

Original Paper

# Associations between External Abdominal Pressure by a Trunk Muscle Training Device and Torque of Trunk Flexion and Extension: Cross Sectional Study

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*(Accepted October 22, 2025)*

**Key words:** external abdominal pressure, trunk flexor muscle strength,  
trunk extensor muscle strength, trunk stability

## Abstract

This study aimed to examine the association between external abdominal pressure by a trunk muscle training device and trunk flexion and extension torques. This cross-sectional study included 25 young asymptomatic female adults. External abdominal pressure was measured using a trunk muscle training device in the standing position, while maximum voluntary isometric trunk flexion and extension torque were measured using a dynamometer in a sitting position. Data were analyzed using correlation, partial correlation, and multiple regression analyses. Correlation analysis revealed significant relationships between external abdominal pressure and torque of trunk flexion ( $r=0.661$ ,  $p<0.001$ ) and extension ( $r=0.406$ ,  $p=0.044$ ). Partial correlation analysis showed a significant correlation between external abdominal pressure and trunk flexion torque, with trunk extension torque as a control variable ( $r=0.575$ ,  $p=0.003$ ). However, no significant correlation was observed between external abdominal pressure and trunk extension torque with trunk flexion torque as a control variable ( $r=0.085$ ,  $p=0.692$ ). Multiple regression analysis revealed that trunk flexion torque ( $\beta=0.621$ ,  $p=0.003$ ) significantly influenced the external abdominal pressure (Adjusted  $R^2=0.391$ ,  $p=0.002$ ,  $f^2=0.642$ ). These findings suggest that external abdominal pressure, as measured using a trunk muscle training device, is primarily associated with trunk flexor muscle strength.

## 1. Introduction

Trunk muscle training is recommended in clinical practice guidelines for chronic low back pain (CLBP)<sup>1</sup>. Additionally, a systematic review and meta-analysis highlighted the importance of trunk muscle training in improving sports-specific athlete performance and key physical fitness metrics, such as muscular strength, power, agility, and linear sprint speed, in young and adult athletes<sup>2</sup>. Another systematic review emphasized that trunk muscle training contributes to a stable and strong core, which may facilitate more efficient use of the lower and upper extremities, improve functional performance in older adults, and support the successful performance of activities of daily living<sup>3</sup>. Based on these studies<sup>1-3</sup>, trunk muscle training has received

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significant attention not only for rehabilitation but also for young athletes, adult athletes, and for preventing falls in older adults.

Recently, an innovative trunk muscle training device named RECORE (Nippon Sigmax Co., Ltd., Tokyo, Japan) was developed<sup>4)</sup> (Figure 1). RECORE consists of an inflatable cuff integrated into a belt and a mechanical manometer that measures pressure, similar to a sphygmomanometer. For measurement, the cuff is placed around the subject's abdomen in a sitting or standing position, and pressure is gradually applied to the abdominal wall. An electrically operated pump is used to inflate the cuff until an adequate resistance is encountered from the abdominal muscles. The pressure value indicated on the manometer before the measurement is defined as the baseline pressure. For external abdominal pressure measurements, force is applied to the abdomen to resist the cuff, and the pressure in the cuff reaches its peak. External abdominal pressure is calculated as the ratio of peak pressure to baseline pressure (kPa). For training, the subjects contracted the muscles of the abdominal wall intermittently or continuously under pressure from the cuff. This exercise is similar to the voluntary co-contraction of the abdominal muscles, known as abdominal bracing<sup>5)</sup>, which is one of the most effective techniques for increasing trunk stability<sup>6)</sup>. RECORE-measured external abdominal pressure has been shown to be a clinically relevant marker, with muscle weakness correlating with conditions like chronic low back pain, risk of falling, and risk factors for future osteoporotic vertebral fractures in older adults<sup>7,8)</sup>. Furthermore, RECORE-based strengthening exercises are effective in improving muscle strength and patient-reported outcomes, including physical function and quality of life<sup>9)</sup>. These previous studies suggested that external abdominal pressure, as measured by RECORE, indicates the ability of the core muscles to generate intra-abdominal pressure and spinal column stability, which are produced by the contraction of the core muscles<sup>7-9)</sup>. The core is a group of trunk muscles that surround the spine and abdominal viscera, consisting of the abdominals (front and sides), paraspinals (back), diaphragm (roof), and pelvic floor muscles (base)<sup>10)</sup>.

