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Effects of core strengthening exercise on colon transit time in young adult women

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ABSTRACT

Background/objective: This study investigated the effects of core strengthening exercise (CSE) on colon transit time (CTT) in young adult women.**Methods:** Eighty women (mean age 23 years) were enrolled and randomly assigned to participate in a 12-week, instructor-led group CSE program (CSE group [CSEG]; n = 40) or to maintain usual daily activities (control group [CG]; n = 40). 27 participants in the CSEG and 21 participants in the CG completed the study. The CSE program consisted of 60-min sessions, two days a week, for 12 weeks. CTT was measured using a multiple marker technique with a radio-opaque marker. Data were analyzed with a 2-way, repeated measures ANCOVA.**Results:** After the 12-week intervention, The CSEG showed significant improvements in trunk flexor power ($P = 0.031$), peak torque ($P = 0.032$), and endurance ($P = 0.011$). The CSEG also showed improvements in the sit-up ($P < 0.001$) and side-step ($P = 0.043$) tests compared to the CG. While there was not a significant group difference between the CSEG and CG, left CTT ($P = 0.021$) and total CTT ($P = 0.006$) decreased significantly within the CSEG group only.**Conclusion:** The 12-week CSE program increased abdominal strength but did not improve CTT compared to the control group. This study also provides preliminary data that CSE may reduce left CTT and total CTT, but additional clinical trials are needed.© 2021 The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Constipation has a significant impact on quality of life and on health care costs.¹ Constipation is a common digestive disorder that more frequently affects women.^{2–4} The prevalence of constipation in Korea is 16.7%, which is higher than the world's average of 11.6%.⁵ In particular, the prevalence of criterion-diagnosed constipation among young adult women in Korea is between 28.9% and 32.5%, and the prevalence of self-diagnosed constipation is between 46 and 56%.^{3,5}

Collegiate women engage in several behaviors that contribute to constipation including irregular sleeping habits, lack of physical

activity (PA), and poor diets.^{4,7–10} Treatment strategies for constipation typically include changes in bowel habits and lifestyles, increased fiber and water intake, medication, behavioral therapy, physical therapy, and biofeedback.^{2,8,11,12} In addition, complementary alternative therapies, such as abdominal massage and increased daily PA are known to reduce constipation symptoms.^{8,13–17} However, the relationship between exercise and constipation is still not clear: Some studies show that moderate-intensity aerobic exercises play a protective role against constipation¹⁸ while other studies show that acute strenuous exercise may increase abdominal pain, diarrhea, and constipation.^{18,19}

Core strengthening exercises (CSE) may be one approach to improve gastrointestinal (GI) motility and treat constipation. Core muscles include those that surround the spine and abdomen, lumbar spine, hip and pelvis, and thoracolumbar fascia.^{20–22} Specific core exercise training also develops the transverse abdominal, multifidus, diaphragm, and pelvic floor muscles. Performing exercises that increase core muscle strength increases the pressure inside the abdomen,^{23,24} which may increase colorectal movement

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because of GI tract stimulation.

Despite the potential benefits, however, few studies have examined the relationship between CSE and the GI tract. Moreover, there are limited data from randomized controlled trials on the effects of CSE specifically on GI motility. Therefore, the present study examined the effect of a CSE training program on the GI motility of female college students. We hypothesized that implementation of a 12-week CSE program would reduce colon transit time (CTT) compared to a no-exercise control group.

Methods

Participants

Female students from Seoul National University were recruited over a 3-month period. Eligibility criteria included a period of 12 months without participation in any structured exercise program and no physical limitations impeding normal activity. Exclusion criteria were current diagnoses of cardiovascular, metabolic, or orthopedic diseases with potential effects on exercise participation or CTT and taking any medications for diarrhea and constipation symptoms. A total of 80 women were enrolled to participate in a 12-week instructor-led group CSE program (CSE group [CSEG]; n = 40) or to maintain their usual daily activities (control group [CG]; n = 40). The CONSORT flow diagram is depicted in Fig. 1.

Ethics

The study was designed in accordance with the Declaration of Helsinki (2000; World Medical Association) and carried out with pre-approval from the Institutional Review Board of Seoul National University (IRB No: 1411/001-020).

