Analysis of muscle activity during active pelvic tilting in sagittal plane

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ABSTRACT. Background: Pelvic tilting is performed to improve lumbopelvic flexibility or retrain the motor control of local muscles. However, few studies investigated the activity of local muscles during pelvic tilting. Purpose: The purpose of this study was to investigate muscle activity during anterior and posterior pelvic tilting. Method: Twelve healthy males (age, 22.6 ± 1.4 years) participated. Fine-wire electrodes were inserted into the bilateral lumbar multifidus (MF) and transversus abdominis (TrA). Surface electrodes were used to record activity of the bilateral rectus abdominis, external oblique, and erector spinae (ES), and the unilateral right latissimus dorsi, gluteus maximus, semitendinosus, and rectus femoris muscles. The electromyographic activities during anterior and posterior pelvic tilting in a standing position were recorded and expressed as a percentage of the maximum voluntary contraction (%MVC) for each muscle. Results: The activities of the bilateral MF (right: 23.9 ± 15.9 %MVC, left: 23.9 ± 15.1 %MVC) and right ES (19.0 ± 13.3 %MVC) were significantly greater than those of the other muscles during anterior pelvic tilting. The activity of the left TrA (14.8 ± 16.4 %MVC) was significantly greater than that of the other muscles during posterior pelvic tilting. Conclusions: The results suggested that the MF and ES are related to anterior pelvic tilting. The activity of the TrA, which was classified as a local muscle, was greater during posterior pelvic tilting. This study indicated that local muscles such as the MF and TrA may be related to pelvic tilting.

Key words: Pelvic tilting, Local muscle, EMG, Wire electrodes

Pelvic tilting exercises in the sagittal plane are generally used to correct the alignment of the lumbar spine of patients with chronic lower back pain (LBP). A posture that reinforces lumbar lordosis was identified as one of the main causes of LBP. Therefore, to treat LBP medically, it is important to reduce the use of the posture causing lumbar lordosis. Anterior pelvic tilting strengthens lumbar lordosis whereas posterior pelvic tilting has the opposite effect. Therefore, posterior pelvic tilting has been utilized as a rehabilitation method for improving the lumbar spine alignment in LBP patients because it improves lumbar lordosis.

In recent years, it has been argued that local muscles known to play a role in stabilizing the lumbar spine participate in pelvic tilting motion. According to the previous study, local muscles are classified as muscles located in the deep layer of the trunk that are directly attached to the lumbar spine. On the other hand, muscles located in the superficial layer that are not directly attached to the lumbar spine are called global muscles. Furthermore, the multifidus...
(MF) in the local muscles originates at the lumbar spine and it receives segmental motor control from the nervous system\(^6\). In addition, the MF also plays a role in the segmental stability of the lumbar spine and therefore controls lumbar lordosis\(^7\). When the transversus abdominis (TrA) which is among the deepest abdominal muscles is activated bilaterally, it decreases abdominal girth at the same time increasing intra-abdominal pressure. Moreover, the TrA increases the stability of the lumbar spine through the thoracolumbar fascia\(^8\). The MF and TrA are also important for the motor control of the pelvis because they are directly attached to the pelvis.

Many previous studies investigated the muscle activities during pelvic tilting by using electromyograms\(^4,11-17\). Concerning anterior pelvic tilting, several studies reported that the activity of the erector spinae (ES) increased\(^4,11-17\). Using wire electrodes, Anderson et al. reported that the activity of the iliopectoas increased during anterior pelvic tilting\(^8\). Regarding posterior pelvic tilting, Walters et al. reported that the activity of the rectus abdominis (RA) and the external oblique muscle (EO) increased, and Partridge indicated that the activity of the EO increased more strongly than that of the RA\(^11,13\). In addition, Carman et al. emphasized that the activity of the internal oblique (IO) increased most strongly among the abdominal muscles during posterior pelvic tilting\(^7\). A review study by Vézina concluded that the muscle activity patterns during posterior pelvic tilting were unclear irrespective of LBP\(^10\).

