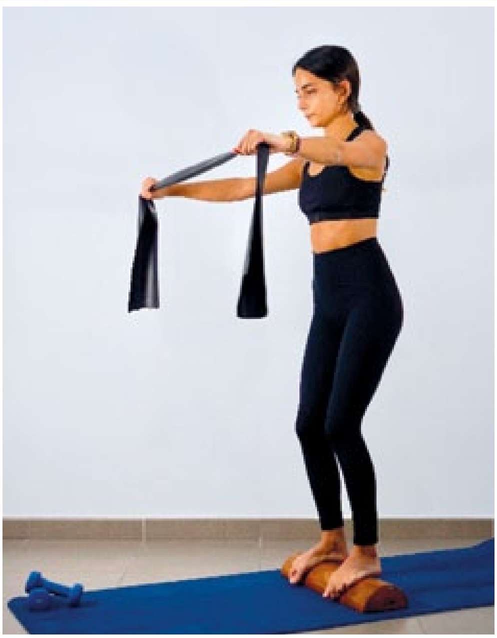
Exercise	Description
	Starting position: propped kneeling, chin close to the neck, lumbar region in a neutral position, hands under the shoulder joints, knees under the hip joints, active shoulder girdle. While breathing freely, the spine is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles.
	Starting position: lying on the back on a roller, legs bent on the ground, chin close to the neck, lumbar region in a neutral position (not pressed to the ground). While breathing freely, the spine is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).
	Starting position: lying on the back on a roller, legs bent on the ground, chin close to the neck, lumbar region in a neutral position (not pressed to the ground). While breathing freely, the spine is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).

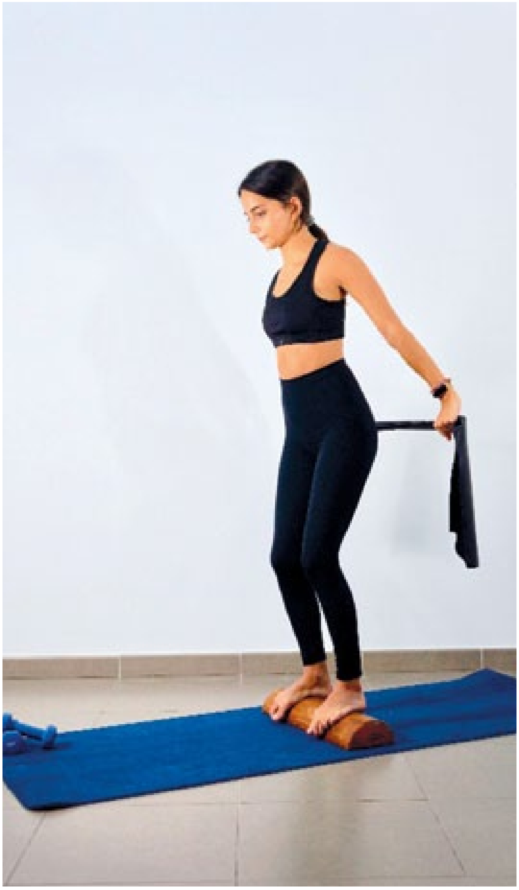
Exercise	Description
	Starting position: lying on the back on a roller, legs bent on the ground, chin close to the neck, lumbar region in a neutral position (not pressed to the ground). While breathing freely, the spine is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).
	Starting position: cross-legged sit. The torso is tilted forward so that the ischial tuberosities are on the ground all the time and to avoid bending the torso. The upper limbs in internal rotation, shoulder joints bent inwards. The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).
	Starting position: upright kneeling, knee joints hip-width apart, placed directly under the knee joints (no rotation in the hip joints). The torso is tilted forward so that the toes are on the ground all the time and to avoid bending the torso. The knee joints are slightly bent, the upper limbs are in internal rotation, placed on the iliac crest (elbows bent at an angle of 90°). The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).

Exercise	Description
	Starting position: standing, feet hip-width apart, directly under the knee joints (no rotation in the hip joints). The torso is tilted forward so that the heels are on the ground all the time and to avoid bending the torso. The knee joints are slightly bent, the upper limbs are in internal rotation, placed on the iliac crest (elbows bent at an angle of 90°). The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing the hip joint (pelvic floor muscle contraction first).
	Starting position: standing, feet hip-width apart, directly under the knee joints (no rotation in the hip joints). The torso is tilted forward so that the heels are on the ground all the time and to avoid bending the torso. The knee joints are slightly bent, the upper limbs are in internal rotation, placed on the thighs (elbows bent at an angle of 90°). The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** while simultaneously contracting the pelvic floor muscles followed by flexing in the hip joint (pelvic floor muscle contraction first).

Exercise	Description
	Starting position: lying on the back with legs bent at the knees, feet hip-width apart firmly on the ground (bridge). The upper limbs along the body. Hold a yoga ball or brick between the knee joints. The pelvis and spine (vertebra by vertebra) are lifted with exhalation until the torso rests on the shoulder girdle. During the movement, isometric tension of the lower limbs and the pelvic floor occurs.
	Starting position: lying on the back with legs placed on a Swedish ball. Upper limbs raised, holding a resistance band . The pelvis and spine (vertebra by vertebra) are lifted while you are exhaling until the torso rests on the shoulder girdle only. During the movement, isometric tension of the lower limbs, pelvic floor and upper limbs occurs, while the resistance band is stretched.
	Starting position: lying on the back with legs bent at the hip and knee joints, ball between the knees, upper limbs bent at the shoulder joints at an angle of 90°. During the movement, isometric tension of the upper limbs, lower limbs and the pelvic floor occurs.

