Original Article

Effect of limbering up of the muscles attached to the pelvis on the strength of upper and lower extremity and trunk muscles through the transitional network

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Abstract.

[Purpose] To study the effect that limbering up of the muscles attached to the pelvis has on muscle strength of the trunk and upper and lower extremities, which are not being exercised, and to investigate the possibilities for clinical application. [Subjects and Methods] A total of 152 healthy adult men. Sthenometry was conducted using a handheld dynamometer to assess the effect of limbering up of the upper gluteus maximus, hamstrings, and internal abdominal oblique muscles attached to thoracolumbar fascia on the trunk and upper and lower extremities. The exercises were slowly performed 20 repetitions. Subjects were divided into AB group (n=49) measuring abdominal and back muscle strength, K group (n=42) measuring knee flexor and extensor strength, and S group (n=61) measuring shoulder flexor and external rotator strength and compared to non-exercising controls. [Results] In the exercise groups, exercising either gluteus maximus or hamstrings significantly increased the strength of abdominal and back muscle strength, K group (n=42) measuring knee flexor and extensor strength, and S group (n=61) measuring shoulder flexor and external rotator strength and compared to non-exercising controls. [Conclusion] This may be useful in rehabilitation of injuries to the trunk and upper and lower extremities.

Key words: Handheld dynamometer, Muscle strength, Fascia

INTRODUCTION

The contractile force of muscle fibers is transmitted via the perimysium and the epimysium. The deep layers of fascia that surround muscles and bones form a capsule 1 mm thick composed of two or three parallel layers of collagen fiber bundles that can resist traction from a range of different directions. Most skeletal muscle tendons are connected to the bone indirectly via the fascia1). There are fascia routes involved in the transmission of the tensile force of muscles on three levels, namely within muscle fibers, within muscles, and within fascial compartments2), and muscle contractions pass not only via

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fascia during joint movement\(^6\), occurrence of excessive collagen crosslinking to the fascia, limitations in joint mobility, and imbalance in muscle tension persists for a long period of time, then there will be changes in the tension of the muscles and strengthening exercises not be achieved, but also the condition in which muscle contraction is limited will persist. If such an exercises cannot be sufficiently performed. As a result, not only will the expected muscle strength increase due to muscle to a pain experience, or due to extended work posture or lifestyle habits prior to the injury\(^4,5\), then these muscle-strengthening training. If pain occurs due to exercise of the muscles that one wishes to strengthen, or if overstressing of muscles occurs due to the central core of the body is unstable. That is, most “joint motions” require that the trunk be stable, and activity of trunk muscle groups is important for the stability of the trunk.

For example, abdominal muscles such as transversus abdominis work in advance, stabilizing the lumbar spine and pelvic girdle\(^7,8\). It is this prior activity of the trunk muscles that enables the powerful, accurate movement of peripheral muscle groups. The stability of the lumbar spine and pelvic girdle is important even in basic activities of daily living such as standing up and walking, and for that purpose, it is believed that muscles such as the multifidus, the transversus abdominis, the pelvic floor muscle, and the diaphragm, which are deep muscles within the trunk muscles, as well as the abdominal oblique muscles, which are superficial muscles, act cooperatively to achieve stability\(^9\). For trunk muscles, in addition to cooperation between lateral and longitudinal muscles, coordinated activity of deep and superficial muscles is also important. Therefore, smooth activity becomes possible only with stability of the trunk, that is, the lumbar spine and pelvic girdle.