Among previous studies related to pelvic tilting, several studies have investigated the local muscles such as the MF and TrA. Although Carman et al. examined the activity of trunk muscles during pelvic tilting by using wire electrodes, the local muscles were not the target of their examination\(^7\). Urquhart et al. reported that the activity of the IO and TrA increased significantly during posterior pelvic tilting in a prone position in an examination using wire electrodes\(^8\). Although the possibility that the TrA in the local muscle participated in posterior pelvic tilt was shown, a contribution of the TrA in the position other than the prone position is unclear.

Problems in this field are that the activity of the local muscle in a standing position and the influence of the muscle activity of lower limbs are not apparent during pelvic tilting. Our hypothesis is that the local muscles influence anterior and posterior pelvic tilting. Therefore, we measured the local muscle of the trunk and the muscle of lower limbs with the standing position. The purpose of this study is to examine the activity of the local muscle and the muscle of lower limbs during anterior and posterior pelvic tilting in the standing position.

Subject and Methods

Twelve healthy male (age: 22.6 ± 1.4 years; height: 169.9 ± 5.7 cm; body mass: 69.6 ± 7.6 kg) without LBP participated in the study. All of the participants were right-handed and former athletes who had previously rugby, track and field, baseball, basketball, etc.; however, they did not perform regular exercises currently. The exclusion criteria included a history of lumbar spine disorders, neurological disorders and/or spinal surgery. A physical examination was performed by a physical therapist to confirm whether the participants had abnormal restrictions of hip or spinal mobility. This study was approved by the Ethics Committee of the University of Tsukuba (approval number. 21-208). All subjects gave informed consent to participate.

**Anterior/posterior pelvic tilting**

The neutral pelvic position was defined as an erect and relaxed standing posture while the subjects crossed both arms in front of their chests. First, anterior pelvic tilting was performed from this neutral pelvic position, followed by posterior pelvic tilting. Participants were instructed to maintain a normal breathing rhythm throughout the motion, but the speed of the motion was at the discretion of each subject. Before the experiment was conducted, the subjects practiced anterior and posterior pelvic tilting sufficiently with active movements. Participants who could not perform anterior or posterior pelvic tilting were assisted manually by physical therapist in their exercise.

**Range measurement of pelvic tilting using the pelvic tilt angle (Fig. 1)**

The subjects were recorded by photography from the dominant-hand side in the neutral pelvic position, the maximal anterior tilting position, and the maximal posterior pelvic tilting position. The distance between the subjects and the camera was 3 m. The camera was set to the height of the greater trochanter of the femur of each subject. The pelvic tilt angle was measured from the photographic data using Image-J (NIH; Bethesda, Maryland, USA). The pelvic tilt angle was defined as an angle between the horizontal line and the line that links the anterior superior iliac spine to the posterior superior iliac spine. An increased pelvic tilt angle occurs during anterior tilting, whereas a decreased pelvic tilt angle occurs during posterior tilting. Furthermore, the differences between the angle of the neutral position and the maximal anterior and posterior pelvic tilting positions were calculated to investigate the range of pelvic tilting.

**Electromyography (EMG)**

The activity of the trunk and hip muscles was recorded by EMG using bipolar fine-wire and surface electrodes. EMG of the bilateral TrA and the MF was measured using
Muscle activity during pelvic tilting

Figure 1. Pelvic tilting

Anterior tilting position  Neutral pelvic position  Posterior tilting position

Table 1. Position of electrodes

<table>
<thead>
<tr>
<th>Muscle</th>
<th>electrode position</th>
</tr>
</thead>
<tbody>
<tr>
<td>wire electrodes</td>
<td></td>
</tr>
<tr>
<td>TrA (bilateral)</td>
<td>Approximately midway between the rib cage and the iliac crest</td>
</tr>
<tr>
<td>MF (bilateral)</td>
<td>Approximately 2 cm lateral to the L5 spinous process</td>
</tr>
<tr>
<td>Surface electrodes</td>
<td></td>
</tr>
<tr>
<td>RA (bilateral)</td>
<td>3 cm lateral to the umbilicus</td>
</tr>
<tr>
<td>EO (bilateral)</td>
<td>Midway between the costal margin of the ribs and the iliac crest, approximately 45°to the horizontal line</td>
</tr>
<tr>
<td>ES (bilateral)</td>
<td>3 cm lateral to the L3 spinous process</td>
</tr>
<tr>
<td>RF (right side)</td>
<td>Midway between the anterior superior iliac spine and the superior margin of the patella</td>
</tr>
<tr>
<td>ST (right side)</td>
<td>Midway between the ischial tuberosity and the medial condyle of the tibia</td>
</tr>
<tr>
<td>GMa (right side)</td>
<td>Midway between the sacrum and the greater trochanter</td>
</tr>
<tr>
<td>LD (right side)</td>
<td>Medial side of anterior axillary line to the T9 spinous process level</td>
</tr>
<tr>
<td>Reference electrode</td>
<td>Over the sternum</td>
</tr>
</tbody>
</table>