Exercise	Description
 1  2	Starting position: lying with your back on a Swedish ball, legs bent at the hip and knee joints, upper limbs with weights bent at the shoulder joints at an angle of 90°. During the movement, there is isotonic tension (abduction and adduction [1] + flexion [2]) of the upper limbs and the pelvic floor.
	Starting position: front supports on unstable ground (Swedish ball). When in the position, there is isometric tension in the abdominal (core) muscles and pelvic floor.

Exercise	Description
	Starting position: standing, feet hip-width apart, directly under the knee joints (no rotation in the hip joints). The knee joints are slightly bent, the upper limbs are bent at an angle of 180° (elbows bent at an angle of 90°). The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** with co-contraction of the pelvic floor muscles and stretching of the tape held in the hands (pelvic floor muscle contraction first).
	Starting position: standing, feet hip-width apart, directly under the knee joints (no rotation in the hip joints). The knee joints are slightly bent, the upper limbs bent at an angle of 90°. The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** with co-contraction of the pelvic floor muscles and stretching of the tape held in the hands (pelvic floor muscle contraction first).

Exercise	Description
	Starting position: standing, feet hip-width apart, directly under the knee joints (no rotation in the hip joints). The knee joints are slightly bent, and the shoulder joints are extended. The torso is elongated (elongation), 3 × inhale through the nose + exhale through the mouth*. Exhale, hold your breath and perform the so-called mock inhalation** with co-contraction of the pelvic floor muscles and stretching of the tape held in the hands (pelvic floor muscle contraction first).
	Starting position: lying with the back on a Swedish ball. During the exercise, there is isotonic tension in the abdominal (core) muscles, pelvic floor, and upper limbs.

Exercise	Description
 	Starting position: standing with the torso resting against a wall (stabilized position). While breathing freely, isometric tension of the core muscles occurs with simultaneous tension in the area of the upper limbs in various configurations.

Exercise	Description
 	Starting position: corrected position, sitting on a Swedish ball (unstable position), with a neutral position of the pelvis, feet firmly on the ground. While breathing freely, isotonic tension of the core muscles occurs with simultaneous tension in the area of the upper limbs in various configurations (flexion, abduction, alternating movements).
	Starting position: one-legged kneeling with upper limbs resting on a Swedish ball (unstable position). While breathing freely, isotonic tension of the core muscles occurs with simultaneous tension of the pelvic floor muscles and the forward movement of the torso.

* Make sure the lower abdomen is lowered towards the spine during exhalation.
** Fake inhalation – sucking in air while not taking air in, when the chest widens and the abdomen is sucked inward.

4.2. Soft tissue manual therapy in pelvic floor dysfunction treatment

The use of various manual techniques: myofascial release, trigger points technique, and physical therapy (transcutaneous electrical nerve stimulation [TENS], functional electrical stimulation [FES], warmth and cold) are the treatment of choice in pelvic floor dysfunctions. Trigger points in the myofascial tissues may be one of their sources (243). Manual techniques may remove trigger points (by improving the blood flow in the vessels), balance the hyperactivity (hypertonia), and increase pelvic floor muscle strength. (244) According to the definition by the International Federation of Orthopaedic Manipulative Therapists (IFOMT), manual therapy is "a specialised area of physiotherapy devoted to proceeding in neuromusculoskeletal diseases based on clinical inference and the use of highly specialised treatment methods including manual techniques and therapeutic exercise". Apart from joint techniques, which are characterised by suddenly exceeding the physiological range of motion, there are the so-called soft techniques which, among others, consist of therapy for trigger points, myofascial release, or muscle energy techniques (245). The desired effects of the soft techniques' use are vasodilation, increase in tissue mobility, a decrease in the concentration of chemical pain mediators, reduction of hypersensitivity to pain as well as an improvement in tissue integrity and moveability (246). Soft tissue manipulation is a kind of manual therapy and understanding it as a kind of mechanotherapy may impact not only the course of the conducted therapy but also the planning of reliable clinical trials (247). **Mechanotherapy** is defined as any manual intervention which uses mechanical stimulants for changes in the tissues on a biomechanical level through **mechanotransduction** processes (whose goal is to improve tissue function). Mechanotransduction is a mechanism through which a specialised cell (e.g. fibroblasts, telocytes) transforms a mechanical stimulant (twisting, tensing, squeezing, stretching, bending, and rubbing) on chemical activity (23,248). According to some authors, the use of soft tissue mobilization may have a direct impact on molecular pathways, cellular response, tissue structure, and function as well as their healing, repair, and regeneration (249,250). The elastic strain of soft tissue structures leads to tension within their elasticity and transmission of pulling forces through integrins on the fibres which form the cell cytoskeleton. The mechanical factor reaches the inside of the cell and causes various reactions on the molecular level in it. The reactions may have a character of quick changes observed in tissues on the hormonal regulation level (e.g. elevating the level of endorphins) or a long-lasting character which consists in the expression of growth factors that initiate tissue structural adaptation to the altered external conditions (e.g. VEGF, FGF expression) (248,251,252).

