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Original Article

Comparison of Abdominal Muscle and Subcutaneous Fat Thickness and Core Stability between Normal Weight Non-Obesity, Normal Weight Obesity, and Obesity Groups in Young Korean Women

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Abstract

Background: We compared abdominal muscle and subcutaneous fat thicknesses, and core stability among young Korean women with normal weight non-obesity (NWNO), normal weight obesity (NWO), and obesity (OB).

Methods: Between May and September 2024, fifty-seven female university students from K University in Gwangju, Republic of Korea, were classified into three groups (NWNO: n = 15, NWO: n = 20, and OB: n = 22) based on body mass index and body fat percentage. The thicknesses of the abdominal muscles, including the transverse abdominis (TrA), internal abdominal oblique (IO), and external abdominal oblique (EO) muscles, and of the subcutaneous fat were measured using real-time ultrasound imaging. Core stability was assessed using trunk extensor, trunk flexor, and side-bridge endurance tests. Data were analyzed using one-way ANOVA with a significance level of 0.05.

Results: Significant differences were observed in the thicknesses of the TrA ($P = 0.002$), EO ($P = 0.001$), and subcutaneous fat ($P < 0.05$) between groups. The OB group had the greatest TrA and subcutaneous fat thicknesses. The side-bridge endurance test revealed a significant difference in core stability ($P = 0.002$), with the OB group demonstrating the lowest core stability.

Conclusion: Although the OB group had the largest muscle thickness, it demonstrated lower core stability than the NWNO group. These results suggest that obesity might impair neuromuscular activation and muscle fiber recruitment, leading to functional limitations despite increased muscle mass. These findings emphasize the importance of preventing and managing normal-weight obesity in women in their 20s.

Keywords: Core; Core stability; Obesity; Muscle thickness

Introduction

Obesity is a major health concern worldwide. Cardiovascular disease, diabetes, and certain cancers are the leading causes of disability-adjusted life years and are associated with excess weight (1). Body mass index (BMI), calculated from height and weight, is widely used to diagnose obesity due to its simplicity, low cost, and non-invasiveness (2). The WHO defines overweight

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as a BMI ≥ 25 kg/m² and obesity as a BMI ≥ 30 kg/m², regardless of ethnicity or gender. BMI is a standard tool used to assess cardiometabolic risk based on body weight (3). Although practical for large populations, BMI has limitations in identifying excess fat at the individual level. Although it has reasonable specificity, its low sensitivity misclassifies nearly half of those with a high body fat percentage (BF%) as non-obese. Thus, it may not reliably indicate health status (4). Evidence suggests that both fat mass and lean muscle mass are crucial for assessing the metabolic risks linked to excess weight (5), particularly in Asians, where BMI may underestimate the severity of obesity. Due to these limitations, normal-weight obesity (NWO) has emerged as a key marker of metabolic disorders associated with excess weight (6).

NWO is a condition where an individual has a normal BMI (18.5–24.9 kg/m^2) but a high percentage of body fat; moreover, an increased waist circumference and abdominal/visceral fat are observed (7). In other words, excess body fat and normal BMI indicate that NWO individuals are likely to have low muscle mass (8). Individuals with NWO have elevated metabolic risk profiles, such as low-grade inflammation, impaired glucose tolerance, oxidative stress, and dyslipidemia, compared to those with normal weight non-obesity (NWNO) (9). Other studies have suggested that NWO is pathologically associated with sarcopenia, an unfavorable atherogenic lipid profile, and insulin resistance (4, 10). NWO is common in Asia (9). In Korea, NWO is increasing among young women due to poor eating habits caused by unhealthy lifestyles, repeated inappropriate dieting, decreased exercise or physical activity in daily life, and changes in body composition (11). Asians have been reported to have more central fat, upper body fat, subcutaneous fat, and abdominal visceral adipose tissue than Caucasians (12).