The surface electrodes were used for all muscles except the MF and TrA. Before placing the surface electrodes, the skin was rubbed with a skin abrasive and alcohol to reduce the skin impedance to less than 2 kΩ. If the measured impedance exceeded 2 kΩ, then the surface electrodes were removed, and the skin preparation process was repeated.

Pairs of disposal Ag/AgCl surface electrodes (Vitrode F-150S; NIHON KOHDEN Corp, Japan) were attached, parallel to the muscle fibers, with a center-to-center distance of 2 cm, to the following muscles: the bilateral RA, EO, ES, unilateral Rectus femoris (RF), semitendinosus (ST), gluteus maximus (GMa) and latissimus dorsi (LD). A reference electrode was placed over the sternum (Table 1).

fine-wire electrodes fabricated from 2 strands of urethane-coated stainless-steel wire (0.05 mm diameter; Unique Medical Co, LTD, Japan), and distance between the strands (electrodes) was 5 mm. The fine-wire was threaded into a hypodermic needle (23 gauge × 60 mm) with 2 mm of urethane removed and the tips bent backward to form 1–2-mm hooks. Wire electrodes were sterilized by autoclaving (High Clave HVE-50; HIRAYAMA MANUFACTURING Corp, Japan) at 121°C for 20 min. Through ultrasound imaging, the intramuscular electrodes were inserted bilaterally in the TrA and MF using a guide needle, by a surgeon (Table 1). After the electrodes reached the targeted muscles, they were stimulated by the electric stimulation device (Ohm Pulser; Zen Iryoki Co, Japan), and muscular contraction was confirmed by ultrasound imaging.
Maximum voluntary contraction (MVC) trials

MVC trials were performed for each muscle to normalize the EMG data, and the EMG signal amplitudes were recorded. For the RA, MVC was tested by a partial sit-up with the knees and trunk flexed and the hands behind the head. Manual resistance was applied to the shoulders directed toward the trunk extension. For the EO, the subject was positioned in a supine position with the knees flexed, the hands behind the head, and the flexed trunk rotated to the opposite side. Resistance was applied to the shoulders in the direction of the trunk extension and the opposite rotation direction. The MVC for the MF and ES was examined by a trunk extension from a prone position while applying resistance to the upper thoracic area directed toward the trunk flexion. The MVC for the TrA was recorded during the performance of a maximal expiratory maneuver with abdominal hollowing in a sitting position. For the LD, the subjects performed a shoulder extension in a prone position. Resistance was applied to the wrists up to the shoulder flexion. For the GMa, the MVC was examined using a hip extension with the knee flexed at 90° in a prone position. Resistance was applied to the posterior surface of the thigh directed toward the hip flexion. For the ST, the MVC was examined using a knee flexion in a prone position, while resistance was applied to the posterior part of the ankle in the direction of the knee extension. The MVC for the RF was determined using a knee extension in a sitting position with resistance applied to the anterior part of the ankle directed toward the knee flexion. Subjects were given similar verbal support for each of the MVC trials to ensure maximal effort was exerted. Concerning the MVC data collected by EMG in the isometric phase, the electromyogram of muscles under isometric contraction was recorded for 3 seconds. Moreover, the 1 second which was the largest and consistent signal activity in that 3 seconds was used for analysis.

