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Training methods for strengthening muscles around the pelvis: a narrative review

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Abstract

Few studies have examined how to strengthen the muscles around the pelvis after trauma and none mention the trunk. This narrative review focuses on rehabilitation after pelvic trauma and discusses it from the perspective of muscle strengthening. The literature was searched to identify methods for strengthening muscles around the pelvis (i.e., the trunk to the lower extremities). We also examined the reference lists of the papers captured by our literature search to identify additional potentially relevant research. Our review proposes methods for strengthening each muscle around the pelvis. At present, it is not possible to establish a clear strengthening method for the diaphragm and pelvic floor muscles. We recommend exercise within the bodyweight range starting immediately after pelvic fracture surgery. Muscle strengthening exercises should be started after about 12 weeks when the sutured muscles have fused.

Keywords: Muscle, Training, Method, Trunk, Pelvis

題目：骨盤周囲筋の筋力トレーニング方法：ナラティブレビュー

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抄録:：

外傷後に骨盤周囲筋の強化方法を検討した報告はほとんどなく、体幹にまで言及した報告は渉猟されない。本稿では骨盤外傷後のリハビリテーションに焦点を当て、筋力強化の観点から考察する。骨盤周囲（体幹から下肢）の筋肉を強化する方法を調査するため、関連する論文を引用して、ナラティブレビューを作成した。その結果、骨盤周囲の各筋を鍛える方法が紹介された。横隔膜と骨盤底筋については、明確な強化方法が確立されていないのが現状であった。骨盤骨折手術直後の患者には、自身の体重の範囲内での運動が推奨される。術中に縫合した筋が癒合する術後約12週間から積極的に筋力強化を行うのが適切と考えられる。

Introduction

This paper focuses on rehabilitation after pelvic trauma from the perspective of muscle strengthening. Many muscles are attached to the pelvis and are involved in protecting the pelvic organs and adjusting the body's center of gravity. The core is defined as an anatomical box consisting of several muscle groups, including the rectus abdominis (RA) anteriorly, the internal and external obliques laterally, the erector spinae (ES), lumbar multifidus (LM), and quadratus lumborum posteriorly, the diaphragm superiorly, and the pelvic floor muscles (PFM) and iliopsoas muscle inferiorly [1,2]. From a practical perspective, the core muscles are the center of most of the kinetic chains in the body and transfer forces to the extremities [3]. Almost all the relevant studies have reported electromyographic (EMG) activity as a percentage of maximum voluntary contraction (% MVC), millivolts (mV), or microvolts (μV). This review focuses on training methods that can be used to strengthen the muscles around the pelvis. Furthermore, the muscles around the hip, especially the gluteal muscles, have important functions in transmitting force from the pelvis to the lower extremities. There are reports on the effectiveness of hip adduction and abduction exercises in the early postoperative period in patients with pelvic trauma [4]. However, few reports mention these exercises and none mention the trunk. Focusing on rehabilitation for pelvic trauma, we introduce a training method that can be implemented even if there is a load limit on the pelvis. This review also includes several previous studies involving healthy participants. We hope that it will serve as a reference for everyone involved in the rehabilitation of patients with trauma involving the pelvis.

Literature search

A systematic review and meta-analysis were performed using PubMed on March 18, 2023. We performed a literature search using PubMed on March 18, 2023.The search terms used were “training”, “method”, and the relevant muscle name. The search period included the previous 10 years. After reading the titles and abstracts, we eliminated studies that were not performed in humans and those that were unrelated to training methods and obtained the full-text versions of potentially eligible studies. We also reviewed the reference lists of the retrieved papers to identify further potentially relevant literature.

Front

Rectus abdominis

The initial search identified 10 articles on exercises for the RA muscle. After screening titles and abstracts, 8 articles were excluded. The remaining 2 articles [5,6] were included in the review after obtaining their full-text versions. The exercise that elicited the highest EMG activity of the RA was the "static curl-up" with hands behind the neck, the hips flexed at 60°, and knees flexed at 90° (81.0 ± 10.9% MVC) followed by the static curl-up with the arms crossed over the chest, the hips flexed at 60°, and knees flexed at 90° (67.6 ± 15.7% MVC) [7]. Using BOSU balls during sit-ups and added resistance on activation of the core muscles, the upper and lower RA activities were increased through upper body and dual instability by 21%–24% in comparison with that for a stable surface [8]. Based on the % MVC values for the RA muscle during exercises, V-sits (in a supine position on the floor with the arms extended over the head and the legs extended, participants lift the legs up to a 45° angle and extend the arms up toward the ankle) had an MVC of 80% and achieved markedly greater RA contraction when compared with the curl-up [9].