Randomization

At the end of the baseline assessment, participants were randomly allocated on a 1:1 ratio to the CSEG or CG via a computer-generated a series of odd or even numbers. Group allocations were kept in sealed envelopes by an investigator who was not directly involved in the study. The same investigator assigned the subject to one of the groups based on odd numbers to the CG and even numbers to the CSEG. This study was single-blinded. Researchers participating in recruitment and measurement were blinded to all participants. However, neither the participants nor the researchers who guided the core exercise program were unable to be blinded due to the nature of the intervention. Researchers guiding the program did not participate in any testing procedures.

Sample size

The sample size was calculated based on predictions of 12-week changes on the TCTT, which is detected by significant group-by-

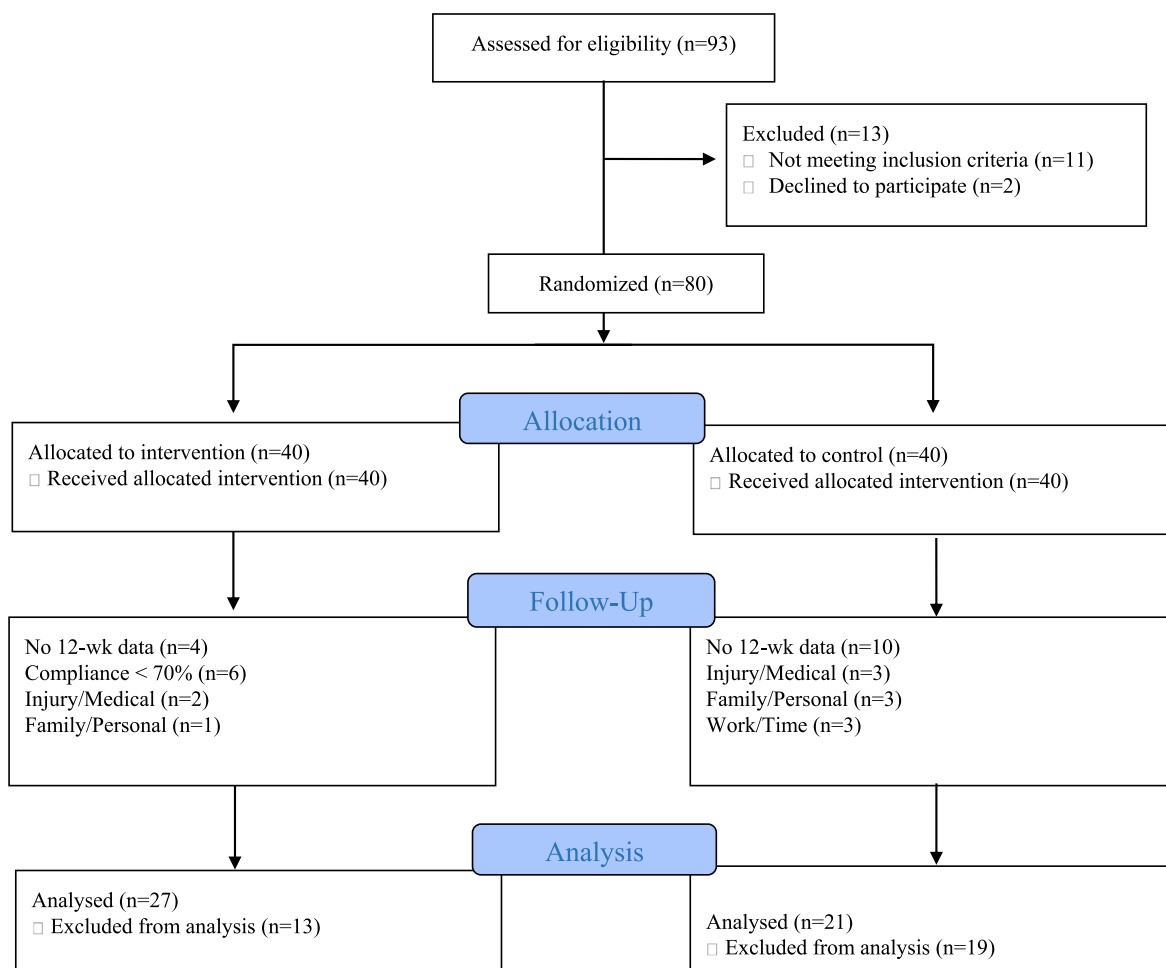


Fig. 1. CONSORT diagram. CONSORT, Consolidated Standards of Reporting Trials.