In addition to commands from the central nervous system to each muscle group, construct factors of the muscles are involved in their coordinated activity. For the transmission of force among the spine, pelvis, and lower limbs, the thoracolumbar fascia largely transmits force within the human body not only longitudinally, but also diagonally. Based on the functional relationship among biceps femoris, gluteus maximus, latissimus dorsi, and erector spinae or multifidus muscles, Mooney et al.\(^10\) proposed conducting trunk rotation training as a training method for cases with pain in the lower lumbar spine or pelvic girdle, but the extent of force that can be transmitted in vivo has not been clarified. In this way, if one hypothesizes that the contraction of muscle groups related to the thoracolumbar fascia increases muscle exertion of other surrounding muscles, then muscle strength maintenance and strengthening of other areas may be possible due to exercise of muscle groups related to the thoracolumbar fascia. Accordingly, the purpose of this research was to study the effect that exercise of the muscles attached to the pelvis has on muscle strength of the trunk and upper and lower extremities, which are not being exercised, and to investigate the possibilities for clinical application.

### SUBJECTS AND METHODS

The subjects were 152 healthy adult men of mean age 23.6 ± 3.7 years (18–33 years), mean height 170.7 ± 5.8 cm, and mean weight 65.7 ± 10.2 kg. Subjects with symptoms that interfered with activities of daily living were excluded, as were those who had received a medical diagnosis of joint impairment in the limbs or trunk within the previous two years. Forty-nine subjects were allocated into the AB group whose abdominal and back muscle strength was measured, 42 subjects were allocated into the K group whose knee flexor and extensor strength was measured, and the remaining 61 subjects were allocated into the S group whose shoulder flexor and external rotator strength was measured. The effect of the exercise was determined by dividing the subjects in each group into a non-exercise group and an exercise group (Table 1).

Among the muscles that are attached to the pelvis and that are related to pelvic stability, we selected and exercised three

| Table 1. Subject number of each subgroup (total=152) |
|---------------------------------------------------|
| AB group | K group | S group |
|----------|---------|---------|
| Non-Exercise group | 17 | 14 | 16 |
| Exercise group | 16 | 14 | 14 |
| Gluteus maximus | 16 | 14 | 14 |
| Hamstrings | 16 | 14 | 14 |
| Internal oblique abdominal | 14 | 17 | |
| Subtotal | 49 | 42 | 61 |

AB: Abdominal and back sthenometry; K: knee extensor and flexor sthenometry; S: shoulder flexor and external rotator sthenometry.
of them, namely, the upper gluteus maximus, the hamstrings, and the internal abdominal oblique muscles, which are easy
to palpate. For the upper gluteus maximus, the subject adopted a side-lying position with both hips and knee joints flexed,
and externally rotated the hip on the superior side. For the hamstrings, the subject stood facing a wall with the knee to be
exercised placed against the wall, and flexed the knee joint at 90°. For the internal abdominal oblique muscles, the subject
adopted a supine position with an air stabilizer placed beneath the hips, and rolled the pelvis to the left and right. The
exercises used were chosen because they can easily be incorporated into clinical programs, involve the co-contraction of deep
and superficial muscles, and do not use equipment to impose a load. The subjects were instructed to perform the exercises
slowly at a speed of 1 Hz, only 20 repetitions on one time on each side.

While each type of exercise was being performed, we confirmed that the target muscle was activated by palpation and
observation of the trajectory of motion. In contrast, while having colleagues perform each of the exercises, using surface
electromyogram we established that the activity in the muscle that was being measured did not increase.

Members of the AB group did not perform internal abdominal oblique muscle exercise as this muscle was the prime mover
and measured muscle, and members of the K group did not perform hamstring exercise as this muscle was the prime mover
and measured muscle.

Sthenometry was conducted using a handheld dynamometer (Mobie, SAKAI Medical Co., Ltd., Tokyo, Japan) by physio-
therapist. We used a method in which the maximum isometric voluntary contraction is performed while the subject is sitting,
measuring the muscles attached to the pelvis before and after exercise. Each measurement method was practiced in advance,
then two measurements were taken as a pre-exercise muscle strength and the highest values were registered. To prevent
muscle fatigue, the subjects were given a 5-minute break after exercises of the muscles attached to the pelvis. Two measure-
ments were taken as post-exercise muscle strength and the highest values were recorded. A third measurement was taken if
there was at least a 10% difference between two consecutive measurements, and the highest value of two measurements with
the least difference was recorded.