Core stability has gained attention due to studies showing delayed or reduced activation of deep core muscles, such as the lumbar multifidus and transverse abdominis (TrA), in patients with chronic low back pain (LBP). Loss of tonic TrA activation occurs during walking and limb movements, leading to reduced lumbar support and increased joint stress (13). These deep core muscles, linked to the thoracolumbar fascia, stiffen the lumbar spine by increasing intra-abdominal pressure and enhancing segmental stability. Core endurance tests, such as trunk extensor, flexor, and side bridge tests, reliably assess core stability in both clinical and athletic settings (14). They require minimal, low-cost equipment, and measure endurance by recording the maximum hold time in a test position. Obesity is associated with reduced back and core endurance, increasing the risk of musculoskeletal injuries such as LBP. Physical inactivity was negatively correlated with muscle strength and positively correlated with obesity in children. Individuals classified as obese based on BMI and BF% showed lower endurance than their non-obese peers. Obesity impairs skeletal muscle contractility and trunk endurance (15).

The exact mechanisms of obesity-related muscle dysfunction remain unclear. However, potential factors include metabolic abnormalities (such as oxidative stress, inflammation, and anabolic resistance), a shift toward type I muscle fibers, and muscle fat accumulation (16). Excess abdominal and visceral fat overstretches the core muscles, creating a length-tension disadvantage and increasing metabolic demands, which can lead to dysfunction and reduced core stability (17). Choi et al. (18) reported an inverse relationship between lipid droplets, single-fiber contraction velocity, and specific power. Higher total and visceral fat levels are correlated with lower muscle density, which is associated with decreased physical performance in obese individuals. Studies have associated high BMI with LBP and suggested that fat accumulation within muscles contributes to dysfunction. However, research comparing core instability among the NWNO, NWO, and obesity (OB) groups is limited. Without proper management, NWO may progress to obesity, increasing the risk of musculoskeletal disorders associated with core instability. Overweight and obesity are associated with certain types of LBP related to core instability (19). Additionally, individuals with obesity have thickened muscles

but impaired function. To better understand obesity-related muscle dysfunction, it is essential to compare the abdominal muscle thickness and core function between obese and normal-weight individuals.
According to the 2024 InBody Report (2018–2022) (11), the NWO rate among Korean women in their 20s was 15.8%, the highest among the results of analyzing 2,187,224 body composition data points from women in their 20s worldwide. This study examined the differences in abdominal muscle and subcutaneous fat thickness, as well as core stability, among young Korean women in their twenties in the NWNO, NWO, and OB groups.

Methods

Participants

A total of 57 female university students were recruited from K University (Gwangju, South Korea) between May and September 2024. The sample size was determined using G*Power software version 3.1.9.4 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) and derived by inputting the following parameters: α (two-sided) (0.05), effect size f (0.50), and power β (0.80). This resulted in a sample size of 42 participants for a one-way analysis of variance (ANOVA) being required. Initially, 86 women were enrolled, taking into account the expected dropout rate. Subsequently, 29 patients were excluded because they were underweighting or experienced musculoskeletal pain. Ultimately, 57 participants were recruited (Fig. 1).