time interaction effects on the main outcome. Using a moderate effect size (Cohen's $f = 0.3$) based on previously published findings,^{8,36} we estimated that a sample of 80 participants was needed to detect these effects with an alpha of 0.05 and power of 0.8. In anticipation of potential drop-outs (15%) or a reduction in compliance over the 12-week intervention, we recruited a total of 93 participants.

Core strengthening exercise program

Participants in CSEG engaged in an instructor-led CSE program that consisted of 60-min sessions, two days a week, for 12 weeks. Each of the sessions included 10 min of warm-up exercises, 40 min of CSE, and 10 min of stretching (cool-down). During the first week, the core exercises started at a low intensity using Borg's rating of perceived exertion (RPE = 11–13) to allow adaptation to the exercise routine and minimize soreness. From weeks 3–8, the core exercises were modified to provide increasing intensity (RPE 13–15), using a combination of crunches, plank holds, and other types of weight-bearing movements performed in 3 sets of 15–20 repetitions. In weeks 9–12, the core exercises and intensities stayed the same, but the volume was increased to 3 sets of 20–40 repetitions.^{25,26} Since this was an efficacy study of CSE on CTT, participants with less than 70% attendance were not included in the final analyses. Following the Dietary Reference Intakes for Koreans (KDRIs), the participants were given dietary advice by a dietitian concerning the consumption of fluid and fiber at the start of study.²⁷

Control group activities

Participants in CG were instructed to maintain their typical daily routine, including their PA patterns and dietary intake. As in CSEG, a dietitian also gave CG participants advice concerning the consumption of fluid and fibers. There was no additional contact with CG participants outside of the baseline and 12-week follow-up assessments.

Measurement of physical characteristics

Dual-energy X-ray absorptiometry (DEXA, Hologic, USA) was used to measure height, weight, body mass index (BMI in kg/m^2), percentage fat, fat mass, percentage lean, lean body mass (LBM), and total body bone mineral content (BMC). The Spirit CK-101 sphygmomanometer (Spirit Medical Co. Ltd., New Taipei City, Taiwan) was used to measure blood pressure and resting heart rate with the participants in a seated position after a 5-min rest. The International Physical Activity Questionnaire (IPAQ) was used to measure total PA and sedentary time estimated in metabolic equivalents (MET)-minutes per week.²⁸ To determine dietary nutritional content and energy intake, all participants recorded their daily dietary information once per week during pre- and post-assessment using the 24-h dietary recall method. The dietary records were analyzed using the Computer-Assisted Personal Interview System (CAPIS, Seoul, Korea).

Measurement of trunk muscle power, endurance, and physical fitness

Trunk muscle power, endurance, and physical fitness were quantitatively assessed at baseline and at the 12-week follow-up. The HUMAC NORM 2006+ trunk extension/flexion modular components (Computer sports medicine Inc., MA, USA) was used to measure trunk muscle power and endurance. The measurement method followed previous studies.^{29,30} The range of motion (ROM)

was centered on the hip joints at 95° of flexion and –15° of extension. For evaluation of trunk muscle power, five repetitions were performed at 60°/sec, and for trunk muscle endurance, 15 repetitions were performed at 90°/sec.^{23,24}

Handgrip strength (Takei Kiki Kogyo (TKK) 5401 grip dynamometer; Takei Scientific Instruments Co. Ltd., Tokyo, Japan) was calculated as the average of the maximal contractions from both hands. Participants were randomly assigned to start the test with their right or left hand and instructed to squeeze the dynamometer as hard as possible for three trials separated by 60 s with alternating hands.³¹