For abdominal/back muscle strength measurements, the subject was seated on a chair with feet flat on the floor and arms
crossed in front of the chest. During back muscle strength measurements, the subject sat with the pelvis tilted posteriorly
and the trunk slightly flexed so that the inferior angle of the scapula was at the peak, and measurements were made by the
compression method with the handheld dynamometer fixed between the wall and the subject’s back. During abdominal
muscle strength measurements, the pelvis was placed in the intermediate position and measurements were made by the
traction method, with the strap of the handheld dynamometer placed against the xiphoid process and pulled forward.

For knee flexor/extensor muscle strength measurements, the subject was seated on the edge of a bed so that the soles of the feet did
touch the floor, and held onto the bed with the hands. Measurements were performed on the right knee. During knee flexor
muscle strength measurements, the pelvis was tilted anteriorly and during knee extensor muscle strength measurements it
was tilted posteriorly, and measurements were made by the traction method with the strap of the handheld dynamometer
placed at the distal end of the tibia with the knee joint flexed at 90°.

For shoulder flexor/external rotator muscle strength measurements, the subject was seated in a chair with feet flat on the
floor, and measurements were performed on the throwing arm. During shoulder flexor muscle strength measurements, the
shoulder was flexed at 90° with extended elbow, and measurements were made by the traction method with the strap placed
at the distal end of the humerus. During shoulder external rotator muscle strength measurements, the arm was positioned at the
side of the trunk with the elbow flexed, and measurements were made by the traction method with the strap placed against the
distal forearm while the shoulder was slightly internally rotated. Muscle strength was expressed as kg/kg bodyweight (BW).

Two sthenometric measurements were taken in the non-exercise subgroups, which served as control groups, and two more
measurements were taken after the same amount of time as in the exercise subgroups.

Muscle strength was normalized to bodyweight. Using JSTAT, a free statistical software, we compared pre- and post-break
muscle strength in the non-exercise subgroups as well as pre- and post-exercise muscle strength in the exercise subgroups.
In each group, the ratio of the next measurement to the previous measurement was regarded as the rate of change. For the
comparison of measured values obtained before and after each exercise, we conducted the Wilcoxon signed-rank test and
calculated effect sizes.

For the comparison by exercise type, rates of change were compared regarding the non-exercise subgroups. A Mann-
Whitney U test was used for comparisons between the different types of exercises. Analysis of variance (ANOVA) or multiple
comparisons were used for some specific comparisons.

This study was approved by the Ethics Committee of Saga University (approval no. 24-34), and informed consent was
obtained from the subjects both orally and in writing.

RESULTS

There were no significant differences between the mean ages, heights, and weights of the subjects in the non-exercise
subgroup and the upper gluteus maximus and hamstring exercise subgroups of the AB group (Table 2). The abdominal
muscle strength significantly increased (p=0.0006) from 47.4 kg/kg BW to 51.7 kg/kg BW due to exercising the upper glu-
eterus maximus muscle, and the effect size was large (0.79). Muscle strength significantly increased (p=0.0013) from 42.9 kg/
kg BW to 43.5 kg/kg BW due to hamstring exercise, and the effect size was also large (0.75). No significant difference
was observed in the non-exercise subgroup. The back muscle strength significantly increased (p=0.0021) from 36.7 kg/kg BW to 40.6 kg/kg BW due to exercising the upper gluteus muscle, and the effect size was large (0.72). Hamstring exercise significantly increased (p=0.0443) the strength of the back muscles from 44.5 kg/kg BW to 48.1 kg/kg BW, and the effect size was large (0.51). No significant difference was observed in the non-exercise subgroup.

There were no significant differences between the mean ages, heights, and weights of the subjects in the non-exercise subgroup and the upper gluteus maximus and internal abdominal oblique muscle exercise subgroups of the K group (Table 3).