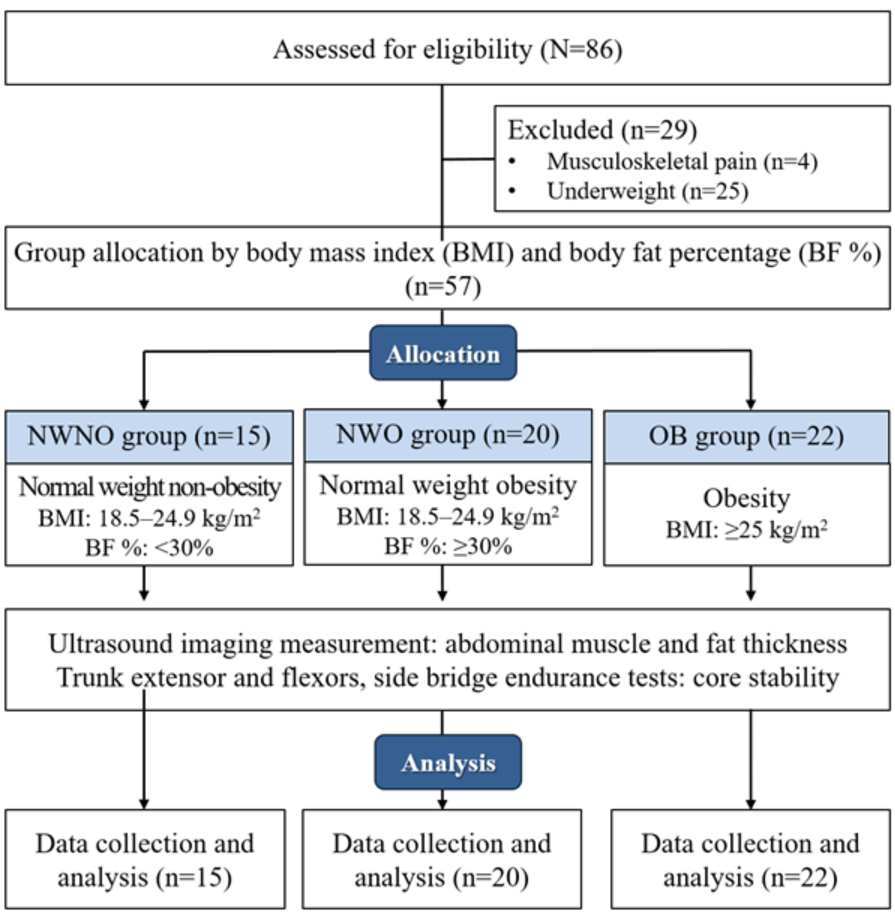

Fig. 1: Flow chart of the experimental procedure

The participants were allocated to the NWNO, NOW, and OB groups based on their BMI and body fat percentage (BF%). Body mass index (BMI) and BF% were obtained using the body composition measurement apparatus InBody-570 (InBody Co., Seoul, Republic of Korea). Participants were categorized as NWNO (BMI 18.5–24.9 kg/m^2, BF% < 30%), NWO (BMI 18.5–24.9 kg/m^2, BF% ≥ 30%), OB (BMI ≥ 25 kg/m^2) based on Korean criteria (20). Participants were excluded if they were underweighting with a BMI < 18.5 kg/m^2 or had musculoskeletal, nervous, or cardiovascular diseases within the past six months, or had a history of musculoskeletal surgery or congenital malformation. The general characteristics of the participants are listed in Table 1.

Table 1: General characteristics of subjects (N = 57)

Characteristics	NWNO group (n = 15)	NWO group (n = 20)	OB group (n = 22)
Age (yr)	21.9 ± 2.5[a]	21.6 ± 1.6	20.7 ± 1.7
Height (cm)	164.8 ± 5.7	162.7 ± 4.1	162.2 ± 5.3
Weight (kg)	56.1 ± 6.1	56.2 ± 4.7	81.4 ± 16.8
BMI (kg/m^2)	20.7 ± 2.1	21.2 ± 1.3	30.8 ± 5.2
BF (%)	25.6 ± 2.0	34.0 ± 2.5	42.6 ± 5.7

[a]Mean ± standard deviation; BMI, body mass index; BF (%), Body fat percentage (%); NWNO, normal weight non-obesity; NWO, normal weight obesity; OB, obesity

The experimental protocol was approved by the Institutional Review Board of K University (No. 2025-015). All participants voluntarily provided consent after understanding the experimental purpose and procedures. This study was conducted following the principles of the Declaration of Helsinki.