Another method known to strengthen the RA is the "front plank" (performed in the prone position with posterior pelvic tilt and body weight supported by the forearms and feet; the feet are a shoulder width apart and the spine is maintained in a neutral position). This method has been reported to increase the % MVC to 77.48%, especially with scapular adduction and posterior pelvic tilt [10].

Other studies have identified the following core exercises on a ball/device as achieving the highest EMG related to % MVC in the RA: the "suspended roll-out plank" (performed in an inclined standing position with each hand placed on the strap handles, elbows and wrists placed below the shoulders, arms perpendicular to the floor, and shoulders flexed to approximately 45°; the shoulders are then flexed and the hands are moved forward) [11,12] and the "suspended front plank" (holding the front plank position with the forearms on a suspended device) [12]. Core exercises on a ball/device, such as curl-ups on BOSE balls, the roll-out plank, and the suspended front plank, are also recommended for high activation of the RA. Suspension training systems introduce instability into the exercise, which then can lead to increased EMG activity. However, EMG activity may vary depending on the type of suspension training system used [6].

Transversus abdominis

The initial search identified 141 articles on exercises for the transversus abdominis (TA) Muscle. After screening of titles and abstracts, 130 articles were excluded. A further 9 articles were excluded after obtaining the full-text versions. The remaining 2 articles [6,13] were included in the review. One of the studies examined activation of the TA during the "bird dog" exercise, in which the contralateral upper limb and ipsilateral lower limb are raised and found that this exercise elicited greater EMG activity in the TA (2.63 ± 3.11 mV) than in the internal oblique or multifidus muscles [14]. In the other study, Li et al. found that the elbow-toe with the left arm and right leg lift exercise produced the highest EMG activity in the left TA (50.6 ± 28.4% MVC) [15]. They reported that the sling exercise, which can be performed in the prone, supine, or side-lying positions, activated the local trunk muscles [15]. Despite the higher % MVC activity (58.64 ± 6.99%) in the TA during the side-lying position, the authors recommended prone and supine sling exercises for stabilizing the lumbar region, given its high local/global muscle ratio [16].

Lateral

The initial search identified 3 potentially relevant articles, none of which were excluded upon screening of the titles and abstracts. One of these articles was excluded after obtaining the full-text versions, leaving 2 articles for inclusion in the review [5,6]. A search for papers on the internal and external obliques yielded the same results.

Internal obliques

The front plank exercise with scapular adduction and posterior pelvic tilt gave the highest % MVC for the internal obliques (IO; 119.92 ± 60.26% MVC) [10]. Cortell-Tormo et al. considered there to be a synergistic relationship between scapular adduction and posterior pelvic tilt which would increase the activity of the core muscles, given that scapular adduction increases the intensity of the exercise, leading to difficulty in maintaining the position [10]. In free-weight exercises, the highest EMG values for the IO were recorded during the exercise using the kettlebell swing with Kime (abdominal pulse at the top of the swing; 80.8 ± 43.7% MVC) [17]. Patterson et al. found that bilateral and unilateral bench press exercises increased the activity of the IO when performed unilaterally (0.05 mV) and by about 2.5-fold when performed bilaterally [18].

External obliques

The curl-up with the hip flexed at 90° results in the highest activation within the traditional core group (with maximal expiration, 70.74 ± 20.57% MVC; with slow expiration, 65.18 ± 24.83% MVC; with maximal inspiration, 63.95 ± 20.32% MVC) [19]. The external obliques (EO) showed EMG activity of 0.416 ±0.174 mV for 10 repetition maximum loading comparisons in the unstable upper body position during sit-ups performed on BOSU balls [8]. The front plank exercise with scapular adduction and posterior pelvic tilt elicited the highest EMG activity (110.78 ± 65.76% MVC) [10]. Furthermore, the front plank exercise with 20% of body weight added achieved 0.2 mV in the EO [20]. The standing unilateral dumbbell press achieved 0.4 mV in the EO, and the seated unilateral dumbbell press achieved about 0.3 mV, although contractions of EO were significantly stronger when the dumbbell press was performed unilaterally rather than bilaterally in both the standing and seated positions [21].