Muscle metabolism after exercise has been examined using positron emission tomography (PET) scanning, and the muscle contraction maneuver under pressure produced by RECORE creates coordinated contraction of the deep and superficial core muscles at the anterolateral aspect (rectus abdominis, external oblique, internal oblique, transverses abdominis), top (diaphragm), and base (levator ani) of the core<sup>11)</sup>. External abdominal pressure, as measured by RECORE, showed a significant positive correlation with 30 s sit-up frequency ( $r=0.47$ ), indicating its association with abdominal muscle strength. RECORE-measured external abdominal pressure did not show a significant correlation with trunk extension strength measured by a standing pull-up exercise ( $r=0.20$ ), a method that reflects the ability of the trunk extensor muscles in asymptomatic male participants<sup>4)</sup>. Furthermore, studies investigating the link between RECORE exercise and core extensors are limited; for example, one study failed to show <sup>18</sup>F-fluorodeoxyglucose (FDG) uptake of the multifidus muscle after RECORE exercise<sup>11)</sup>. This suggests a gap in evidence regarding RECORE's

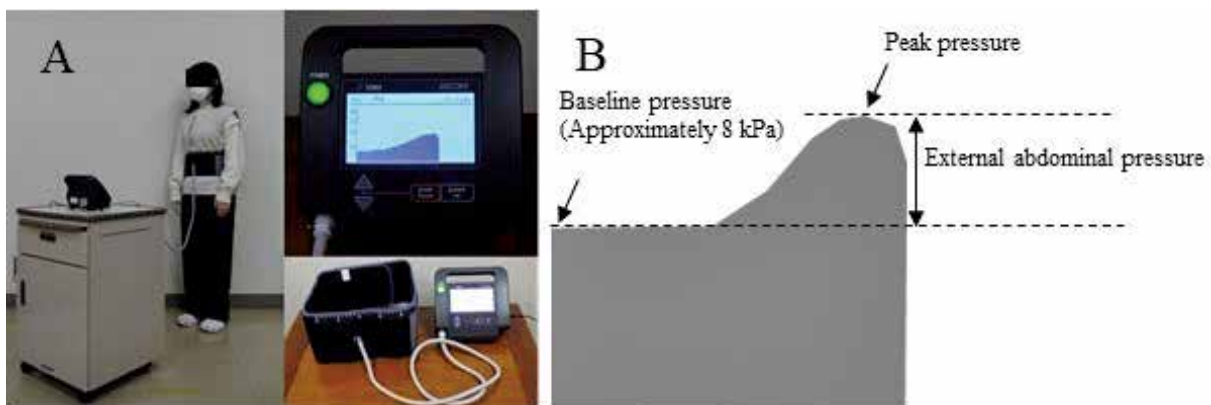


Figure 1 External abdominal pressure device (RECORE) (A) and schematic diagram of the device screen during measurement (B)

ability to capture trunk extensor function. In contrast, it has been reported that abdominal bracing can be an effective maneuver for increasing strength and power during movements involving the trunk and hip extensions, although no significant change in the strength of trunk flexion was observed<sup>12</sup>. If abdominal bracing, which is involved in core stabilization, improves trunk extensor muscle strength, it follows that there should be an association between external abdominal pressure measured using RECORE and trunk extensor muscle strength. Since the 30 s sit-up frequency and standing pull-up exercises primarily engaged the hip flexors and extensors, respectively, it was necessary to examine the relationship with measurements that primarily reflect trunk flexion and extension muscle strength. Therefore, this study aimed to investigate the relationship between external abdominal pressure measured using RECORE and trunk flexion and extension torque measured using a dynamometer.

## 2. Methods

### 2.1 Participants

This cross-sectional study included 25 asymptomatic young adults. Their mean ( $\pm$  standard deviation) age, height, weight, body mass index, and abdomen perimeter were  $20.2 \pm 0.4$  years,  $159.4 \pm 4.8$  cm,  $52.5 \pm 6.1$  kg,  $20.7 \pm 1.9$  kg/m<sup>2</sup>, and  $67.4 \pm 4.9$  cm, respectively. Since we plan to study elderly women with osteoporosis and spinal deformities in the future, we first decided to establish baseline data for healthy women. Exclusion criteria were as follows: a neuromuscular disease, acute low back pain within the past 6 months, a history of back surgery, pregnancy, thrombosis, heart disease, stroke, aneurysm, abdominal wall herniation, spinal tumor or infection, and acute vertebral fracture.

### 2.2 RECORE

Participants measured external abdominal pressure using RECORE, with the baseline pressure set at approximately 8 kPa<sup>11</sup> in the standing position. They were then further instructed to "take a large inhalation and then contract the abdominal muscle groups while maintaining an upright position."