Measurements

Real-time ultrasound imaging measurement

Real-time ultrasound imaging (MyLab, Esaote Europe, Maastricht, the Netherlands) was used to assess the thickness of the abdominal muscles [TrA, internal oblique (IO), and external oblique (EO) muscles] and subcutaneous fat. A 4 cm linear transducer (13 MHz) was placed transversely on the anterolateral abdomen between the iliac crest and the 12th rib. The examiner palpated the anatomical landmarks, applied ultrasound gel (Aquasonic 100; Parker Inc., Orange, NJ, USA), and adjusted the angle for optimal imaging. All images were captured at the end of expiration and measured using screen calipers. Muscle thickness was recorded along a vertical reference line, 10 mm from the TrA myofascial junction (Fig. 2). The myofascial border was identified as a hypoechoic area with dark- and bright-contrast pixels. Test-retest reliability was established by measuring muscle thickness in a relaxed state 24 hours apart (21).

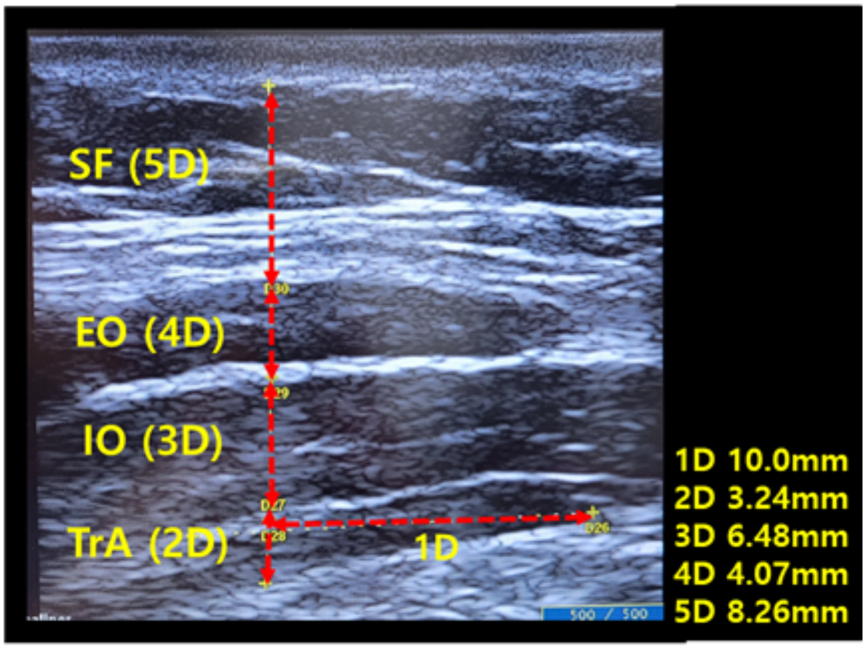

Fig. 2: Real-time ultrasound imaging measures (TrA, transverse abdominis; IO, internal abdominal oblique; EO, external abdominal oblique; SF, subcutaneous fat)

Core stability tests

Core stability was assessed using trunk extensor, trunk flexor, and side-bridge endurance tests (Fig 3). Trunk extensor endurance test was measured with the modified Biering-Sorensen test (ICC ≥ 0.77) (22). The participants lay down prone on a treatment table with their legs secured and arms crossed over their chest. They lifted and maintained their trunks horizontally while the examiner timed the duration until the trunk angle changed by 10° or until they voluntarily stopped. Trunk flexor (ICC = 0.95) and side-bridge endurance (ICC ≥ 0.97) tests were assessed using the methods described by McGill et al. (23). For the flexor test, participants lay supine with their arms crossed and knees at 90°, lifting their upper body off the bed. For the side-bridge test, the participants lay on their side with their legs extended and their elbows flexed at 90°, supporting their body on their forearms. They lifted their hips to form a straight line from their head to their feet and maintained this position. During each test, the maximum hold time was recorded (in seconds). The tests ended when the posture could no longer be maintained or when fatigue/pain increased. There was a rest time of at least 10 min between each test (13).