Back

Erector spinae

The initial search identified 11 articles, 8 of which were excluded after screening the titles and abstracts. After reviewing the full-text versions, all 3 remaining articles were included [5,6,22]. Activation of ES was greater during back extension exercises (~63% MVC) than in the other exercises when performed on the floor (~63% MVC) and on the bench (~56% MVC) [8]. ES showed greater contraction in the squat than in the prone bridge with 20% of body weight added (0.1 mV vs 0.35 mV), and the activity of ES during squat movement increased with each repetition (fourth over first and sixth over fourth) [20]. Activation was higher for core exercises on the suspended bridge than for those on the floor (61.51 ± 13.85% MVC vs 45.50 ± 9.47% MVC) [23]. Silva et al. reported that the EMG activity in the ES muscle was 0.99 ± 0.06 mV after using the shaper device for 5 min [24]. Among free-weight exercises, the greatest activation was found for the deadlift exercise (barbell, ~90% MVC; hex bar, ~80% MVC) and hip-thrust exercise (~85% MVC). The % MVC was particularly high in the upward phase of the hip thrust [25]. The barbell deadlift with 4 elastic bands produced the greatest ES activation and a 2-repetition maximum deadlift achieved the highest mV value (0.357 mV) [26].

Lumbar multifidus

The initial search identified 5 articles. After screening the titles and abstracts, 2 articles were excluded. After reviewing the full-text versions, 1 of the remaining 3 articles was excluded and the other 2 were included in the review [6,13]. The activity of the LM improved from about 40% MVC for bridge on the floor to nearly 45% MVC for bridge on the ball [27]. Unilateral LM activity was 0.85 ± 0.48 mV when the contralateral upper limb was raised from the 4-point kneeling position and 0.86 ± 1.01 mV when the bird dog exercise was performed [13]. LM activity during an inverted row with pronated grip using a portable suspension device, and weight resistance was 46.3 ± 25.3% MVC for 1-leg weight-bearing and 46.9 ± 21.5% MVC for 2-leg weight-bearing [28]. LM activity during push-ups was 3.97 ± 0.43% MVC when performed on the floor and 7.35 ± 0.66% MVC when using the suspension device [29].

Upper edge

Diaphragm

We searched the literature for training methods and the effects of strengthening on the diaphragm and respiratory muscles, which constitute the upper edge of the core muscles. The diaphragm is difficult to examine electromyographically because of its location deep within the body. The initial search identified 354 potentially relevant articles. After screening of the titles and abstracts, 341 articles were excluded. Nine of the remaining 13 articles were excluded after review of the full-text versions, leaving4 articles for inclusion in the review [30–33].

A training device based on pressure thresholds was used in most of the studies. The initial effort intensity was very similar in all studies at 40%–60% of maximum inspiratory pressure [30]. The number of training sessions ranged from 2 to 7 per week and were of 15–30 min in duration [32]. The shortest and longest durations of inspiratory muscle training were 5 weeks and 8 weeks, respectively [33]. Seven studies that included a total of 212 participants provided mean change scores that could be pooled, and meta-analysis showed a positive effect of inspiratory muscle training on maximal inspiratory pressure [33]. The average increase in maximal inspiratory pressure was higher in the intervention group than in the control group (26.3 ± 4.9 cm H_2O vs 3.7 ± 4.1 cm H_2O). However, the meta-analysis revealed moderate heterogeneity [33].