The sit-up (K-111 Sit-up measuring instrument, KL sports Ltd., Seoul, Korea) test was assessed as the maximum number of sit-ups performed in one minute. Participants were asked to lie down in a supine position with knees bent and feet flat on a mat with hands placed on the side of the head with fingers over the ears. Participants were instructed to elevate their trunk until the elbows made contact with the top of their bent knees and then to return to the starting position. Participants completed as many sit-ups as possible in this manner for one minute.³²

For the side step test, participants stood at a center line then jumped 90 cm to the side (e.g., right) and touched a line with the closest foot, jumped back to the center, then to the other side, and then back to the center (K-115 Side step measuring instrument, KL sports Ltd., Seoul, Korea). This was considered one complete cycle. The participants were asked to complete as many cycles as possible in one minute.³³

Standing broad jump (K-108 Standing parasympathetic jump measuring instrument, KL sports Ltd., Seoul, Korea) was tested over three trials. Participants began the broad jump with their toes on a marked line fixed at the 0-cm mark of the tape. The distance from the rearmost heel strike to the starting line was marked and measured. The participants were asked to jump as far as possible, and the maximum distance of the three trials was recorded.³⁴

Measurement of CTT

CTT was assessed at baseline and follow-up using abdominal radiography and the multiple radio-opaque marker technique. Participants ingested a single gelatin capsule containing 20 radio-opaque markers at the same time every day for three consecutive days (Kolomark™, MI Tech Co. Ltd., Pyeongtaik, Korea). Supine abdominal radiography was performed two times on the fourth and seventh days. Following standard procedures, the mean CTT (hours) was calculated by counting the number of radio-opaque markers that remained in the colon (Total CTT (TCIT) and the three colonic segments: right [RCIT], left [LCIT], and recto-sigmoid [RSCTT]) and multiplying this value by 1.2. To determine segmental transit times, the large intestine was divided into three segments according to the method by Metcalf et al.^{6,35–38}

Statistical analysis

Descriptive statistics were expressed as mean \pm standard deviations (SD). Data were assessed for normality using the Shapiro-Wilk test, and all outcomes were found to be normally distributed prior to analyses. The significance of changes in body composition, physical fitness, and segmental CTT following CSE were assessed by a 2 (group: CSEG or CG) \times 2 (time: baseline or 12-week follow-up) repeated measures ANCOVA, with BMI and the baseline value of each outcome included as covariates. Post-hoc pairwise comparisons were examined using the Bonferroni-adjustment to the overall P -value. A P -value of less than 0.05 was considered statistically significant. All statistical analyses were carried out using SPSS for Windows, version 26.0 (SPSS Inc., Chicago, IL, USA).

Results

Of the 93 participants pre-screened for eligibility, 80 were enrolled and randomized, and 48 completed follow-up testing. The dropout rate was 32.5% in the CSEG and 47.5% in the CG. The enrollment, allocation process, and reasons for dropout are presented in Fig. 1. Participants from the CSEG were withdrawn due to medical changes that inhibited study participation (n = 4), compliance <70% with the exercise program (n = 6), and various personal reasons (n = 3). In the CG, 19 participants were withdrawn due to refusal to participate in study procedures (n = 10) and various personal reasons (n = 9). On average, participants attended 74% of their scheduled exercise sessions over 12 weeks. The final groups included 27 CSEG participants (mean age: 22.9 years) and 21 CG participants (mean age: 22.9 years). There were baseline group differences in adiposity measures including weight (P = 0.020), BMI (P = 0.011), fat mass (P = 0.021), and percent body fat (P = 0.021), with the CSEG group having higher values for each variable. No other group differences were observed at baseline. Participant characteristics are presented in Table 1.

Physical characteristics

The effects of the 12-week intervention on physical characteristics are presented in Table 2. At the end of the 12-week intervention, the CSEG participants showed significant increases in LBM. However, no significant changes over time were observed between the CSEG and the CG in other anthropometric variables (BMI, percentage fat, fat mass, percentage lean mass, BMC), blood pressure and resting heart rate, PA, or energy intake.

Trunk muscle power, endurance, and physical fitness

Changes in trunk muscle power, endurance, and physical fitness parameters are presented in Table 3. The CSEG group showed significant improvements in trunk flexor power (P = 0.031), peak torque (P = 0.032), and endurance (P = 0.011). The CSEG group also showed improvements in the sit-up (P < 0.001) and side-step (P = 0.043) tests compared to the CG.