Fig. 3: Core stability tests (A. trunk extensor endurance test, B. trunk flexor endurance test, and C. side bridge endurance test)

Statistical Analysis

The means and standard deviations of height, weight, BMI, and BF% were analyzed using descriptive statistics. The Kolmogorov-Smirnov test was used to verify the normality of the data. According to the normal distribution, one-way ANOVA was used to analyze the differences in abdominal muscle and subcutaneous fat thickness, and core stability between the NWNO, NWO, and OB groups. $ICC_{3,1}$ was used to evaluate the test-retest reliability of the real-time ultrasound imaging results. The $ICC_{3,1}$ values were interpreted as follows: $ICC_{3,1} < 0.50$ (poor), 0.50–0.75 (moderate), 0.76–0.90 (good), > 0.90 (high). The absolute reliability was determined by calculating the coefficient of variation (CV), standard error of measurement (SEM), and minimum detectable change (MDC). These parameters were calculated as follows: $CV = 100 \times (2 \times (SDd / \sqrt{2})/(X1 + X2))$, SDd = standard deviation of the difference between two measures (SD), X1 and X2 = respective means of the two measures; $SEM = SD \times \sqrt{(1 - ICC)}$; MDC = z-score (95% CI) × SEM × √2 (24). All data were analyzed using the SPSS software package version 21; (IBM Corp., Armonk, NY, USA) and Microsoft Excel 2019 (Microsoft Inc., Redmond, WA, USA). Statistical significance (α) was set at 0.05.

Results

General characteristics of the participants

Fifty-seven participants were categorized into three groups based on BMI: NWNO (n = 15), NWO (n = 20), and OB (n = 22). The final data were recorded. There were no statistically significant differences in general characteristics among the three groups (Table 1).

Comparison of abdominal muscle and subcutaneous fat thickness among groups

The thicknesses of the TrA ($P = 0.002$), EO ($P = 0.001$), and subcutaneous fat SF ($P < 0.05$) among the three groups were significantly different. Post-hoc analysis using the Bonferroni test revealed significant differences between the NWNO and OB groups (TrA, $P = 0.002$; EO, $P = 0.002$; SF, $P < 0.05$) and between the NWO and OB groups (TrA, $P = 0.034$; EO, $P = 0.006$; SF, $P < 0.05$) (Table 2).

Table 2: Comparison of Abdominal Muscle and Subcutaneous Fat Thickness Between Groups (N = 57)

Variables (unit: mm)	NWNO group (A, n = 15)	NWO group (B, n = 20)	OB group (C, n = 22)	F(*p*)Post hoc	
TrA	4.21 ± 1.02[a]	4.94 ± 1.99	6.46 ± 2.19	7.072 (0.002)*	A|C†, B|C
IO	8.68 ± 1.73	7.23 ± 2.04	8.43 ± 3.17	1.819 (0.172)	A, B, C
EO	6.55 ± 1.45	7.22 ± 1.72	10.29 ± 4.50	8.246 (0.001)*	A|C, B|C
SF	7.71 ± 2.75	10.61 ± 2.36	18.73 ± 6.42	31.487 (0.000)*	A|C, B|C

[a]Mean ± standard deviation; NWNO, normal weight non-obesity; NWO, normal weight obesity; OB, obesity; * $P < 0.05$; †Significant differences between groups; TrA, transverse abdominis; IO, internal abdominal oblique; EO, external abdominal oblique; SF, subcutaneous fat

Comparison of core stability among groups

Only the side-bridge endurance test showed significant differences among the three groups ($P = 0.002$). The Bonferroni test indicated a significant difference between the NWNO and OB groups ($P = 0.002$) (Table 3).