Traditional thoracic load carriage exercise, which imposes an additional mass load on the thoracic cavity, hinders exercise performance and capacity. The reason for this is that the cardiovascular and pulmonary effects of thoracic load carriage are different from the effects of other modes of exercise and impose stress on the cardiopulmonary system during exercise that is greater than that during intensity-matched unloaded exercise [34]. Almost all studies used threshold training applied to inspiration and expiration. The threshold devices used included the POWERbreathe (HaB International Ltd., Warwickshire, UK), PowerLung (PowerLung, Inc., Burlington, ON, Canada), and the Respiratory Threshold Model 2 trainer (Philips Respironics, Murrysville, PA, USA) [35]. Faghy et al. compared a flow-resistive face mask worn for 6 weeks during high-intensity interval training versus pressure threshold loading inspiratory muscle training, and found that time trial performance improved in all groups [36]. However, post-intervention, maximal inspiratory pressure and diaphragm thickness were improved only by inspiratory muscle training (by 32% and 9.5%, respectively). In another study in which abdominal draw-in lumbar stabilization exercise with respiratory resistance was performed for 50 min, 3 times a week, by women aged 40–49 years with low back pain, diaphragmatic thickness during inspiration was significantly higher after 4 weeks in the intervention group than in the control group (0.22 ± 0.03 mm vs 0.08 ± 0.02 mm), as was the contraction rate as calculated by dividing the thickness of the contracted diaphragm by that of the relaxed diaphragm (0.88 ± 0.13 mm vs 0.31 ± 0.09 mm) [37]. Adding acupuncture to the standard therapy plan used in that study improved diaphragm muscle strength and ameliorated respiratory muscle fatigue in patients with chronic obstructive pulmonary disease and improved the efficiency of rehabilitation [38].

Recent evidence suggests that diaphragm-sparing motor recruitment patterns are altered following respiratory muscle training, which may contribute to improved ventilatory efficiency [39]. The effect of training on the diaphragm has attracted attention not only in terms of muscle strength but also with regard to neurological development (recruitment). Raux et al. found that sustained inspiratory loading may support motor reorganization such that phrenic motoneuron recruitment is reduced [40]. Cerebral blood oxygenation-dependent signals were analyzed in 11 healthy volunteers during 5 min of random single breath inspiratory threshold loading (ITL) and 5 min of continuous ITL using MRI to measure changes in cerebral activation induced by ITL. Continuous ITL was found to induce signal changes in many areas, including the premotor cortices, both insula, the cerebellum, and the reticular formation of the lateral mesencephalon [41]. This “diaphragm sparing” may be part of an adaptive strategy to optimize recruitment of the respiratory muscles during sustained inspiratory loading, thereby improving the efficiency of the respiratory muscles during inspiration [41].

In contrast, Ramsook et al. found no change in the respiratory muscle activity measured by EMG following 5 weeks of pressure threshold inspiratory muscle training in comparison with the pre-training level or a sham-control group [42]. Inspiratory EMG activity was not changed by respiratory muscle training in the study by Ramsook et al. [42], but breathing training was noted to reduce dyspnea [41]. Walterspacher et al. evaluated the relationship of inspiratory pressure threshold loading, inspiratory flow resistive loading, and voluntary isocapnic hyperpnea with EMG activation in the sternocleidomastoid muscle, parasternal muscle, and diaphragm in randomized order and found that although all methods mainly stimulated the accessory respiratory muscles, mainly activation of the diaphragm occurred in inspiratory pressure threshold loading [43]. However, it was noted that the most important factors influencing respiratory muscle activation were maintenance of a specific target mouth pressure (or volume for voluntary hyperpnea) during training and the instructions provided on how to perform respiratory muscle training [43].

Overall, these findings support the recommendation to match respiratory muscle training as closely as possible to the ventilatory demands of patients on a case-by-case basis [35]. An important consideration is whether muscle recruitment patterns are affected by the way in which individuals are instructed to perform respiratory muscle training, given that when subjects are not given any specific instructions on muscle recruitment during inspiratory muscle training, the diaphragm, sternocleidomastoid, and scalene muscles are all activated to a similar degree [44]. However, when participants are specifically instructed to engage the diaphragm, the EMG activity and production of pressure in the diaphragm increase significantly, suggesting that the way in which participants perform inspiratory maneuvers during inspiratory muscle training can meaningfully affect motor recruitment patterns [44].

Bottom

Pelvic floor muscles

The literature search initially identified 162 potentially relevant articles, 96 of which were excluded after screening of the titles and abstracts. Most of the articles were research reports on urinary incontinence in the antenatal or postnatal setting and did not focus on the strength of the PFM. After obtaining the full-text versions of the 66 remaining articles, 27 further articles were excluded, leaving 39 articles for inclusion in the review.