Table 1
Baseline participant characteristics.

Characteristics	All (n = 48)	Intervention group (n = 27)	Control group (n = 21)	P value
Age (yrs)	22.9 (2.9)	22.9 (3.2)	22.9 (2.7)	
Weight (kg)	56.2 (6.0)	57.9 (6.0)	53.9 (5.2)	0.020*
Body mass index (kg/m ²)	21.1 (2.2)	21.9 (2.2)	20.3 (1.9)	0.011*
Percentage fat (%)	31.9 (3.5)	32.8 (3.3)	30.8 (3.5)	0.021*
Fat mass (kg)	17.5 (3.4)	18.5 (3.3)	16.2 (3.2)	0.021*
Lean body mass (kg)	34.9 (3.0)	35.5 (3.2)	34.0 (2.5)	0.091
Total body BMC mass (kg)	2.0 (0.1)	2.0 (0.2)	1.9 (0.1)	0.163
Systolic blood pressure (mmHg)	112.5 (8.6)	113.5 (9.5)	111.1 (7.2)	0.334
Diastolic blood pressure (mmHg)	74.1 (7.8)	74.1 (8.9)	74.0 (6.4)	0.982
Resting heart rate (beats/min)	83.1 (13.3)	78.2 (2.4)	80.6 (2.4)	0.485
Total physical activity (MET-min/week)	1154.7 (1012.6)	1258.7 (1111.5)	1004.6 (858.0)	0.287
Sedentary time (min/d)	468.9 (605.1)	356.5 (215.5)	615.7 (899.8)	0.623
Energy intake (kcal/d)	1492.2 (344.0)	1463.2 (337.2)	1550.3 (366.4)	0.692
Fiber (g/d)	3.8 (1.9)	3.6 (1.4)	4.1 (2.5)	0.549
Carbohydrate (g/d)	219.5 (55.9)	211.0 (51.4)	227.9 (60.4)	0.465
Protein (g/d)	56.6 (15.4)	54.0 (14.2)	59.3 (16.6)	0.409
Fat (g/d)	48.3(13.8)	45.0 (11.7)	51.7 (16.0)	0.232

The values are shown as the means (SD).

*P < 0.05 was considered statistically significant.

BMC = bone mineral content; MET = metabolic equivalent units.

Segmental CTT

Changes in segmental CTT are presented in Table 4. There were no significant between-group differences; however, post-hoc within-group analyses indicated that LCTT (P = 0.021) and TCTT (P = 0.006) decreased significantly in the CSEG only. There were no changes in RCTT or RSCTT. There were also no significant changes in any CTT segment for the CG from baseline.

Discussion

The primary findings from this randomized controlled trial are that CSE led to reductions in LCTT and TCTT within the CSEG only. However, CSE did not lead to a significant reduction in CTT compared to a no-intervention control group. Little research has been done on the relationship between exercise and CTT. Studies on the association between aerobic exercise or combined exercise and CTT have reported significant effects. However, these studies were conducted on psychiatric patients with low PA.^{8,36} Our study found that CSE may reduce CTT, similar to previous studies. However, comparisons between groups did not show significant differences. The lack of significant findings between groups may be because healthy women were recruited for this study. In general, the LCTT and TCTT in Asian women is approximately 12 h and 30–40 h, respectively.^{6,39} The baseline LCTTs in the CSEG and CG were 10.9 h and 10.6 h, respectively, and the TCTT in the CSEG and CG were 37.5 h and 24.7 h, respectively. At follow-up, LCTT and TCTT were 6.9 h and 25.5 h, respectively, in the CSEG group. Thus, even though transit times significantly decreased in the CSEG group, they were not significantly different from the CG, possibly because the participants did not report pre-existing constipation and were already within accepted normative values of CTTs. It is possible that significant group differences might be observed in samples with known constipation complaints. Moreover, to correct the CTT difference between groups at the baseline, we adjusted the BMI and baseline CTT values, but the large difference of segmental CTT in each group at the baseline may not be able to correct the sample selection bias.

