

Asian squat exercise for sedentary male adolescents: A randomized controlled trial assessing its effects on the strength of the Gluteus Maximus, Quadriceps Femoris, and Soleus muscles

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Abstract

Background: The global increase in sedentary behavior among adolescents has caused considerable reductions in musculoskeletal fitness, particularly in lower limb muscle strength, including the gluteus maximus (GMAX), quadriceps femoris (QF), and soleus (SOL). This decline increases the risk of various diseases, functional impairments, and overall mortality. While resistance training effectively mitigates these effects, accessible bodyweight exercise alternatives remain underexplored. The Asian squat, when performed using an evidence-based protocol, offers a practical and efficient means to increase muscle strength in this population.

Objective: This study evaluated the effects of an eight-week Asian squat exercise program on the bilateral strength of the GMAX, QF, and SOL muscles in sedentary adolescent males. **Materials and methods:** A randomized, single-blind, controlled trial with a pre- and post-test design was performed. Twenty-eight participants were randomly assigned to either an intervention group ($n = 14$), which completed supervised Asian squats for eight weeks, or a waitlist control group ($n = 14$), which continued their usual activities. Muscle strength of the GMAX, QF, and SOL was assessed bilaterally using standardized methods. **Results:** The intervention group showed significant within-group improvements in muscle strength for all assessed muscles (all $p < 0.001$), with large effect sizes (GMAX: $d = 1.015$ – 1.050 ; QF: $d = 0.956$ – 1.020 ; SOL: $d = 1.816$ – 2.016). Between-group comparisons indicated significantly greater strength gains in the intervention group compared to controls (Δ GMAX: $d = 4.413$ – 4.738 ; Δ QF: $d = 4.140$ – 4.828 ; Δ SOL: $d = 2.539$ – 3.027 ; all $p < 0.001$). **Conclusion:** An eight-week Asian squat exercise program effectively improves strength in the GMAX, QF, and SOL muscles of sedentary adolescent males, highlighting its value as a time-efficient, equipment-free method to counteract muscle weakness associated with sedentarism.

Keywords: youth, inactivity, resistance training, well-being

Introduction

A sedentary lifestyle has detrimental effects on muscle strength (Huang *et al.*, 2022). Worldwide, 81% of adolescents aged 11–17 do not meet recommended physical activity guidelines (Guthold *et al.*, 2020), a trend related to increasing rates of reduced muscle strength among school-aged youth (Garcia *et al.*, 2020). This decline leads to poorer physical fitness, faster muscle fatigue, and overall systemic deconditioning (Huang *et al.*, 2022; Kumareswaran, 2023). Additionally, it increases the risk of developing type 2 diabetes, metabolic syndrome, cardiovascular disease, cancer, and increases all-cause mortality (Katzmarzyk *et al.*, 2019; Sluijs *et al.*, 2022). Importantly, a decrease in lower extremity muscle strength—including major muscle groups such as the gluteus maximus (GMAX), quadriceps femoris (QF), and soleus (SOL)—is closely associated with morbidity, mortality, and reduced quality of life (Loprinzi, 2016; Aguilar-Agon *et al.*, 2019), underscoring the urgency of addressing sedentary habits in this population.

Several studies show that adolescents spend nearly 50% of their waking hours in sedentary activities, which amounts to approximately 7.5–8 h daily (Kuzik *et al.*, 2022). In Indonesia, 87.1% of adolescents are classified as inactive (World Health Organization, 2018). As a result, physical activity is widely recognized as essential to counteract the harmful effects of sedentary behavior (Bull *et al.*, 2020). International guidelines recommend that adolescents engage in at least 60 min of moderate-to-vigorous physical activity each day, complemented by three weekly sessions focused on muscle-strengthening exercises (Parrish *et al.*, 2020).

Physical activity interventions such as squats, lunges, and calf raises are proven methods for increasing adolescent muscle strength (Jung *et al.*, 2023). Among these, squats—classified as a closed kinetic chain exercise—activate all major lower extremity joints and muscle groups simultaneously (Zawadka *et al.*, 2020). Their effectiveness stems from engaging the hip, knee, and ankle muscles, making squats a highly recommended

approach for improving lower limb strength (Cabral *et al.*, 2023). Notably, squatting increases lower limb muscle activity by 20%–40% compared to walking (Raichlen *et al.*, 2020), potentially reducing injury risk through increased neuromuscular stability (Lee *et al.*, 2022). Squat depth significantly influences biomechanical outcomes (Kubo *et al.*, 2019), with deeper squats eliciting greater activation of the GMAX, QF, and SOL muscles, promoting neuromuscular adaptation and increasing functional performance (Pallarés *et al.*, 2020; Cabral *et al.*, 2023). This corresponds with the biomechanical profile of the Asian squat as a deep, equipment-free variation, highlighting its potential for optimizing muscle activation while offering a practical and accessible intervention for adolescents.