PFM training was devised by Kegel in 1948 for patients with urinary incontinence postpartum and is recommended as the first-line treatment for pelvic floor dysfunction [45,46]. The PFM muscles contract to hold back urine, and this contraction is confirmed by transvaginal palpation or ultrasonic tomography. In men, biofeedback from an anal probe is used most frequently to confirm that contraction is performed correctly, followed by digital rectal examination and combined methods (e.g., digital rectal examination plus visualization of the base of the penis) [47]. There is no consensus on a specific training instruction (e.g., "patients were taught to contract the pelvic floor" vs "patients were instructed to contract the anal muscles around the examiner's finger") [47]. There is also no consensus on the amount of exercise required to improve the functioning of the PFM. A review of PFM training protocols revealed a range of recommendations for PFM contractions that range from 5 to 200 per day [48]. Considering that there is a difference in understanding on the part of patients and how difficult it is to perform correct contractions, not only the number of times but also the frequency, contraction time, and duration are different in each study and are not standardized [48].

PFM training exercises are performed in a variety of positions, including lying on the back with legs bent and the pelvis lifted, lying on the back with bent legs, sitting on a gym ball, standing, walking, and using the stairs [49]. Activation of the PFM should consist of short dynamic contractions, with 2–3 sets and a 1-minute break in between and a gradual increase in the number of repetitions [49]. We recommend that patients stop their flow twice during urination. Contraction of the PFM is ensured by asking the patient to make the pelvic floor "concave". The exercises are performed twice daily for approximately 30 minutes [49]. In another study, PFM training increased the strength of the PFM measured by digital palpation and the Muscle Strength Oxford Scale and increased the PFM pressure measured using a perineometer [50]. In that study, EMG activity in the PFM increased significantly from a slump-supported posture (sitting with decreased lumbar lordosis) to an upright-unsupported posture in both groups. The activity of the PFM increased further in unsupported sitting with straight back in comparison with slump-supported sitting [51]. PFM training can also be performed in the standing position with the ankles in a neutral position or dorsiflexion to facilitate greater maximal contraction of the PFM [52]. In a study that focused on stress urinary incontinence, PFM training combined with EMG biofeedback achieved better outcomes than PFM training alone [53].

Although there is an impression that Pilates is effective, there is currently insufficient evidence of it alone being effective. It has also been reported that Pilates, the Paula method, and hypopressive exercise performed alone do not increase PFM strength [54,55]. Our systematic review found that the evidence for incorporating breathing exercise in addition to or instead of PFM training in clinical practice is scant or non‑existent and that breathing exercises alone do not strengthen the PFM [56].

Use of virtual reality has become popular in rehabilitation and is now starting to be used in the field of PFM training. However, the effects of training using virtual reality methods have been found to be inferior to those of traditional PFM training, which remains the standard of care for urinary incontinence [57,58]. Vibratory stimulation has been suggested to improve muscle function and can be applied directly to a specific muscle or indirectly to other muscle groups [59]. Perineal vibratory stimulation appears to provide good results in the treatment of female stress urinary incontinence, but the heterogeneity and small number of studies performed to date preclude conclusions about its efficacy [60]. Training alone is not easy, so increasing opportunities for engagement in PFM training is the most important factor in optimizing positive behavioral changes [61]. Moreover, it has been reported that when PFM training is performed under supervision of a physiotherapist, there is no significant difference between group and individual approaches [62].

The use of mobile apps has increased with the aim to improve adherence with PFM training. Multiple mHealth apps are available online and provide PFM training programs, but vary in quality, are mostly not linked to either credible sources or scientific evidence, and only 1 has been evaluated in a randomized clinical trial [63,64]. Future app development should focus on improving overall quality and inclusion of evidence-based content; furthermore, including features that can increase adherence with treatment would be valuable [64].

Iliopsoas

We first searched the database for the iliac muscle, which is attached to the pelvis. The initial search identified 16 potentially relevant articles, all of which were excluded after screening their titles and abstracts. We also searched for papers on the psoas major and iliopsoas muscles but did not find any that included EMG testing data. Our failure to find any relevant research could probably be explained by the difficulty of assessing muscle activity associated with hip flexion and the inability to apply electrodes to deep muscles. Therefore, we conducted an additional search for the effects of training on hip flexor strength and found 1 report [65]. In that study, 33 healthy participants were divided into a training group (in which the dominant leg was exposed to 3 sets of the contents shown in a photo each week for 6 weeks) and a control group. The results showed that hip flexor strength was significantly enhanced in the dominant leg in the training group in comparison with the control group. No significant change was observed in the non-dominant leg in either the training group or the control group.