In this study, the CSEG showed a significant increase in lean body mass compared with the CG. In addition, CSE significantly increased trunk flexor muscle power, endurance, and physical performance.^{40,41} There are many studies demonstrating that CSE

Table 2
Physical characteristics before and after the intervention.

Variable	Intervention group		Control group		Between-group difference in mean change from baseline P value
	Baseline (n = 27)	12 weeks follow-up (n = 27)	Baseline (n = 21)	12 weeks follow-up (n = 21)	
Age (yrs)	22.9 (3.2)		22.9 (2.7)		
Weight (kg)	57.9 (6.0)	58.3 (6.2)	53.9 (5.2)	54.1 (5.2)	0.583
Body mass index (kg/m ²)	21.9 (2.2)	22.1 (2.4)	20.3 (1.9)	20.4 (1.8)	0.607
Percentage fat (%)	32.8 (3.3)	29.9 (3.1)	30.8 (3.5)	28.7 (3.2)	0.097
Fat mass (kg)	18.5 (3.3)	16.7 (3.1)	16.2 (3.2)	14.9 (3.0)	0.131
Lean body mass (kg)	35.5 (3.2)	36.7 (3.3)	34.0 (2.5)	34.6 (2.5)	0.036*
Total body BMC mass (kg)	2.0 (0.2)	2.1 (0.2)	1.9 (0.1)	2.0 (0.1)	0.911
Systolic blood pressure (mmHg)	113.5 (9.5)	112.1 (10.6)	111.1 (7.2)	108.0 (9.3)	0.514
Diastolic blood pressure (mmHg)	74.1 (8.9)	74.8 (6.1)	74.0 (6.4)	72.2 (9.4)	0.342
Resting heart rate (beats/min)	78.2 (2.4)	83.9 (2.8)	80.6 (2.4)	81.9 (2.0)	0.247
Total physical activity (MET-min/week)	1258.7 (1111.5)	1692.8 (1219.8)	1004.6 (858.0)	1384.5 (1520.5)	0.813
Sedentary time (min/d)	356.5 (215.5)	420.0 (176.7)	615.7 (899.8)	434.1 (184.3)	0.184
Energy intake (kcal/d)	1463.2 (337.2)	1421 (83.5)	1550.3 (366.4)	1320.7 (140.2)	0.096
Fiber (g/d)	3.6 (1.4)	3.5 (1.1)	4.1 (2.5)	3.4 (1.4)	0.408
Carbohydrate (g/d)	211.0 (51.4)	200.8 (62.8)	227.9 (60.4)	185.0 (70.2)	0.137
Protein (g/d)	54.0 (14.2)	52.0 (12.8)	59.3 (16.6)	46.9 (15.6)	0.027*
Fat (g/d)	45.0 (11.7)	44.3 (10.0)	51.7 (16.0)	43.1 (9.9)	0.138

The values are shown as the means (SD).

*P < 0.05 was considered statistically significant.

BMC = bone mineral content; MET = metabolic equivalent units.

Table 3
The changes in trunk muscle power, endurance and physical fitness of the subjects after 12 weeks CSE training.

Variable (N·m)	Intervention group		Control group		Between-group difference in mean change from baseline P value
	Baseline (n = 27)	12 weeks follow-up (n = 27)	Baseline (n = 21)	12 weeks follow-up (n = 21)	
Trunk muscle power					
Flexor					
Average power per repetition	56 (17.4)	64 (13.0)	54 (14.2)	51.2 (17.9)	0.031*
Peak torque	78.5	84.2	74.8	68	0.032*
Trunk muscle power					
Extensor					
Average power per repetition	110.2 (27.8)	130.6 (23.7)	104.7 (24.2)	117.3 (25.8)	0.221
Peak torque	174.7	191	160.7	169.3	0.402
Trunk muscle endurance					
Flexor					
Average power per repetition	69.1 (19.5)	83.8 (17.7)	69.2 (18.7)	68.0 (21.1)	0.011*
Peak torque	70.5	78.1	66.7	65.8	0.089
Trunk muscle endurance					
Extensor					
Average power per repetition	141.2 (37.8)	176.8 (36.0)	136.5 (35.9)	156.2 (29.7)	0.102
Peak torque	152.1	176	144.1	158.4	0.280
Physical fitness test					
Grip strength (kg)	25.0 (2.9)	24.6 (3.1)	25.2 (4.1)	25.3 (2.6)	0.595
Sit up (rep/60sec)	20.7 (9.4)	33.4 (8.5)	24.0 (8.9)	28.8 (8.0)	<0.001**
Side step (rep/20sec)	29.6 (0.6)	32.3 (0.7)	31.3 (0.7)	32.4 (0.8)	0.043*
Standing broad Jump (cm)	139.4 (18.6)	143.7(20.2)	147.5 (19.0)	146.0 (15.7)	0.053