### 2.3 Trunk flexion and extension torques

Maximum voluntary isometric trunk flexion and extension torques (Nm) were measured using a dynamometer (Isoforce GT-350, OG Wellness Co., Ltd., Okayama, Japan) (Figure 2). Participants were positioned in an upright sitting posture with the upper limbs crossed in front of the chest. Straps were used to secure participants at the pelvis and anterior thigh to minimize compensatory movements from the hip



Figure 2 Dynamometer

joint. The center of the sensor pad was placed posteriorly at an axillary height. A chest strap was used to secure the upper trunk against this posterior sensor pad. The sensor, located between the pad and the dynamometer unit, detects force in both tensile and compressive directions. Trunk flexion and extension torques were measured as the tensile force (pulling tension) and compressive force (pushing pressure), respectively; and exertion occurred while the secured upper trunk was placed against the posterior pad.

#### 2.4 Procedure

Prior to the analysis, participants performed a warm-up exercise, defined as a submaximum exertion practice consisting of 2 to 3 repetitions at approximately 50% of the perceived maximum effort. The testing sequence was as follows: trunk muscle strength, extension torque, and flexion torque. Following a 3 min rest after the warm-up, the participants were instructed to exert maximal force by progressively increasing effort for 5 s. This was performed twice for each measurement task (pressure or torque) with a 3 min rest interval between trials to exclude the influence of fatigue. If the difference in the peak pressure or torque between the two trials in each task exceeded 10 %, additional trials were performed<sup>13</sup>. The highest recorded value of peak pressure or torque for each task was selected for further analysis.

#### 2.5 Statistical analyses

Statistical analyses were performed using the SPSS Statistics 23.0 (IBM Japan Inc., Tokyo, Japan), with a significance level of 5%. The Shapiro-Wilk test was performed to test the normality of the measured values for analysis. Pearson's correlation analysis was conducted to examine the relationship between external abdominal pressure and trunk flexion and extension torque. Additionally, partial correlation analysis was performed to identify confounding factors. To examine the factors influencing RECORE measurements, we conducted multiple regression analyses using the forced entry method with external abdominal pressure as the dependent variable and trunk flexion and extension torque as the independent variables. To address multicollinearity, we calculated the variance inflation factor (VIF) value, and variables with a VIF value greater than 10 were excluded from the independent variables<sup>14</sup>. The normality of residuals in the multiple regression analysis was confirmed using the Shapiro-Wilk test. Additionally, G\*Power 3.1 software (Franz Faul, Universitat Kiel, Germany) was used to calculate the post-hoc actual power using Pearson's correlation coefficient and multiple regression analysis. The recommended power was set at 0.8. The effect sizes ( $r$ ) for correlation were classified as small (0.1), medium (0.3), and large (0.5). For regression analysis, effect sizes ( $f^2$ ) were classified as small (0.2), medium (0.15), and large (0.35)<sup>15</sup>.

### 3. Results

The measured values are listed in Table 1. In the correlation analysis (Table 2), significant correlations

Table 1 Mean  $\pm$  standard deviation of measurement values

External abdominal pressure (kPa)	12.3 $\pm$ 4.0
Torque	
Trunk flexion (Nm)	188.4 $\pm$ 50.2
Trunk extension (Nm)	265.0 $\pm$ 56.5

Table 2 Pearson's correlation coefficient between external abdominal pressure and torque

	r	p	Power
Trunk flexion	0.661	<0.001	0.967
Trunk extension	0.406	0.044	0.539

between external abdominal pressure and trunk flexion torque ( $r=0.661$ ,  $p<0.001$ ), as well as trunk extension ( $r=0.406$ ,  $p=0.044$ ), were observed. In the partial correlation analysis, we observed a significant correlation between external abdominal pressure and trunk flexion torque, with trunk extension torque as a control variable ( $r=0.575$ ,  $p=0.003$ ). However, no significant correlation between external abdominal pressure and trunk extension torque was observed with trunk flexion torque as a control variable ( $r=0.085$ ,  $p=0.692$ ). The multiple regression analysis identified trunk flexion torque ( $\beta=0.621$ ,  $p=0.003$ ) as a factor significantly influencing the external abdominal pressure (Adjusted  $R^2=0.391$ ,  $p=0.002$ ,  $f^2=0.642$ ) (Table 3). The VIF was 1.395, indicating no concerns regarding multicollinearity. The Shapiro-Wilk test confirmed the normality of the residuals ( $p=0.227$ ).