In the Bazie Cochrane Database of Systematic Reviews, there are several extensive review protocols on the use of manual therapy in various disease (253–257). Among them, the only one referring to the pelvic floor is the publication by Lonkhuyzen et al. (257) from 2016 which evaluates the usefulness of physiotherapy in the treatment of bladder and intestine dysfunctions in children. One of its options is manual therapy within the abdomen referred to as "abdominal wall massage" (257). A systematic review of 2017 refers to the use of osteopathic manual therapy (OMT) in lower urinary tract symptoms (LUTS) in women. Among them, there are stress and mixed urinary incontinence. This shows that an intervention in the form of OMT brings more beneficial therapeutic effects compared to the control group (without intervention). OMT are various techniques used within the osteopathic system so it is difficult to isolate a particular technique that affects LUTS in the analysed publications, which is emphasised by the authors of the review (258). According to the osteopathic concept, the origin of LUTS may lie in the ligaments connected with the bladder, uterus, pelvic floor muscles, obturator foramen, pubic symphysis, sacral bone, or thoracic spine (258). Here, it is worth mentioning that in OMT, a patient's body is treated as a whole, i.e. all the organs, muscles, and body structures are seen in the context of their surroundings while a particular dysfunction (e.g. urinary incontinence) cannot be fully understood or treated without taking it into account (97,259) → More in chapter 4.2.2. (see page 100).

Hung et al. (52) published a randomised intervention trial in the form of alternative methods of treatment in stress and mixed urinary incontinence in women in which they included: respiratory diaphragm training as well as the synergy of pelvic floor muscles and abdominal muscles which consisted of 8 individual therapy sessions (2 times a month for 4 months). The control group consisted of women (n=35) who performed pelvic floor muscle exercises on their own, at home. After the intervention, the participants from the experiment group (n=35) reported a recovery or an improvement in their symptoms by over 90%. Apart from that, quality of life, the maximum pelvic floor muscle contraction, a 20-minute pad test, and miction diary were evaluated. According to the authors of the publication, this form of therapy may be an alternative method of urinary incontinence conservative treatment in women (52). In 2019, the results of a study were published (191). It assessed the impact of neuromuscular manual therapy (one of the forms of soft tissue manipulation) and vibration therapy on the symptoms of urinary incontinence (evaluated with questionnaires) as well as elasticity, stiffness, and myofascial tone measured with the objective Myoton Pro device. Sixty women from 50 to 70 years old took part in the project. They had reported urinary incontinence in their gynaecological history. Each of the participants underwent vibration therapy (300 Hz for 15 min.) within the abdomen, pelvic floor, lumbar spine, and gluteus maximus muscles. Then, particular manual techniques were performed within the diaphragm, psoas muscle, piriformis muscle, quadratus lumborum muscle as well as sacrotuberous and sacrospinous ligaments. The intervention protocol encompassed 8 meetings, two times a week with a minimum interval of 48 hours between the meetings. Changes were observed in all the parameters concerning elasticity and stiffness which were examined and subject to myofascial structure therapy. The parameters connected with muscle stiffness and tone were reduced and the ones concerning elasticity of the selected structures grew. The observed changes were significant both in the comparison of the left and right side of the body as well as before and after eight interventions. The results of the surveys conducted before and after the manual therapy intervention indicated a decrease of urinary incontinence symptoms by 43% based on the PFDI-20 questionnaire and by 56% based on PFIQ-7 (191).

Table 24. Example of soft tissue manipulation use in pelvic floor dysfunction. Developed together by the team from Poland, Italy and Spain during the project (26,52,191,260–263)

Location	Therapists	Patient
Rectus abdominis fascia: preparation of the soft tissues for the work within the diaphragm.	In a standing position, behind the patient's head, with arms located on the rectus abdominis, he or she stretches the abdominal fascia towards the pubic symphysis for 90 seconds. The level of the pressure on a patient's tissues is regulated based on feedback and should be between 5 to 7 with 10 as the maximum pressure tolerated by the patient (26).	In a supine position, with bent hip and knee joints and feet resting on the ground.
Respiratory diaphragm: Learning diaphragmatic respiration to relax abdominal walls and indirectly pelvic floor. The patient is asked to take a normal breath with his or her nose in such a way that he or she feels the abdomen filling with air. Then he or she exhales in a relaxed manner with his or her mouth or nose. After the instructions on proper breathing have been provided, manual techniques can be applied.	In a standing position, on his or her left or right side around the patient's abdomen. The therapist places both thumbs at the of the bottom ribs, in a position which is typical of diaphragm therapy. The pressure is applied until the tissue's stretching limit and maintained until there is a sense of tissues relaxing. The level of the pressure on a patient's tissues is regulated based on feedback and should be between 5 to 7 with 10 as the maximum pressure tolerated by the patient.	In a supine position, with bent hip and knee joints and feet resting on the ground.

Table 24. cont.