The values are shown as the means (SD). *P < 0.05 was considered statistically significant. **P < 0.01 was considered statistically significant. Trunk muscle power; 5 repetitions were performed at 60°/sec, trunk muscle endurance; 15 repetitions were performed at 90°/sec.

leads to the improvement of trunk muscle strength and endurance, as well as functional mobility.⁴² Some previous research has reported that CSE can enhance neuromuscular control, joint stability, and muscle performance.⁴⁰ Granacher et al. (2013) reported that specific CSE (i.e., stabilization, segmental stabilization, and motor control) developed the transverse abdominals, multifidus, diaphragm, and pelvic floor muscles.⁴¹ Through these studies, performing exercises that increase core muscle strength increased

muscular strengthening, dynamic balance, and functional mobility. However, there are few studies about the relationship between CSE and GI motility.

The relationship between PA or exercise and CTT is not yet clear. It has been shown that PA allows food to pass quickly in the large intestine, thereby reducing the intake of water in the intestine, reducing the time to pass through the colon, and preventing constipation.⁴³ On the other hand, physical inactivity increases CTT,

Table 4
The changes in segmental CTT of the subjects after 12 weeks CSE training.

Variable (hour)	Mean (SE)		Mean (95% Confidence Interval)	Within-group difference in mean changes from baseline	Between-group difference in mean change from baseline
	Baseline	12 weeks follow-up	within-group changes	P Value	P Value
Control group (n = 21)					
RCTT	5.3 (1.3)	6.5 (1.5)	0.7 (–3.0–4.4)	0.693	
LCTT	10.6 (2.3)	8.7 (1.5)	–2.2 (–6.1–1.6)	0.247	
RSCCT	8.7 (2.3)	11.9 (2.8)	0.2 (–5.6–5.1)	0.924	
TCTT	24.7 (4.8)	27.2 (4.8)	1.2 (–7.4–9.8)	0.792	
Intervention group (n = 27)					
RCTT	9.0 (1.8)	6.4 (1.5)	–1.3 (–4.4–1.7)	0.384	0.813
LCTT	10.9 (2.0)	6.9 (1.8)	–3.7 (–6.9–0.6)	0.021*	0.551
RSCCT	17.4 (2.9)	12.1 (2.0)	–2.8 (–7.2–1.5)	0.197	0.483
TCTT	37.5 (4.4)	25.5 (3.8)	–9.4 (–16.4–2.4)	0.006*	0.117

The values are shown as the means (SD). *P < 0.05 was considered statistically significant. Values are expressed as fitted mean and all are adjusted for baseline value, BMI. RCCT, right colon transit time; LCTT, left colon transit time; RSCCT, recto-sigmoid colon transit time; TCTT, total colon transit time.

increasing the risk of constipation.⁴⁴ Most research to date has examined the effects of aerobic exercise on various aspects of digestion and motility, and studies have produced mixed results. Strid et al. (2010) measured the gastric emptying of 15 healthy, well-trained athletes. The participants underwent tests to measure gastric emptying, small bowel transit, and colonic transit with radiopaque markers during a resting week and during a week with aerobic training (1–2 h per day, mainly running). They reported that small bowel transit was accelerated during a week with aerobic training.⁴⁵ On the other hand, van Nieuwenhoven et al. (2003) showed increased mouth-to-cecum transit time during exercise in athletes who suffer from exercise-induced GI motility disturbances. However, no change in mouth-to-cecum transit time during intense activity has been shown.⁴⁶ In the general population, Cordian et al. (1986) reported that a three-week aerobic running program significantly decreased CTT in a sedentary population. They examined 17 healthy, untrained young volunteers during three weeks of aerobic exercise. The exercise participants showed a significant decrease in their CTTs.⁴⁷ However, other studies have found no effects of PA on CTT. For example, four weeks of regular exercise did not improve constipation symptoms in patients with chronic idiopathic constipation.⁴⁸ However, the four-week exercise intervention was relatively short like most studies in this area, including ours, and longer interventions may be required to see significant effects, particularly in samples with known constipation complaints.