Around the hip joint

Gluteus maximus

The initial literature search identified 20 articles, 11 of which were excluded after screening of the titles and abstracts. Five of the 9 remaining articles were excluded after review of the full-text versions, leaving 4 articles [66–69] for inclusion in the review.

In another study, step-up exercises were found to be useful for increasing activity in the gluteus maximus muscle [70]. In that study, muscle activity was observed to be 97.47 ± 84.58% MVC in the eccentric phase and 240.98 ± 201.56% MVC in the concentric phase. Furthermore, muscle activity ranging from 75.54 ± 46.66% MVC to 152.96 ± 133.3% MVC was observed in multiple evaluations of the associated step-up exercise. Muscle activity exceeded 60% MVC in multiple evaluations of the deadlift, with a mean 88% MVC observed for the hex bar deadlift and a mean 95% MVC for the barbell deadlift [25].

Hip thrusts also had multiple evaluations, including the rotation barbell hip thrust [71], the traditional barbell hip thrust [25,72–74], the American barbell hip thrust [73], the pull barbell hip thrust [71], the band hip thrust [73], and the feet-away barbell hip thrust [71], with the average muscle activity being 75.41 ± 18.49% MVC [69]. Squat also exceeded 60% MVC in multiple evaluations, with 71.34 ± 29.42% MVC muscle activity observed for the belt squat [75], 70 ± 15% MVC for the split squat [72], and 65.6 ±15.1% MVC for the modified single-leg squat [76]. Lunges also exceeded 60% MVC in multiple evaluations, with 66 ± 13% MVC observed for traditional lunge exercise and 67 ± 11% MVC for inline lunge exercise [77].

Gluteus medius/minimus

The highest activity level (≥40% MVC) in the anterior, medial, and posterior segments of gluteus medius was achieved by the hip hitch/pelvic drop exercise [78–82]. The highest activity level (≥40% MVC) for both the anterior and posterior segments of gluteus minimus was observed during the hip hitch/pelvic drop exercise and isometric standing hip abduction [78].

Rehabilitation for pelvic fractures

Rehabilitation or training programs need to be tailored according to whether they are intended for patients or athletes. Important considerations are the timing after injury and the intensity and posture when performing exercise.

Early post-acute orthopedic injury or surgery

It is important to be aware of dehiscence of the muscle repaired owing to overload in strength training after pelvic fracture surgery. Generally, tendon healing occurs in 3 phases: an inflammatory phase (1 week after injury), a fibroblastic phase (3 weeks after injury), and a remodeling phase (8 weeks after injury) [83].

An animal experiment showed that healing of repaired tendons and bone starts with formation of a fibrovascular interface tissue between the tendon and bone [84]. Six weeks after surgery, the fibrovascular interface tissue has already invaded the tendons and bone. It has been reported that continuity of collagen fibers is re-established between the tendon and bone at 12 weeks after surgery. In a study of total hip arthroplasty with external rotator muscle repair, 75% of the repaired tendons separated within 3 months [85] and 43%–53% separated within 3 months [86]. Furthermore, in rehabilitation after rotator cuff repair surgery, it is recommended to start active range of motion exercises at 6–12 weeks after surgery and strength training after 12 weeks [87].

Therefore, after pelvic fracture surgery, the therapist or trainer should communicate with the orthopedic surgeon to understand the affected muscles and how to treat them. Furthermore, a rehabilitation plan that includes aggressive strength training of the repaired muscle should be started at 12 weeks after surgery. The exercises should be started with body weight on the bed, taking care to limit the weight on the pelvis and lower limbs as shown in Figures 1–7.

Patients after orthopedic surgery and healthy older adults

If 12 weeks have passed since the injury and muscle union has been confirmed, the intensity of exercise can be increased stepwise. Even healthy elderly people without obvious disease or osteoarthritis may be trained under a certain amount of load. If the intensity is insufficient, we recommend exercising with equipment such as a balance ball, slings, kettlebells, or barbells as suggested (Figures 8–13).

Conclusion

This review has introduced a training method for the muscles around the pelvis. Abdominal and back and gluteal muscles are presented with effective strengthening methods based on % MVC. There are some unclear points about how to strengthen the diaphragm along the upper edge and the pelvic floor muscles that form the bottom, so further research is awaited. In early rehabilitation after pelvic fracture, it is necessary to consider muscle invasion. We recommend that a rehabilitation plan that includes aggressive strength training of the repaired muscle should be established starting 12 weeks after surgery.