Table 3: Comparison of Core Stability Between Groups (N = 57)

Variables (unit: sec)	NWNO group (A, n = 15)	NWO group (B, n = 20)	OB group (C, n = 22)	F(*p*) Post hoc	
Trunk extension endurance test	72.19 ± 57.89[a]	52.63 ± 52.14	43.45 ± 29.04	1.791 (0.177)	A, B, C
Trunk flexion endurance test	41.94 ± 32.05	45.79 ± 41.50	34.91 ± 23.81	0.580 (0.563)	A, B, C
Side bridge endurance test	36.94 ± 25.61	27.26 ± 13.02	17.09 ± 8.56	6.907 (0.002)*	A | C†

[a]Mean ± standard deviation; NWNO, normal weight non-obesity; NWO, normal weight obesity; OB, obesity; $*P < 0.05$; † Significant differences between groups

Reliability for repeated measures of abdominal muscle and subcutaneous fat thickness

The test-retest reliability was assessed using real-time ultrasound imaging (Table 2). $ICC_{3,1}$ values indicated high reliability: TrA (0.974, CV = 4.48%, SEM = 0.30 mm, MDC = 0.84 mm), IO (0.962, CV = 3.51%, SEM = 0.40 mm, MDC = 1.11 mm), and EO (0.994, CV = 1.81%, SEM = 0.24 mm, MDC = 0.67 mm). Subcutaneous fat thickness also showed excellent reliability ($ICC_{3,1}$ = 0.994, CV = 1.81%, SEM = 0.24 mm, MDC = 0.67 mm) (Table 4).

Table 4: Test-retest reliability for repeated measures of abdominal muscle and subcutaneous fat thickness using a real-time ultrasound imaging

Variables	Test (Mean ± SD, mm)	Re-test (Mean ± SD, mm)	$ICC_{3,1}$	95% CI	CV (%)	SEM (mm)	MDC (mm)
TrA	4.64 ± 2.00[a]	4.80 ± 1.74	0.974*	0.924–0.991	4.48	0.30	0.84
IO	8.22 ± 2.11	8.29 ± 2.01	0.962*	0.892–0.987	3.51	0.40	1.11
EO	6.84 ± 1.79	6.80 ± 1.76	0.988*	0.964–0.996	1.25	0.19	0.54
Sub Fat	9.33 ± 3.16	9.37 ± 3.11	0.994*	0.981–0.998	1.81	0.24	0.67

[a]Mean ± standard deviation, TrA, transverse abdominis; IO, internal abdominal oblique; EO, external abdominal oblique; Sub Fat, subcutaneous fat; SD, standard deviation; $ICC_{3,1}$, intraclass correlation coefficient based on the model (3) and type (single measurement); $*P < 0.01$; CI, confidence interval; CV, coefficient of variation; SEM, standard error of measurement; MDC, minimal detectable change

Discussion

This study compared and analyzed abdominal muscle and subcutaneous fat thickness, and core stability among female college students in their 20s in NWNO, NWO, and OB groups. The results showed significant differences in TrA, EO, and subcutaneous fat thickness across the groups, with the OB group exhibiting the greatest TrA and EO thicknesses. Core stability, as assessed by the side-bridge endurance test, was the lowest in the OB group, with significant differences between the NWNO and OB groups.

Functionality can be evaluated by assessing fiber size, thickness, and morphology of the abdominal muscles (21). Sung et al. (25) found no significant group differences in muscle composition among 58 female college students; however, they noted higher muscle ratios in the groups with higher BMI. Similarly, Rostami et al. (26) reported a positive correlation between BMI and EO thickness (r = 0.392) in 90 healthy men aged 18–38 years, whereas Springer et al. (27) reported a similar relationship between lateral abdominal muscle thickness and BMI (r = 0.66) in 32 healthy adults aged 18–45 years. Consistent with these findings, we observed significant group differences in TrA, EO, and subcutaneous fat thickness, with the OB group showing the most important values. These results reinforce the correlation between BMI and abdominal muscle thickness, emphasizing its relevance as a research focus.