Table 3 Multiple regression analysis results

	B	$\beta$	95%CI (Lower, Upper)	p	VIF
(Constant)	1.556		-5.083, 8.194	0.632	
Trunk flexion	0.050	0.621	0.018, 0.081	0.003	1.395
Trunk extension	0.005	0.076	-0.022, 0.033	0.692	1.395
$R^2$ , Adjusted $R^2$			0.441, 0.391		
F (p)			8.694 (0.002)		
$f^2$ , Power			0.642, 0.927		

B: Partial regression coefficient;  $\beta$ : Standard partial regression coefficient; CI: Confidence interval; VIF: Variance inflation factor; The p-value in the Shapiro-Wilk test of residuals was 0.227.

#### 4. Discussion

This is the first study to show an association between external abdominal pressure assessed using RECORE and the torque generated during trunk flexion and extension. A significant positive correlation was observed between external abdominal pressure and trunk flexion torque in both correlation ( $r=0.661$ ) as well as partial correlation ( $r=0.575$ ) analyses. Additionally, multiple regression analyses identified trunk flexion torque as a factor significantly influencing external abdominal pressure. The correlation coefficient of 0.661 between external abdominal pressure and trunk flexion torque in this study was higher than the reported correlations ( $r = 0.47$ ) between external abdominal pressure and the number of sit-ups performed in 30 sec in a previous study<sup>4</sup>). The differences may be attributed to the fact that 30 sec sit-up frequency involves more hip flexor activity than trunk flexor activity, whereas trunk flexion torque is considered to reflect the trunk flexor muscle's strength more accurately. Furthermore, the RECORE device, which features an inflatable cuff (width: 11.4 cm, length: 79.4 cm) wrapped around the participant's abdomen and the abdominal muscles, applies pressure to the abdominal wall, and the measured value reflects the resistance exerted by the abdominal muscles against the cuff. Therefore, this mechanism explains why trunk flexion torque, representing the primary action of the abdominal muscles, was identified as a significant factor influencing external abdominal pressure in the multiple regression analysis.

Although a significant positive correlation was observed between external abdominal pressure and trunk extension torque ( $r=0.406$ ) in the correlation analysis, no significant correlation was observed in the partial correlation analysis between external abdominal pressure and trunk extension torque ( $r=0.085$ ) with trunk flexion torque as a control variable. Therefore, this suggests a spurious correlation between external abdominal pressure and trunk extension torque, with the trunk flexion torque considered as a confounding factor. Kato et al.<sup>11</sup> did not observe FDG uptake in the multifidus muscle after exercise using RECORE as measured by PET. FDG accumulation in the muscles can be used as an indicator of muscle activity level as

well as glucose intake by the muscle, which has a high correlation with the intensity of muscle activity<sup>16</sup>. A previous study reported that the percentage of maximal voluntary contraction (MVC) values for the rectus abdominis, external abdominal oblique muscles, internal oblique muscles, and erector spinae were 17.3%, 44.8%, 74.4%, and 22.8%, respectively, during maximal voluntary abdominal bracing<sup>17</sup>. Furthermore, when performing the RECORE exercise at 60% of maximal voluntary effort, the corresponding MVC values (23.9%, 40.5%, 62.9%, and 16.0%, respectively) showed no significant differences compared to those recorded during maximal bracing. This finding suggests that the muscle activation pattern induced by the RECORE exercise is functionally similar to that of maximal bracing, but it still engages the erector spinae only at low activation levels (below 25% MVC). RECORE promotes abdominal bracing and strongly elicits activity in the abdominal muscle group (particularly the internal obliques), thus correlating with the maximum muscle strength during trunk flexion where the abdominals are the prime movers. On the other hand, extension torque assesses the maximum performance capacity of the prime movers (erector spinae). However, the activity of the extensors engaged by RECORE remains at a low level aimed at stabilization and therefore does not correlate with the indicator of maximal strength.

This study had certain limitations. First, the sample size was small; only female participants were recruited, and no potential sex differences were observed. Additionally, trunk alignment changes may have influenced external abdominal pressure measurements. However, since the examiner assessed posture visually while measuring external abdominal pressure, trunk flexion movements were not quantitatively analyzed based on trunk flexor muscle activity. Given the cross-sectional nature of this study, a future longitudinal study is warranted to investigate the effects of trunk training with RECORE on trunk flexion and extension torque.

## 5. Conclusion

Our findings prove that external abdominal pressure measured using RECORE is significantly associated with trunk flexor muscle strength.

## Ethical considerations

Written informed consent was obtained from all participants. The study protocol was approved by the Ethics Committee of the Kawasaki University of Medical Welfare (No. 24-001).

## Acknowledgments

We thank the students of the Department of Physical Therapy at Kawasaki University of Medical Welfare for their help in collecting the research data. We would like to thank Editage ([www.editage.jp](http://www.editage.jp)) for English language editing.

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