PA and exercise may help regulate the GI tract through its effects on the autonomic nervous system, which regulates digestion, respiration, and heart rate.^{49,50} Aerobic exercise training can increase the activity of the parasympathetic nervous system and decrease sympathetic activity at rest.⁵¹ Specifically, the parasympathetic neural innervation to the smooth muscle cells in the colon plays a significant role in regulating propulsive colonic motility, particularly prior to defecation.⁵² Most of this research has been conducted using aerobic exercise, so it is not clear whether highly localized strength training would have the same effects on the parasympathetic nervous system. Furthermore, since resting heart rate did not change and slightly increased in the CSEG, this suggests that other mechanisms such as increased abdominal pressure may contribute to the reduced CTT in this group. To clarify this mechanism, larger randomized and well-controlled trials are

needed.

This study had various strengths. It is one of the few studies examining the relationship between exercise, specifically CSE, and CTT in women, who have increased rates of constipation compared to men. The 12-week intervention was also longer than most prior exercise and CTT studies, although longer trials are clearly warranted. We also used objective measurement methods to assess CTT.

There are also limitations of this study. First, we cannot generalize these results to other, more general populations, other age groups, or men since the study was conducted in healthy female college students. Second, this study showed a high rate of attrition compared to other exercise intervention studies, which may introduce a selection bias confounding the results. One major contributor to the high dropout rate could be the lengthy assessment time (pre and post-test period of 7 days) and difficult assessment schedule (x-rays were taken exactly four days and seven days after taking Kolomark at the same time every for three days). Moreover, there was no additional contact with CG participants during the 12-week intervention, which may contribute to a higher dropout rate in the control group. Third, the participants' diet and fluid intake were not fully controlled during the CTT assessment period, which can affect CTT through differences in fiber or water content between baseline and follow-up. Furthermore, we have found that there is a statistically significant difference in BMI between the CSEG and CG in the pre-test. Thus, we adjusted for BMI in our analysis to avoid the potential confounding effects of BMI on CTT. We also ran all analyses unadjusted for the BMI, and the results were similar. Indeed, in our study, the effect of BMI on CTT is minor. Finally, assessments were not scheduled considering the participants' menstrual cycles (i.e., menstrual phase during testing was likely different between participants and between baseline and follow-up). This is an important consideration since hormones (e.g., progesterone) released throughout the menstrual cycle can affect GI function.⁶

In conclusion, we found that a 12-week CSE program increased abdominal strength but did not improve CTT compared to a control intervention among healthy female university students. This study also provides preliminary data that CSE may reduce LCTT and TCTT, but follow-up studies in larger samples of patients with constipation are warranted to confirm these initial results.

Author contributions

Bong Kil Song designed the research study, collected the data, analyzed the data, and drafted the manuscript; Dongsuk Han designed the research study; performed the study procedures, collected the data, and drafted the manuscript; Angelique G. Brellenthin interpreted findings and revised the manuscript; Yeon Soo Kim designed the research study; all authors read and approved the final version of the manuscript.

Institutional review board statement

This work was performed in accordance with the Declaration of Helsinki (2000) of the World Medical Association. Full approval for the study was obtained from the Institutional Review Board of Seoul National University (IRB No: 1411/001-020). All patients provided written informed consent.

Clinical trial registration

This study is registered at https://cris.nih.go.kr/cris/en/search/search_result_st01.jsp?seq=14970. The registration identification number is KCT0004336.

Informed consent statement

All participants provided written informed consent.

Declaration of competing interest

All authors declare no conflicts of interest.

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