Knee extensor strength significantly increased (p=0.0494) from 99.7 kg/kg BW to 105.6 kg/kg BW, and the effect size was large (0.53). Although exercising the abdominal internal oblique muscle increased knee extensor strength from 94.8 kg/kg BW to 96.3 kg/kg BW, no significant difference was observed. No significant difference was observed in the non-exercise subgroup. Although exercising the upper gluteus maximus muscle increased the knee flexor strength from 48.1 kg/kg BW to 50.2 kg/kg BW, the difference was not statistically significant. Exercising the abdominal internal oblique muscle significantly increased knee flexor strength (p=0.0353) from 45.4 kg/kg BW to 49.2 kg/kg BW, and the effect size was also large (0.56). No significant difference was observed in the non-exercise subgroup.

In the S group, the mean age was below 25 in both exercise and non-exercise subgroups, but it was significantly higher in the hamstring exercise subgroup and abdominal internal oblique muscle exercise subgroup. There was no difference in mean height or mean weight between the members of the non-exercise upper gluteus maximus, hamstring, or internal abdominal oblique muscle subgroups (Table 4).

Strength of the shoulder flexors significantly increased (p=0.0081) from 32.9 kg/kg BW to 36.5 kg/kg BW, and the effect size was large (0.68). Although hamstring exercise decreased shoulder flexor strength from 39.2 kg/kg BW to 37.7 kg/kg BW, no significant difference was observed. Shoulder flexor strength slightly decreased from 34.4 kg/kg BW to 34.0 kg/kg BW due to exercising abdominal internal oblique muscle, but no significant difference was observed. No significant difference was observed in the non-exercise subgroup.

Although exercising the upper gluteus maximus increased the shoulder external rotator strength from 13.6 kg/kg BW to 14.5 kg/kg BW, no significant difference was observed. Hamstring exercise increased shoulder external rotation strength from 14.7 kg/kg BW to 16.1 kg/kg BW, but no significant difference was observed. Exercising abdominal internal oblique muscle decreased shoulder external rotation strength from 15.6 kg/kg BW to 14.9 kg/kg BW, but no significant difference was observed. No significant difference was observed in the non-exercise subgroup.

**DISCUSSION**

In this research, we selected the upper gluteus muscle, the hamstrings, and the internal abdominal oblique muscles, which are attached to the pelvis, and considered to be related to pelvic stability, and are easy to palpate. We studied the effect of their strengthening exercises on the muscle strength of abdominal and back muscles, knee joint flexor and extensor muscles, and shoulder flexor and external rotator muscles, which were not exercised. The contractile strength of muscles is transmitted via the fascia not only along the longitudinal axis of the body but also laterally, connecting with other muscles beyond a specific muscle’s points of origin and insertion. We hypothesized that the contractions of muscles that are connected to the thoracolumbar fascia, one of the strongest and largest areas of fascia in the human body, may augment the contraction of other muscles, and that tension of the thoracolumbar fascia due to muscle contraction may increase the efficiency of action of other muscles by stabilizing the lumbar spine and pelvis.

Although there was a slight difference in the mean age of the subjects who underwent exercise, the fact that male muscle strength peaks at around the mid-20s meant that this difference was unlikely to have had a major effect on our results. In everyday activities, the left and right legs are normally used to a similar extent, and as none of our subjects in this study
were competitive athletes engaged in high-level training, no account was taken of the dominant foot in knee flexor/extensor muscle strength measurements. Most adults use their left and right arms to different extents, however, and the throwing arm was therefore used for measurements of shoulder joint muscle strength.