Location	Therapists	Patient
Piriformis muscle	While standing behind the patient, he or she palpates the edge of the gluteus maximus muscle and greater trochanter to look for trigger points within the piriformis muscle. With ischemic compression/pressure on the hurting spot, he or she gradually causes the ailment to ameliorate. The compression is performed multiple times, until the pain subsides completely.	Lying on the side, the lover limb closer to the bed is straight and the knee of the one which undergoes therapy is bent at the right angle.
Quadratus lumborum muscle	On the side of the patient's abdomen, he or she starts applying pressure, from the iliac crest towards the 12th rib; the muscle can be treated from the iliac crest to the 12th rib with pressure on potential trigger points; then the therapist moves on to the transverse friction technique from the sacral bone to the side edge of the iliac crest with fingertips of both hands to achieve myofascial relaxation. He or she moves the fingers towards the lower edge of the muscle and at the same time presses towards the back and medially, towards the L1-L4 transverse processes.	Lying on the side, with the lower limb on the side which is subject to therapy in line with the torso and the bottom one with slightly bent hip and knee joints.
Pelvic floor muscles/ indirectly, through ischiorectal fossa	In a sitting position behind the patient's back, he or she locates the ischiorectal fossa and applies pressure for 180 seconds. The level of the pressure on a patient's tissues is regulated based on feedback and should be between 5 to 7 with 10 as the maximum pressure tolerated by the patient (191)	On the right and then on the left side, with hip and knee joints bent at 45 degrees
Sacrotuberous ligament	Starts by rolling the fascia in the sacral bone area in the cranio-caudal direction, then places the fingers on the side surface of its spinous processes and stretches the ligament transversely and lengthwise, omitting the coccyx (pressure mobilisation).	In prone position

Table 24. cont.

Location	Therapists	Patient
Iliopsoas	On the side of the bend lower limb, he or she places the fingertips on the edge of the rectus abdominis muscle and locates the iliopsoas. At the same time, the patient bends the lower limb against slight resistance. The pressure on the muscle may be coordinated with the patient's movement of straightening the knee and foot. When the relaxation of the muscle is palpable under the fingertips, the patient makes the movement of a bent limb abduction and adduction while the therapist continues the pressure, moving on to the iliacus muscle. By locating the anterior superior iliac spine, he or she moves the fingertips in the medial direction by rubbing and pressing the trigger points in the belly of the muscle. The technique is completed when the therapist feels a distinct relaxation of the muscle.	In a supine position, with the bent hip and knee of the lower limb which is subject to therapy
Iliolumbar ligament	On the patient's side, putting the fingers between the posterior superior iliac spine and the spinous process of the L5 vertebra, he or she applies pressure mobilisation in the place until the tissues relax.	In prone position
Sacrotuberous ligament	He or she starts rubbing along and across in the area of the greater trochanter of the thighbone and moves on towards ischial tuberosity and the side edge of the sacral bone. The technique ends with tissue rubbing within the area of the pelvis and hip joints with a forearm.	In prone position

4.2.1. Pelvic floor trigger points manual therapy

The definition of a trigger point says that it is a tense fragment of muscle fibre that may hurt on its own or during palpation and the pain may be felt locally or in a different place on the patient's body (102,264). Trigger points are divided into the "active" ones with distinctive referral pain felt by the patient (partially or entirely), and "latent" trigger points which do not recreate any pain during palpation.

The diagnostic criteria for palpation encompass at least two of the defined trigger point diagnostic criteria: palpable tense band along a muscle fibre (or fascia), a spot which is over-sensitive to touch, presence of referred pain (265,266), and, according to some authors, observing an autonomous nervous system response (267). Trigger point therapy (also known as myofascial trigger point therapy) is the mobilisation of soft tissues which consists of: ischemic compression, myofascial release, hook and stretch technique, dry needling, and stretching (102). In the case of this therapy form's use in PFD, it is important to conduct a complete transrectal or transvaginal palpation for the diagnostics of the entire pelvic floor. The examination may allow one to locate places that are tender to pressure, have tense bands, or pain that radiates (see the chapter Pelvic floor diagnostics (see page 43)) (147). Contrary to the external muscle groups, which are treated with the entire palms, transvaginal therapy allows the therapist to use just one or two fingers. After identifying the places where myofascial restrictions occur, they are subject to squeezing, stretching, pressure at the right angle, and additional delicate transverse movements or sliding movement between the fibres to find the lowest resistance referred to as following the tissue. Simultaneous application of external muscle stretching (stretching of the piriformis muscle or isometric stretching of the pubococcygeus muscle) or the external use of warmth helps muscles relax more (147).

IMPORTANT:

→ Some clinicians use the terms trigger point, tender point, and muscle pain interchangeably. It is not physiologically precise and might cause confusion, especially in PFD treatment. In the diagnostic protocol, the concepts need to be clearly distinguished. Tenderness of a different structure than a muscle (e.g. tendon, ligament, joint space, scar) should be referred to as a tender point and muscle tenderness as muscle pain:

- According to Travel and Simons, there is an excessive release of acetylcholine (a substance that causes muscle contractions) in a place where the motor neuron reaches the muscle. This leads to the shortening of a sarcomere (the smallest muscle unit), which, when chronically overstrained, contributes to the development of trigger points (266).
- A chronic sarcomere contraction leads to a failure in the calcium ion uptake in the sarcoplasmic reticulum and an increase in the normal ATP supply. There is a local narrowing in the blood vessels with local ischaemia (decrease in the local blood flow) (266).
- Its first consequence is a pH decrease and then a release of substances which cause inflammation in the muscle tissue (266).