Core stability plays a crucial role in stabilizing the body center, maintaining posture, enhancing movement efficiency, and preventing injury. It particularly requires the harmonious activation of the abdominal and spinal muscles (22). Lee et al. (28) assessed muscular endurance in 30 women in their 20s, and reported that the obese group (BMI > 30 kg/m²) showed the poorest performance, with muscular endurance significantly decreasing as body fat percentage increased. Similarly, Ki and Park (29) evaluated sit-up performance in 559 adolescent girls and found that the morbidly obese group (BMI > 35 kg/m²) performed fewer repetitions than the NWNO, OB, and NWO groups. In the present study, no significant group differences were observed in trunk flexor and extensor endurance tests. However, the results of the side-bridge endurance tests differed significantly. The trunk flexor and extensor endurance tests primarily engage the outer global core muscles. In contrast, the side-bridge endurance test involves these muscles in addition to the deep core muscles that stabilize the spine during pelvic elevation against gravity. This may explain the observed intergroup differences.

A literature review examining abdominal muscle thickness and strength indicated no significant relationship between muscle thickness and strength in studies involving active healthy male college students, suggesting that muscle thickness does not directly affect strength (21). Choi et al. (30) found that older adults (aged 65–79 years) with obesity had greater thigh volume, muscle mass, subcutaneous fat, and thigh strength than their counterparts of normal weight. Strength per unit body weight was higher in normal-weight older adults. These findings suggest that an increased muscle thickness does not necessarily translate into improved muscle strength. Muscle thickness primarily reflects the size and structure of muscles, whereas various factors, including neuromuscular coordination and the type of muscle fibers, influence strength. An increase in abdominal muscle thickness may not directly lead to an increase in muscle strength. Core stability and functional movement assessments may be of greater importance when evaluating the abdominal muscles. In the present study, although the OB group had thicker abdominal muscles than the NWNO group, this observation could not be conclusively linked to increased muscle strength. This can be attributed to the increased intramuscular fat deposits, which reduce muscle tissue stiffness and efficiency. Consequently, the OB group may have exhibited lower muscular endurance than the NWNO group, owing to its inability to sustain prolonged muscle contractions.

The OB group exhibited the largest muscle thickness and lowest core stability. Obesity diminishes skeletal muscle contraction and core endurance, whereas visceral fat accumulation may impose mechanical stress and metabolic burden, potentially resulting in muscle dysfunction (19). Alvarez et al. (31) reported reduced neural activation capacity in adolescents with obesity, suggesting impaired recruitment patterns—lower habitual activity levels in obese youth correlate with diminished muscle activation capacity. A 5 kg/m² increase in BMI was associated with a 1.07-fold increase in the prevalence of LBP in men and a 1.17-fold increase in women. Abdominal obesity induces pelvic muscle imbalance, excessive hip flexor activation, anterior pelvic tilt, and lumbar lordosis, potentially causing LBP (32). Thus, NWO management is crucial to prevent these issues.

This study highlights the importance of NWO management. However, three limitations and recommendations are identified. The first is sample generalization. This study focused on 20-year-old female college students, thereby limiting its generalizability. Future studies should include more diverse age and gender groups. Second, core stability was evaluated using three clinical tests (trunk flexor, trunk extensor, and side-bridge endurance tests). Future studies should incorporate electromyography to assess muscle activation and obtain precise physiological results. Finally, we excluded pain variables. This study excluded variables such as musculoskeletal pain. Future studies should incorporate these variables to enhance their clinical relevance.

Conclusion

This study compared and analyzed abdominal muscle and subcutaneous fat thickness, as well as core stability, among female university students in their 20s from the NWNO, NWO, and OB groups, highlighting the importance of managing normal-weight obesity. The results showed significant differences in TrA, EO, and subcutaneous fat thicknesses, with the OB group exhibiting the greatest TrA and EO muscle thicknesses. However, the side-bridge endurance test revealed significant differences in core stability, with the OB group exhibiting the lowest core stability. This observation suggests that despite the thicker abdominal muscles in the OB group, functional impairment may occur due to reduced muscle performance, reflecting lower physical activity and muscle dysfunction. If NWO is managed well before it progresses to obesity in young women, it is expected to contribute to the prevention of musculoskeletal dysfunction due to core instability.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare no conflict of interests.

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