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Figure legends

Fig. 1 Rectus abdominis training (V-sit exercise). Adapted from [7]

Fig. 2 Transverse abdominis and lumbar multifidus training (bird dog exercise). Adapted from [13]

Fig. 3 Transverse abdominis and internal oblique training (plank exercise). Adapted from [10]

Fig. 4 Erector spinae training (bridge exercise). Adapted from [23]

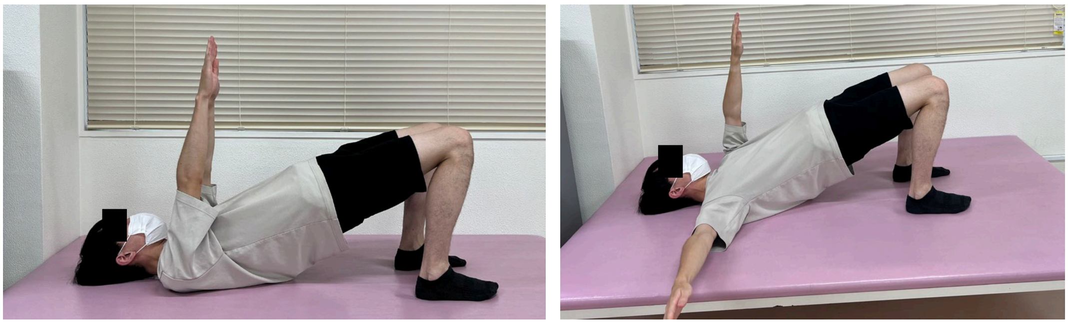

Fig. 5 Lumbar multifidus training (bridge exercise and arm abduction). Adapted from [27]

Fig. 6 Diaphragm training (draw-in with breathing device). Adapted from [37]

Fig. 7 Diaphragm training (side-bench with breathing device). Adapted from [37]

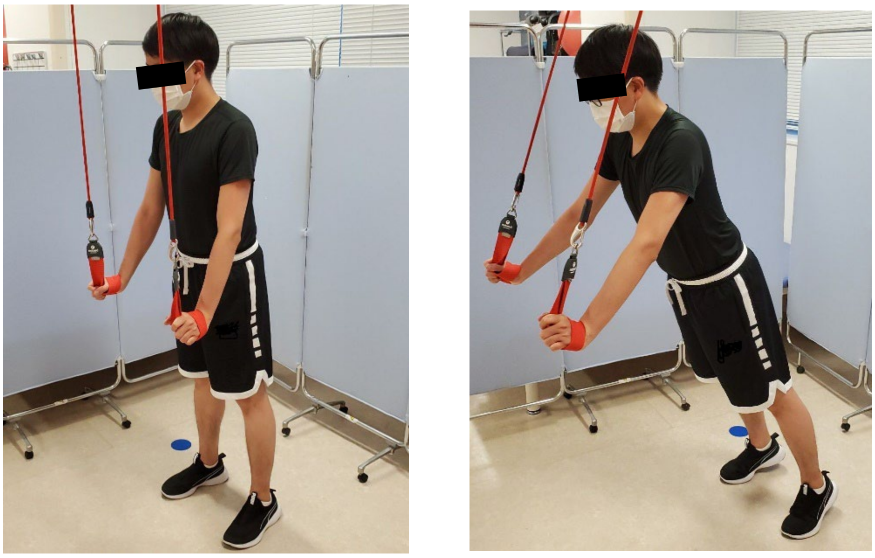

Fig. 8 Rectus abdominis training (with sling). Adapted from [11]

Fig. 9 Transverse abdominis and internal oblique training (with sling). Adapted from [16]

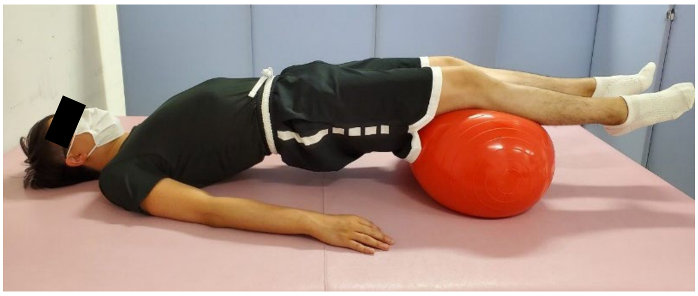

Fig. 10 Erector spinae training (bridge exercise with balance ball)