- Apart from palpation, there currently are no criteria for finding or describing a myofascial trigger point. There are three criteria of key significance to diagnosing TrPs: a tense band in a muscle, exceptional tenderness in the tensed band's location, and the patient's pain recreation (268).
- A recent study has shown that the use of diagnostic criteria for the presence of a tense band, a tender point, local contractile response, and referred pain has medium to perfect credibility (269,270).
- The biochemical markers are present in TrP and around them.

Chronic pelvic pain is characterised mainly by chronic pain around the pelvis and/or perineum with possible pain referral to the lumbar area, sexual organs, groins, pubic symphysis area, coccyx, sacral bone, abdomen. or thigh adductors (271). Fitzgerald et al. (272) In 2009, he published a pilot study on the use of myofascial therapy (one of the manual therapy forms) in the treatment of chronic pelvic pain syndrome (CPPS). Twenty-three symptomatic participants (women and men) were randomly assigned into two groups in which each patient underwent myofascial therapy or massage for 10 weeks. Based on the participants' Global Response Assessment Scale questionnaires, it was noticed that a better therapeutic effect was achieved with the use of myofascial therapy. (272) As a consequence of the pilot study, results concerning the use of myofascial therapy in the treatment of bladder pain and hypertonic pelvic floor muscles were published in 2012. Eighty-one women were randomly assigned to two groups. One of them participated in a 10-week myofascial therapy cycle and the other one in general massage. In this case, the subjective assessments of the participants indicated a better therapeutic effect of the applied myofascial manipulation. Based on the obtained results, it was concluded that myofascial therapy may be an effective tool in treating dysfunctions in the pelvic area. (273)

Manual therapy is one of the tools used in the above-mentioned CPPS and its potential was evaluated by Thiele as early as in the 60s by using it for treating patients with hypertonic pelvic floor muscles' tension. It mainly consisted of normalising the tension of the levator ani muscle, ischiococcygeus, and gluteus maximus to minimise the pain in the coccyx area (274). In 2001, Weiss et al. (260) described the benefits of transvaginal and transrectal pelvic floor muscle manual therapy in patients with overactive bladders and interstitial cystitis (IC). The justification for the study undertaken by this team is interesting. It has stated that the trigger points which occur in the pelvic floor muscles are not only a source of pain and urination dysfunctions but also trigger bladder inflammation through antidromic impulse. What is more, the patients who reported IC are characterised by hypertonia within pelvic floor muscles (260).

In 2018, an extensive analysis was published on the therapeutic potential in the case of IC and bladder pain syndrome (BPS) in which pelvic floor physical therapy PFPT may be used for treating pain and excessive tension in PFM and at the same time result in an improvement of the urinary tract and intestine functions as well as sexual function. In this case, physiotherapy consists of manual therapy of soft tissues (mainly trigger point therapy and myofascial release) of the torso, lower limbs, and PFM. It was also highlighted that PFPT is recommended by American Urology Association as the second treatment option in IC/BPS. (275) Interestingly, in this document, there is additional information on avoiding exercises that strengthen PFM (the so-called Kegel muscles) in the case of hypertonic pelvic floor muscles (275), (276). The reason why publications on IC and BPS were placed there is the fact that in 85% of patients with this disease, PFD occurs too and so too does myofascial pelvic pain (MPP) (275). Currently, there is no standard and repeatable protocol for evaluating myofascial pain in the pelvic floor muscle area. Taking into account the growing amount of evidence that point to the correlation between myofascial pain with chronic pelvic pain syndromes and the data which suggests a connection between subclinical myofascial pain and lower urinary tracts symptoms, a detailed, evidence-based physical examination is necessary. The purpose of the systematic literature review of 2018 was to review the examination methods used in myofascial pelvic floor muscle pain in women (277). The lack of standards as well as significant differences in concepts or diagnostic techniques is confirmed by the study by Meister et al (150).

4.2.2. Therapy based on biotensegrity principles

A series of fascinating articles on biotensegrity and its application for human body biomechanics was published recently (36), (278–282). In a publication form 2020, Graham Scarr (278), asks a significant question on how and why the principle of biotensegrity may be useful when working on the body (manual therapy) and movement therapy. The knowledge of mutual connections between particular structures of a living organism seems to be crucial for understanding the functions and restoring them. What is more, the author explains an aspect which is very important to researchers and practitioners – for some practitioners, the information provided by the patients on the success of the applied therapy is sufficient. Others, in turn, look for answers in science – why was the therapy effective? If the biotensegrity perspective may offer a better understanding of the human body or the reactions which occur in it because of therapy and, as a result, a new clinical approach, why should we (practitioners) not make use of it? Biotensegrity offers another way of perceiving the human body in the light of a new/other understanding of anatomy. It is a sort of concept which describes the connection between all parts of the system and its biomechanics, which integrates them all into a complete functional unit. It is a relation of a completely integrated and dynamic structural organisation that stretches from the smallest particle to the entire organism. It seems that the time has come to look at the body from a broader perspective and start explaining the changes which occur in it thanks to manual therapy. Especially, as studying a biological organisms' tissue structure's spatial and temporal responses to mechanical forces is a developing field in health sciences. (279)