Data processing

The root mean square (RMS) of the EMG amplitude was calculated from the start of the anterior and posterior pelvic tilting until the end of the motion. The raw EMG signals were sampled at 2000 Hz, amplified (MEG-6116; JB640J Nihon Koden Co, Ltd, Japan), band-pass-filtered (20-500 Hz), and full-wave-rectified using analysis software (Vital Recorder and Bimutus-Video; Kissei Comtec Co, Ltd, Japan). The RMSs of the MVC trials were used to normalize the EMG amplitudes obtained during the experimental motion (%MVC). The activity in the neutral pelvic position was subtracted from the activity recorded during pelvic tilting to remove the influence of maintaining the standing position and to compare the activity recorded during pelvic tilting for each subject. The differences in the activity were used for comparisons for each muscle.

Statistical analysis

Tukey’s honestly significant difference (HSD) test was used to compare the EMG activity of each muscle. The level for statistical significance was set as \( \alpha < 0.05 \), and the analysis was performed using PASW Statistics 17 (SPSS Japan Inc, Tokyo, Japan). Effect sizes were calculated using Cohen’s \( d \) for some significantly different pairs. The effect size was considered small (0.2-0.4), medium (0.5-0.7), large (≥0.8).

Results

Muscle activity changes during the anterior pelvic tilting

As a typical case, Fig. 2 shows an EMG wave pattern during anterior pelvic tilting. The left MF (LMF) showed the highest muscle activity among all muscles during anterior pelvic tilting, followed by the right MF (RMF) and right ES (RES). The activities of the LMF, RMF and RES were significantly larger than those of the other muscles. (\( p < 0.05 \)) (Fig. 3). The effect sizes, using Cohen’s \( d \), were 1.18 (RES vs. LTrA), 0.71 (LES vs. ST).

Muscle activity changes during posterior pelvic tilting

As a typical case, Fig. 2 shows an EMG wave pattern during posterior pelvic tilting. The left TrA (LTrA) had the highest activity among all muscles during posterior pelvic tilting. Moreover, the activity of LTrA was significantly larger than those of the other muscles excluding the GMa (\( p < 0.05 \)) (Fig. 4). The effect size, using Cohen’s \( d \), was 0.72 (LTrA vs. LMF).

Pelvic tilting range

The average pelvic tilt angles of the neutral pelvic position and the maximal anterior and posterior pelvic tilting positions were 8.2 ± 4.4°, 21.2 ± 6.4°, and −0.7 ± 6.5°, respectively. Furthermore, the average ranges of anterior and posterior pelvic tilting were 13.0 ± 4.9°, and 8.9 ± 4.5°, respectively.

Discussion

The understanding of which muscles are used during pelvic tilting is vital to optimize its utility in rehabilitation programs. Therefore, the findings of this study will aid in the development of an evidence-based rehabilitation program for correcting the alignment of the lumbar spine in patients with chronic LBP.

During anterior pelvic tilting, the activities of the ES and MF, which are located in the back, were greater than those of muscles in the lower extremities and trunk. Previous studies also reported that the activities of the ES and MF increased during anterior pelvic tilting, and these muscles exhibited similar tendencies to those observed in this study, although the method of normalization and the mea-
Figure 2. The typical wave pattern of EMG


Measurement procedure were different. Blackburn reported that the activities of the ES and MF were approximately 28 and 18% of MVC during anterior pelvic tilting, although measured in the supine position and with surface electrodes. The activities of the ES and MF during anterior pelvic tilting indicated a similar tendency in the supine and
The muscles act activity changes during anterior pelvic tilting (mean±SD)

* The activities of RES, RMF, and LMF were significant greater than those of (1) - (6), (1) - (10). †: The activities of LES was significant greater than those of (1) - (4), (1) - (4). R: right. L: left. RA: rectus abdominis. EO: external oblique. TrA: transversus abdominis. ES: erector spinae. MF: multifidus. RF: rectus femoris. ST: semitendinosus. GMa: gluteus maximus. LD: latissimus dorsi.