Fig. 11 Lumbar multifidus training (bridge exercise and arm abduction with balance ball) Adapted from [27]


[redacted] [redacted]

Fig. 12 Erector spinae training (with kettlebells and barbells). Adapted from [25]


[redacted] [redacted]

Fig. 13 Gluteus training (lunge exercise with kettlebells and barbells). Adapted from [77]

Author contributions

KK designed the overall composition and reviewed the trunk muscles. KS reviewed the leg muscles and rehabilitation. Figs 1–7 were obtained by KK and Figs 8–13 by KS.

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Conflicts of interest

The authors declare no conflicts of interest.

Muscle	Function
Rectus abdominis	Trunk flexion and posterior pelvic tilt Bilateral contraction reduces the distance between the glenoid process and the pubic symphysis.
Transversus abdominis	Known anatomically as the "corset muscle," it not only serves to compress the abdomen, but also stabilizes the lower back through its attachment to the thoracolumbar fascia.
Internal obliques	Bilateral: trunk flexion and posterior pelvic tilt, + increased thoracolumbar fascia tension Unilateral: trunk lateral flexion and ipsilateral trunk rotation Of all abdominal muscle groups, it has the largest physiological cross-section and can generate the greatest isometric muscle force.
External obliques	Bilateral: trunk flexion and posterior pelvic tilt Unilateral: trunk lateral flexion and contralateral trunk rotation
Erector spinae	Bilateral contraction of the erector spinae muscles results in extension of the trunk, neck, and head. The erector spinae attach to the sacrum and pelvis to tilt the pelvis forward and increase lumbar spine kyphosis.
Lumbar multifidus	Bilateral contraction of the lumbar multifidus transversus muscle group results in extension of the body axis skeleton. The added extension torque increases the anteversion of the cervical and lumbar vertebrae and decreases the kyphosis of the thoracic vertebrae. In unilateral contraction, the spine is laterally flexed, but this muscle group is very close to the spine, so the effect of this action is limited.
Diaphragm	Contributes to postural stability of the trunk by increasing abdominal pressure through contraction of the diaphragm. It is the most important inspiratory muscle and increases thoracic capacity in all vertical, lateral, and anterior-posterior directions.
Pelvic floor muscles	Iliococcygeus muscle forms part of the pelvic floor that supports the pelvic organs, maintains the anorectal angle. Relaxes to allow passage of urine and stool. Reinforces the external anal and vaginal sphincters. Increases intra-abdominal pressure when active with the abdominal musculature and diaphragm. Sciaticoccygeus muscle forms part of the pelvic floor, assists the muscularis anorectalis to control urination and defecation.
Iliopsoas	The iliopsoas muscle has actions of hip flexion, both of the femur against the pelvis and of the pelvis against the femur. The psoas major muscle acts in hip flexion, both femur against pelvis and pelvis against femur, lateral flexion of the lumbar spine, flexion of the lumbar region against the sacrum, and vertical stabilization of the lumbar spine.
Gluteus maximus	The gluteus maximus is the primary extensor and external rotator of the hip joint. It is stabilizes the sacroiliac joint and the lumbar region through its own widely attached ligaments and fascia.
Gluteus medius / minimus	The gluteus medius is the largest abductor muscle, with all fibers contributing to hip abduction. Muscle activity of the anterior and posterior fibers of the gluteus minimus play different roles in hip stability because of a slight shift in when each is most active during the stance phase of gait.

Modified from Reference 5

		Post orthopedic injury or surgery				
Types of muscle	**Muscle training**	Immediately	1week	2weeks	6weeks	12weeks
Non-invasive muscles	Aggressive strength training	●	➡	➡	➡	➡
Damaged muscles	Active ROM-ex		●	➡	➡	➡
	Aggressive strength training			●	➡	➡
Repaired muscles	Active ROM-ex	●	➡	➡	➡	➡
	Passive ROM-ex				●	➡
	Aggressive strength training					●

●Start date of muscle training
➡Duration of muscle training