In 1975, Fuller described the tensegrity structure as a combination of elements (hard and soft ones) which undergoes simultaneous squeezing and tensing/stretching and always strives for balance in the most energy-efficient way (configuration). Tensegrity structures provide unlimited possibilities of maintaining stable configurations through changes in the durations of their squeezing and stretching. As every element impacts all the other ones, the tensions are distributed in the entire system which creates a structure that may react to external strengths coming from any direction. Tensegrity structures have a functional connection on every level, from the simplest to the most complex ones, with the whole system working as one unit. (282) Ingber defined the tensegrity model as a structural support for biological systems. It is constituted by a number of elements that are stretched/tensed and resistant to squeezing which provides a stable structure (in homeostasis). The cells of our tissues that undergo stress (mechanical forces) are ready to receive mechanical signals and translate them into biomechanical ones. **Biotensegrity is the basic mechanotherapy principle** (mentioned in chapter 4.2 (see page 93)). The cells themselves are interconnected and they are also connected to the ECM (extracellular matrix), which forms a mechanical biotensegrity system. (279) Changes connected with age/traumas/diseases may result in structural or functional dysfunctions in the body, which reduces the body's ability to maintain homeostasis (tensing=squeezing), which leads to damage in places in which the tensegrity "continuum" (the word was used in fascia's description in this coursebook) is endangered or distorted (e.g. mobility limitation) (281,283).

Therefore, it may be stated that human body structures, like the musculo-skeleto-facial system work more efficiently thanks to the connection of the elastic/stretched elements (e.g. muscles, tendons, fascias) and squeezed ones (e.g. bones). Fascia is an integral part of the human biotensegrity model, as every part is suspended in the net of fascias (36,284). Fascia works as both an element that is resistant to squeezing and one which produces tension (259), while its excessive tension or deformations may lead to its pathological stiffening (78,285,286).

According to Ida Rolf's assumptions (The Rolf Method of Structural Integration), tension balance or its lack in the fascial structures (tension elements) are a strong indicator of bone location and joint function (stiff elements), which means that the human body works as a tensegrity structure. "Balancing" fascial tension with a given mobilization/manipulation of soft tissues is supposed to facilitate the body's central axis to synergize with its gravitational vertical which results in a functional ani-gravity reflex (287). Therefore, it seems that **the principle of biotensegrity for pelvic floor dysfunctions is the following**: any trauma in the pelvic area (e.g. scars connected with childbirth) may lead to excessive tension in the tissues and impact their functions (288). Myofascial release is also one of the therapy forms based on biotensegrity. Crowle and Harley (262) used it in their research with 23 women with pelvic floor prolapse (262). In the project, it was observed that by reducing the pelvic floor's myofascial tissues' tension and restrictions through manual therapy it contributed to the improvement of the pelvic organs' location and reduced the symptoms of their prolapse felt by the women (262).

Currently, there are more and more reports on osteopathic treatment and its impact on the human body (263,289). The treatment is largely based on biotensegrity. To restore tension balance in the human body, manual therapy, nerve, vascular, and lymphatic techniques are used, based on Andrew Taylor Still's words that "life is motion." Mobility restrictions and distorted flow of tissue fluids: blood, lymph, interstitial fluid, and cerebrospinal fluid causes functional and/or structural disorders (→ **see the article by Barassi et al.** (191) **on the use of osteopathic manual therapy in urinary incontinence treatment**).

4.3. Vibration

The use of vibratory stimuli in medicine and rehabilitation is becoming more and more popular (290). Vibrations are a strong proprioceptive stimulus (291) and when used in elderly patients, they can improve balance and gait re-education (292,293) or reduce pain by stimulating alfa and beta afferent motoneuron fibres thanks to the reduced activity of nociceptive fibres (294). When vibratory stimuli were used, it was observed that the strength of the muscles improved and their cross-section surface area grew (295,296), obesity was reduced (297) or gait function was improved in neurological patients (298,299). A vibratory stimulus may be applied directly to the belly or tendon of a muscle (300) or indirectly, with the use of a vibrating platform (Whole Body Vibration, WBV). The use of WBV in combination with exercise is documented in the form of randomised clinical trials (301–303) but no comprehensive review which would make it easier to understand or, more importantly, standardise the intervention protocols, especially in elderly people has appeared in the Cochrane database so far. What is more, the systematic review published in 2019 by Leite et al. (304) mentions weak evidence concerning the use of WBV in clinical practice, in people with various disabilities (304).

The use of a vibratory stimulus is the only option of conservative treatment in pelvic floor dysfunctions. Focal Mechanical Vibration allows stimulation of particular muscle groups and selectively activate type Ia and IIb fibres as well as the Golgi tendon organs (300). However, there is a certain divergence as to the applied vibrations' parameters. According to certain authors (305,306), short applications and low frequencies are less effective. Several studies analysed the effects of a certain intervention referred to as repeatable muscle vibration (rMV) with focal stimulation at 100 Hz frequency and 0.2–0.5 mm amplitudes which lasted for 30 minutes for 3 consecutive days. In these studies, the authors proved that the intervention could modify the mutual influence of the muscle undergoing vibrations and its antagonists and it was correlated with an increase in joint motor coordination. The vibratory stimulus should selectively stimulate type Ia afferent fibres (at the frequency of 100 Hz and amplitude from 0.2 to 0.5 mm (306)), while type Ib and II afferent fibres may be recruited at higher amplitudes (from 20 to 60 Hz) (307,308). There are several receptors that are sensitive to a vibratory stimulant: Pacini, Merkel, Meissner, and Ruffini receptors, which are activated at different vibration frequency levels (309). However, different studies have shown that neuromuscular spindles are the receptors' most sensitive structures. The response of the fibres depends on their current condition, i.e. stretching, relaxation, or contraction (310) – the type Ia fibres are more sensitive to a vibratory stimulus when the muscle is stretched and during voluntary isometric contractions (311,312). According to the latest literature, it was proven that the vibration-induced spindle activation may lead to long-lasting reorganisation of the central nervous system (313). Long-lasting effects were observed only when high-intensity vibrations were applied (100 Hz).