In our methods, there may have been differences in the chairs used during muscle strength measurements at the multiple facilities, or differences in the ease of sitting due to differences in body size. However, for each case the conditions were the same before and after exercise, so there should be little effect on the comparison of the results before and after exercise. We set the number of repetitions to 20 based on the suggestion by Morton et al.11) to push to the limit rather than focusing on the number of repetitions and resistance for improving strength and skeletal muscle mass. Therefore, even though healthy adults performed the exercises in this study, considering the feeling of fatigue in the muscles from exercising or the number of repetitions that allows to experience the sensation of performed exercise, the number of consecutive repetitions was set to 20.

The results of this research show that exercise in the side-lying position to strengthen the upper gluteus maximus increased the strength of the abdominal/back, knee extensor, and shoulder flexor muscles. The exercise in the standing position to

### Table 3. Muscle strength and characteristics of K (knee extensor and flexor sthenometry) group

|                          | Non-exercise subgroup (14) | Exercise group (28) | Total (42) |
|--------------------------|-----------------------------|---------------------|------------|
| Age (years)              | 23.7 ± 3.0                  | 24.4 ± 4.4          | 23.6 ± 3.8 |
| Height (cm)              | 170.3 ± 6.8                 | 170.3 ± 6.8         | 171.0 ± 6.3|
| Weight (kg)              | 67.1 ± 10.9                 | 63.1 ± 11.1         | 66.7 ± 10.5|
| Median knee extensor strength before exercise (kg/kg BW) | 89.7 | 99.7× | 94.8 | 96.6 |
| Median knee extensor strength after exercise (kg/kg BW) | 92.9 | 105.6× | 96.3 | 96.3 |
| Effect size r            | 0.11                        | 0.53×               | 0.16       |
| Median rate of change on knee extensor strength (%) | 102.2 | 105.9 | 102.2 |
| Median knee flexor strength before exercise (kg/kg BW) | 48.3 | 48.1 | 45.4× | 47.4 |
| Median knee flexor strength after exercise (kg/kg BW) | 50.7 | 50.2 | 49.2× | 50.2 |
| Effect size r            | 0.23                        | 0.50                | 0.56×      |
| Median rate of change on knee flexor strength (%) | 97.7 | 105.6 | 108.7† |

Average ± standard deviation, Wilcoxon signed-rank test, ×p<0.05, ANOVA, Mann-Whitney U test, †p<0.05
Effect size r=Z / √n: 0.1<small<0.3, 0.3<medium<0.5, 0.5<large.

### Table 4. Muscle strength and characteristics of S (shoulder flexor and external rotator sthenometry) group

|                          | Non-exercise subgroup (16) | Exercise subgroup (45) | Total (61) |
|--------------------------|-----------------------------|------------------------|------------|
| Age (years)              | 20.7 ± 2.9                  | 23.9 ± 3.9             | 23.4 ± 3.9 |
| Height (cm)              | 168.8 ± 5.8                 | 170.0 ± 6.4            | 170.4 ± 6.0|
| Weight (kg)              | 64.8 ± 9.8                  | 62.1 ± 8.9             | 64.4 ± 9.6 |
| Median shoulder flexor strength before exercise (kg/kg BW) | 35.6 | 32.9× | 39.2 | 34.4 |
| Median shoulder flexor strength after exercise (kg/kg BW) | 36.7 | 36.5** | 37.7 | 34.0 |
| Effect size r            | 0.10                        | 0.68×                 | 0.09       |
| Median rate of change on shoulder flexor strength (%) | 100.2 | 106.8† | 102.1 | 98.8 |
| Median shoulder external rotator strength before exercise (kg/kg BW) | 14.6 | 13.6 | 14.7 | 15.6 |
| Median shoulder external rotator strength after exercise (kg/kg BW) | 14.3 | 14.5 | 16.1 | 14.9 |
| Effect size r            | 0.30                        | 0.48                  | 0.11       |
| Median rate of change on shoulder external rotator strength (%) | 96.3 | 102.3 | 96.0 | 95.9 |