During posterior pelvic tilting, the activity of the TrA was greater than that of other muscles. Previous studies examining abdominal muscles during posterior pelvic tilting using EMG were performed in several positions, including the supine position, the sitting position, and the standing position. The ES and MF adhere to the posterior part of the pelvis. Therefore, it has been suggested that anterior pelvic tilting occurs via increased activities of the ES and MF through traction of the posterior part of the pelvis in an upward direction. Furthermore, the fibers of the MF, which control the movements of each segment of the lumbar spine, are distributed according to individual nerves, explaining their involvement in adjusting the segmental stability of the lumbar spine and controlling lumbar lordosis. Moreover, evidence indicated that the increase in lumbar lordosis is often accompanied by anterior pelvic tilting. As a result, it was emphasized that the increase in the activity of the MF might cause anterior pelvic tilting along with an increase in lumbar lordosis. In summary, the results provide evidence that anterior pelvic tilting is caused by the effects of the MF.
Another study that investigated the TrA using wire electrodes indicated that activity of the TrA increased during posterior pelvic tilting in the prone position\(^4\). In the study by Urquhart, the activity of the TrA was greater compared to the RA and EO, although the conditions in our study and the Urquhart’s study were not the same because the subjects were instructed to perform the exercise with mild effort. Therefore, the results indicate that the activity of the TrA also increased during posterior pelvic tilting in the standing position. In addition, the results provide basic data for planning a rehabilitation program for correcting the alignment of the lumbar spine in the standing position, which are performed frequently during daily activities.

The TrA is located in the deepest layer of the abdominal muscles. Previous studies reported that the TrA was divided into upper, middle, and lower parts, which have different functions\(^25,26\). The middle and lower TrA run from the lateral thoracolumbar fascia, the inguinal ligament, and the anterior iliac crest to the linea alba and the pubis in a horizontal or downward inner direction\(^25,27\). The direction of these parts of the TrA corresponds to the direction of posterior pelvic tilting. Accordingly, posterior pelvic tilting might have been caused by the activity of the TrA.

The results suggest that the local muscles may be related to anterior and posterior pelvic tilting. In other words, the local muscles may control motion in the pelvic sagittal plane, and training of the local muscles may be effective for improvement of lumbar alignment in the sagittal plane of patients with LBP. It might be effective to train the TrA in the patient with excessive lumbar lordosis, and the MF in decreased lumbar lordosis. Further study is necessary to determine whether training of the local muscles can improve posture.

In this study, only the activity of the left TrA increased significantly during posterior pelvic tilting. There is a possibility that the laterality of activity of the TrA is affected by the different use of trunk muscles in daily activities. Because previous studies reported that rapid arm movement activates the deep muscles of the contralateral trunk earlier than the prime mover muscles\(^28-30\), it is expected that the activity frequency of the TrA of the non-dominant side will be greater than that of the dominant side. Therefore, the repetition of this activity pattern resulting in differences between the right and left sides may have influenced the activity of the TrA during posterior pelvic tilting. As this is only speculative, it is necessary to investigate larger and more diverse sample groups regarding the laterality of activity of the TrA. Another point of view, performing pelvic tilting motion is difficult in order that the many muscles get involved. Therefore, the size of the SD means existence of individual difference and the laterality. In addition, the standing position is a lumbar lordosis and anterior pelvic tilt, therefore the anterior pelvic tilting is comparatively easy. On the other hand, the posterior pelvic tilting is a motion against gravitational force. Therefore, the individual difference and laterality might have increased.

For this study, the following points should be considered as limitations. The internal oblique (IO) muscle was not measured because of lack of the number of electrodes for measuring the muscles of lower limb. The previous study reported that the IO participated in posterior pelvic tilting\(^4\). Therefore, not only the TrA but also the IO might be contributed to posterior pelvic tilting. The exercise experience of the subject was inconsistent. It is inarticulate whether the exercise experience of the subject influences laterality of the TrA activity during posterior pelvic tilting. Manual resistance was not added in MVC of the TrA. The measurement of MVC of the TrA was carried out according to previous studies\(^31-33\), however attention is necessary for the difference of the property of MVC.

**Conclusion**

This study attempted to clarify the activities of muscles, including local muscles, during pelvic tilting by using EMG wire electrodes. During anterior pelvic tilting, the ES and MF exhibited significantly larger activities than the other muscles, whereas during posterior pelvic tilting, the TrA exhibited significantly larger activities than the other muscles. Therefore, the findings indicated that local muscles, including the TrA and MF, may be active and participate in anterior and posterior pelvic tilting.

**References**