4.3.1. Clinical applications of vibrations in urinary incontinence

In a retrospective observational case-controlled study conducted at the G.D'Annunzio University in Chieti (Italy), the impact of concentrated mechano-acoustic vibration therapy (VISS) in the rehabilitation of mixed urinary incontinence was studied (190).

The main purpose of the study was to evaluate the symptoms according to a pelvic floor dysfunction questionnaire (PFDI-20) (314) and the assessment of tension and stiffness of the gluteus maximus muscles. Patients from 50 to 70 years old with diagnosed MUI according to the International Continence Society (ICS) guidelines were included (315). The experimental therapy protocol consisted of 10 sessions, 3 times a week for the first 2 weeks and then 2 times a week for the following 2 weeks. A frequency of 300 Hz was used for 15 minutes for each muscle, which was treated by a physiotherapist during the procedure. The follow-up examinations were conducted a month later. Mechano-acoustic vibration was used in each patient with applicators placed on both sides in area of the rectus abdominis, adductors (gracilis, pectineus, adductor longus, adductor brevis), gluteus maximus, quadratus lumborum muscles, and perineum area. The focal mechano-acoustic vibrations were applied with the use of Vibration Sound System (ViSS) (European patent: Ep1824439 – CE 1936 Certificate of Conformity – N_ HD 60114019 - Unibell, Calco - LC, Italy). The device consists of a turbine with the speed of 32,000 revolutions and flowrate of 35 m^3/h, which generates air waves with the pressure of up to 250 mb and a flow modulator which vibrates air with the pressure of up to 630 mb and the frequency of 980 Hz (however the recommended frequency is up to 300 Hz) for generating mechano-acoustic waves (316) (Figure 11, 12, and 13).

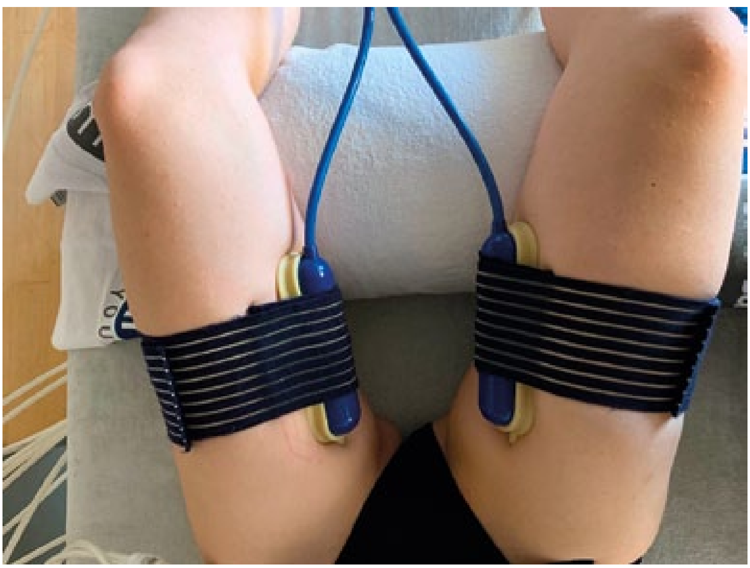


Figure 11. Mechanical vibration focused on the adductor muscles.

Figure 12. Mechanical vibration focused on the gluteus maximus muscles.

Figure 13. Converters used for focused vibration procedure.

All the patients, both in the experimental and control group (list of patients waiting for therapy) received: instructions on the strategy which were supposed to be applied in everyday life to reduce the urinary incontinence symptoms; instructions on isometric gluteus maximus exercises, anterior and posterior pelvic tilts as well as breathing exercises and recommendations including at least 120 minutes of walks per week (each patient received a booklet with the description of the above-mentioned recommendations).

One of the results of this study was vibration therapy's positive impact on reducing the disability index in reference to mixed urinary incontinence in the experimental group compared to the control group. In the experimental group, patients reported an improvement in the urinary incontinence symptoms and quality of life. The differences in the PFDI-20 and PFIQ-7 questionnaire results were statistically significant. The connection between vibration therapy and exercises which strengthened gluteus maximus muscles, anterior and posterior pelvic tilts, breathing exercises and the instruction to walk for at least 120 minutes per week brought encouraging positive results of mixed urinary incontinence symptoms improvement.

Therefore, it seems that vibration therapy may be an effective complement to pelvic floor rehabilitation and it is less invasive than, for example, electrical stimulation (317). The mechanism of the vibration's effect on the pelvic floor muscles and their synergists may be explained by the phenomenon of stimulation of mechanoreceptors, especially Pacinian corpuscles which have the highest sensitivity to a vibratory stimulus (1 mm at the frequency of 250-300 Hz (308) and muscle training with the frequency of 300 Hz planned by the authors in the protocol).