Average ± standard deviation, Wilcoxon signed-rank test, **p<0.01, ANOVA, Mann-Whitney U test, †p<0.01, †p<0.05
Effect size r=Z / √n: 0.1<small<0.3, 0.3<medium<0.5, 0.5<large.
strengthen the hamstrings increased the strength of the abdominal/back muscles. The exercise in the supine position using an air stabilizer to strengthen the internal abdominal oblique muscle increased the strength of the knee flexor muscles. Thus, an increase in the strength of the muscles was indirectly achieved without exercising said muscles. Muscle factors such as muscular hypertrophy have been reported as contributing to an increase in muscle strength, but it is believed that muscular hypertrophy occurs after two weeks into training12), so it is believed that muscle factors have little contribution in exercise that is only for one day, as in the present research. With respect to the contribution of neurological factors in muscle strength gain, Yue and Cole13) found that becoming accustomed to the test method increased maximum voluntary contractions by 3.6%. In this study, since no difference in muscle strength was observed before and after a rest in the non-exercise subgroups, whereas a significant increase in muscle strength was observed in the exercise subgroup, the involvement of neural factors is deemed to be minimal.

The gluteus maximus muscle is firmly attached to the thoracolumbar fascia and is regarded as an important part of the transmission system from the lower extremities to the trunk15), as well as being the agonist for hip extension and external rotation. When the gluteus maximus contracts, the force may also be transmitted to transverse muscles in a pathway via the posterior oblique sling14). The hamstrings not only contribute to knee flexion and hip extension, but are also involved in knee and trunk extension in the standing position when the knee is slightly flexed16), and in anteflexion movements they rotate the innominate bone posteriorly with respect to the sacrum. Cadaver studies have shown that the biceps femoris muscle also transmits force to the thoracolumbar fascia via the pubic tubercle, albeit not to the same extent as the gluteus maximus. Hamstring contractions may also transmit force horizontally via the anterior oblique sling. Smooth muscle-like cells have been identified in all fascial tissue19), and fascia is also known to possess contractile properties, meaning that it may also constitute an active force transmission system. In other words, the contraction of three types of muscles, namely, the upper gluteus maximus, the hamstrings, and the internal abdominal oblique muscles, which are muscles that are attached to the pelvis and were exercised in this research, is not just capable of having an effect in the direction of the muscle lineage through the thoracolumbar fascia, but also appears to affect muscles that are adjacent to contracted muscles. Therefore, in the present research, it appears that the transmission of force through the fascia and the stability of the lumbar spine and pelvis contribute to the muscle strength increase found in muscles other than the muscles being exercised.

Limitations of the present research are that the exercise was only for one day and the muscle strength was only measured after a rest period, so it was not possible to study the persistence of the muscle strengthening effect or the effect of exercise frequency. These are questions for future study.

Clinical application of the present research uses exercise of connected muscles to increase the contraction of muscles for which one wishes to increase muscle strength, or to stabilize joints. These are therapies that use the transmission of the contractive force of muscles in the stabilization of the lumbar spine and pelvis through exercises such as walking and swimming which use the upper extremities and rotate the trunk, as presented by Barker et al18). For example, when there is pain in the trunk due to injuries such as a compression fracture, it is desirable to maintain and strengthen trunk muscles while restricting trunk movements. The therapist can easily strengthen the muscles of the abdomen and back by performing strengthening exercises of the upper gluteus maximum and hamstrings. In order to prevent reduction in knee extensor strength due to fixation from a fracture of the lower extremities, or due to various knee injuries, exercising the upper gluteus maximus can maintain knee extensor strength. Similarly, when one wishes to quickly strengthen the hamstring muscles such as for an anterior cruciate ligament injury, one can easily strengthen the hamstring muscles by exercising the internal abdominal oblique muscles. In cases for which the upper extremities cannot be sufficiently lifted, such as after a clavicle fracture, glenohumeral joint dislocation, or a rotator cuff injury, exercise of the upper gluteus maximus can help in maintaining shoulder flexor strength. In these ways, even when there has been an injury, by exercising muscles other than the injured muscle, a method can be established for performing muscle strengthening exercises without putting a load on the injured muscle. In the future, we plan to study in more detail about effective combinations of the muscles that one wishes to strengthen, and the muscles that increase the contractions of those muscles, in order to establish useful muscle-strengthening exercise methods for injuries.