Currently, it may be observed that many researchers use various forms of support for pelvic floor muscle training, e.g., by performing PFM training on vibration platforms which are a kind of alternative to focal mechanical vibrations (318). There are several important biological reactions connected with exercise on vibration platforms that are worth knowing as one plans interventions that are supposed to improve PFM functions (319). An increase in the muscle activity during WBV is presumably caused by tonic vibratory reflexes and increased motor unit recruitment caused by changes in the lengths of muscle spindles (320). To sum up, focal mechanical vibrations and, to a smaller degree, vibrations applied on the whole body, maybe a significant complement for pelvic floor dysfunction conservative treatment. There obviously is a need for further research in order to propose more unified treatment protocols concerning including mechanical vibrations in the standard rehabilitation programmes.

4.4. Behavioural therapy

Behavioural therapy is a cheap, safe, effective, harmless, and conservative (non-invasive) intervention (321) that prevents and reduces the symptoms of urinary incontinence (UI) (322,323). Currently, it is recommended at the initial stage of UI therapy. The purpose of all the behavioural techniques is to educate a patient in order to avoid invasive procedures. However, they do not limit other treatment options (321,324) and they can be used in combination with other therapies (325). Behavioural therapy should be conducted by healthcare professionals (physiotherapists, nurses, midwives) and its efficiency depends mainly on the patient's motivation and whether he or she follows the recommendations (323,326,327). In order to introduce proper behavioural techniques, previous patient evaluation is necessary and the behavioural intervention itself must be adjusted to a particular problem and the actual needs (328).

Behavioural programmes involve many elements like lifestyle modification and acquiring new habits or behaviours which encompass education on the structure and functions of the urinary system, bladder training (planed urination, miction diary), pelvic floor muscle training (PFMT) and other exercises (including pelvic floor relaxation), active use of pelvic floor muscles for closing urethra and urinary urgency suppression (urge suppression strategies), control techniques (distraction, self-affirmation), pelvic floor stimulation (with or without biofeedback), tibial nerve electrical stimulation, use of vaginal cones, physical activity, balanced diet, and healthy habits (328,333).

4.4.1. Lifestyle modification

All kinds of urinary incontinence are connected with a decrease in the quality of life (334–337). Therefore, it is recommended to change some habits which might play an important role in the development or subsiding of UI, like: avoiding being overweight, proper diet, drinking proper fluids (caffeine reduction, avoiding sodas or alcohol) avoiding constipation, not smoking, and being active (338–341). Women with obesity are two times more susceptible to urinary incontinence than women with normal body mass (342–344). Obesity generates a high pressure in the abdominal cavity which weakens the structures that support the pelvic floor and makes the patient prone to stress UI (345). Therefore, in women who are overweight, reduction of body mass is recommended to reduce UI (346–351). Regardless of body mass, women with UI are advised to avoid foods that stimulate (irritate) the bladder, like apples, chocolate, citrus juices, corn syrup, cranberries, spicy foods, honey, milk, tomatoes, vinegar, sugar, and artificial sweeteners (343). Reducing water intake may increase urinary incontinence episodes due to the production of more concentrated urine which results in a stronger need to urinate and may contribute to the growth of bacteria and inflammation. Because of the above, one should only consider reducing fluid intake at night. Patients who suffer from stress UI may experience more leakages due to cough caused by smoking. Quitting smoking, on the other hand, may reduce the frequency of urination and soothe the overactive bladder symptoms (OAB) (352,353).

4.4.2. Bladder training

Bladder training is the main behavioural technique in urinary urgency treatment (322,324) however it is also recommended in stress and mixed UI (354). The aim of the training is to successively increase the bladder content tolerated by the patient before the contraction of the detrusor muscle and setting fixed intervals between mictions which guarantee that the patient feels dry (355–357). According to the recommendations of the European Association of Urology, the treatment strategy should include correcting wrong patterns connected with excessive miction frequency, improving the control of urinary urgencies, or restoring the patient's trust in the possibility to control her bladder. It is helpful to keep a miction diary (for at least 2 days) during bladder training, in order to evaluate the frequency, duration, and volume of particular mictions, urine leakage incidents, the number of used sanitary pads, the occurrence of the sense of incomplete bladder emptying after miction, pain, or interrupted urine flow. The miction diary also involves the amount of fluid or meals consumed, especially the ones which may lead to increased diuresis (coffee, tea, beer, some fruit, vegetables, or juices). The key element of bladder training is gradually learning to prolong the time between mictions, first by several minutes to ultimately reduce the daily number of mictions. To facilitate the control over urinary urgencies, relaxation techniques are proposed as well as generating artificial pressure on the pelvic floor, e.g., by sitting on a hard surface or activating pelvic floor muscles. Apart from that, it is advisable to limit the so-called "just in case" mictions in which the amount of urine passed is small. It is not recommended to attempt to "push out" urine during or after a miction either (358,359).

Useful links:

- Journal of Women's Health: https://home.liebertpub.com/publications/journal-of-womens-health/42
- International Continence Society Physiotherapy Committee: https://www.ics.org/committees/physiotherapy
- EAU Guidelines on Urinary Incontinence: https://www.sciencedirect.com/science/article/pii/S0302283810010894#fig0005

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