Conflicts of interest
None.

REFERENCES

1) Stecce C, Porzionato A, Lancerotto L, et al.: Histological study of the deep fasciae of the limbs. J Bodyw Mov Ther, 2008, 12: 225–230. [Medline] [CrossRef]
2) Maas H: Myofascial force transmission. PhD dissertation, Vrije Universiteit Amsterdam, The Netherlands. 2006.
3) Robert S, Thomas WF, Leon C, et al.: Fascia: The tensional network of the human body. Elsevier, 2012, pp 123–125.
4) Richardson C, Hodges P, Hides J: Therapeutic exercise for lumbopelvic stabilization 2nd ed. Oxford: Elsevier Limited, 2004, pp 94–106.
5) Moseley GL, Hodges PW: Reduced variability of postural strategy prevents normalization of motor changes induced by back pain: a risk factor for chronic

J. Phys. Ther. Sci. Vol. 30, No. 1, 2018
6) Schleip R, Findley TW, Chaitow L, et al.: Fascia: the tensional network of the human body. Elsevier, 2012 pp 475–486.
7) Hodges PW, Richardson CA, Hasan Z: Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther, 1997, 77: 132–142, discussion 142–144. [Medline] [CrossRef]
8) Hodges PW, Richardson CA: Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exp Brain Res, 1997, 114: 362–370. [Medline] [CrossRef]
9) McGill SM, Grenier S, Kavcic N, et al.: Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol, 2003, 13: 353–359. [Medline] [CrossRef]
10) Mooney V, Pozos R, Vleeming A, et al.: Exercise treatment for sacroiliac pain. Orthopedics, 2001, 24: 29–32. [Medline]
11) Morton RW, Oikawa SY, Wavell CG, et al.: Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men. J Appl Physiol 1985, 2016, 121: 129–138. [Medline] [CrossRef]
12) Moritani T, deVries HA: Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phys Med, 1979, 58: 115–130. [Medline]
13) Yue G, Cole KJ: Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. J Neurophysiol, 1992, 67: 1114–1123. [Medline]
14) Snijders CJ, Vleeming A, Stoeckart R: Transfer of lumbosacral load to iliac bones and legs Part 1: Biomechanics of self-bracing of the sacroiliac joints and its significance for treatment and exercise. Clin Biomech (Bristol, Avon), 1993, 8: 285–294. [Medline] [CrossRef]
15) Vleeming A, Stoeckart R: The role of the pelvic girdle in coupling the spine and the legs: a clinical perspective on pelvic stability. In: Movement, stability & lumbopelvic pain. (eds Vleeming A, Mooney V, Stoeckart R), Edinburgh: Churchill Livingstone Elsevier, 2007, pp 114–137.
16) Cholewicki J, VanVliet JJ 4th: Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. Clin Biomech (Bristol, Avon), 2002, 17: 99–105. [Medline] [CrossRef]
17) Snijders CJ, Vleeming A, Stoeckart R, et al.: Biomechanical modeling of sacroiliac joint stability in different postures. Spine-Philadelphia-Hanley and Belfus, 1995, 9: 419.
18) Barker PJ, Briggs CA: Attachments of the posterior layer of lumbar fascia. Spine, 1999, 24: 1757–1764. [Medline] [CrossRef]
19) Schleip R, Klingler W, Lehmann-Horn F: Active fascial contractility: Fascia may be able to contract in a smooth muscle-like manner and thereby influence musculoskeletal dynamics. Med Hypotheses, 2005, 65: 273–277. [Medline] [CrossRef]