The Asian squat is a full squat variation characterized by flat-foot contact and parallel to the floor (Luna & Dominick, 2023). It is commonly used in daily activities such as resting, using traditional toilets, and performing routine tasks in many Asian cultures. Biomechanically, it involves placing the feet shoulder-width apart, aligning the knees with the hips, and directing the coccyx downward (Chong, 2016; Lu *et al.*, 2020). Despite its prevalence, a systematic review by Ribeiro *et al.* (2023) analyzing 15 squat-related studies revealed a key gap: most muscle-strengthening squat protocols depend on equipment, and none have specifically evaluated the efficacy of the Asian squat. Given adolescents' busy academic and daily schedules, simple, equipment-free, and culturally familiar exercises are essential to encourage consistent muscle-strengthening activities, especially for the lower limbs. A well-designed Asian squat protocol, optimized for safety and effectiveness, could provide a convenient and accessible option. However, comprehensive research is needed to evaluate its potential for increasing lower extremity muscle strength in sedentary adolescents, taking into account both physiological benefits and real-world feasibility.

Materials and Methods

Participants

This randomized single-blind controlled trial involved 28 male adolescents aged 15–17 years from Frateran Catholic Senior High School Surabaya, Indonesia, who were equally assigned to either the intervention group ($n = 14$) or the waitlist control group ($n = 14$). Inclusion criteria required participants to be male, aged 15–17 years, and classified as sedentary based on the Indonesian version of the International Physical Activity Questionnaire (IPAQ). Exclusion criteria included a history or ongoing treatment for musculoskeletal disorders (such as fractures, tendon/ligament/muscle ruptures, arthritis, or congenital abnormalities); neurological conditions (including epilepsy, vertigo, spinal cord or brain trauma, and stroke); cardiovascular or respiratory diseases (such as asthma, pulmonary infections, or heart disease); psychiatric illnesses that might affect participation; and habitual use of squatting postures during toileting activities. Ethical approval was granted by the Health Research Ethics Committee, Faculty of Medicine, Universitas Airlangga (277/EC/KEPK/FKUA/2023). Written assent and informed consent were obtained after participants and their parents or legal guardians received both oral and written explanations of the study protocols, objectives, risks, and benefits. Dropout criteria included missing more than two consecutive exercise sessions, more than 20% of total intervention sessions (at least 4 absences), voluntary withdrawal, or severe illness. Baseline and post-intervention (week 8) assessments of GMAX, QF, and SOL muscle strength were performed by blinded assessors to maintain methodological rigor.

Procedure

The intervention group followed a structured Asian squat program consisting of three weekly sessions over eight weeks, totaling 24 non-consecutive sessions, all supervised by physicians. Each session included three sets, with repetitions increasing gradually: 8 per set in weeks 1–2, 10 in weeks 3–4, 13 in weeks 5–6, and 15 in weeks 7–8, with 2-min rest between sets. Participants were provided with instructional videos explaining the exercise protocol. Before the intervention, a one-week familiarization phase involved two weekly sessions of three sets with five repetitions each.

Before each session, participants underwent a brief clinical screening that included symptom evaluation and monitoring of vital signs (blood pressure, heart rate, respiratory rate, temperature, and oxygen saturation). Exercise was contraindicated if any of the following were present: 1) systolic/diastolic blood pressure exceeding 250/115 mmHg, 2) exertion-related symptoms such as shortness of breath, palpitations, chest, head, joint or muscle pain, pallor, nausea, or vomiting, 3) heart rate above the age-predicted maximum ($220 - \text{age}$) or below 60 bpm, or 4) acute illness.

Cleared participants performed dynamic warm-up exercises targeting the shoulder, trunk, hip, knee, and ankle joints, holding each movement for 10 s with three repetitions. The Asian squat protocol began from a standing position with the gaze forward, arms relaxed, hips and knees fully extended, ankles neutral, and feet shoulder-width apart. The exercise consisted of four phases: the Descent Phase, squatting down to maximal hip and knee flexion, 20° ankle dorsiflexion, 90° shoulder flexion, elbows fully extended, wrists pronated, and trunk and head upright; the Maintenance Phase, holding the squat position; the Ascent Phase, rising to standing with upright posture and neutral alignment of the head, neck, trunk, shoulders, elbows, wrists, hips, knees, and ankles, with gaze forward; and the Rest Phase, remaining standing before the next repetition.

Each phase lasted 1 s, paced by a metronome set to one beat per second. Sessions ended with a 5-min walking cooldown. Vital signs were monitored before exercise, during rest intervals between sets, and after

completion. Participants' perceived exertion (Borg Scale) and pain levels (Wong–Baker Scale or WBS) were recorded post-session. Immediate termination occurred if any of the following appeared: shortness of breath, palpitations, chest pain, headache, muscle or joint pain, pallor, nausea or vomiting, oxygen saturation below 90%, heart rate exceeding the age-predicted maximum, or if the participant chose to stop.

The waitlist control group maintained their usual school or home activities, including attending physical education classes once weekly, without any additional interventions. After the eight-week intervention period, they were allowed to perform the Asian squat exercise only if its safety and effectiveness were confirmed. Data from this group were used only for baseline comparison, and outcomes from their delayed intervention were excluded from analysis, because this was outside the scope of this study.

Test Protocol

Before the intervention, baseline participant characteristics were recorded, including age, height, body weight, body mass index (BMI), femoral length, and tibial length. Pre-intervention nutritional intake—including total protein, carbohydrates, fat, and caloric intake—was evaluated using self-reported dietary logs consisting of three weekdays and one weekend entry, which were analyzed by the nutrition team at Dr. Soetomo General Academic Hospital Surabaya. Initial metabolic equivalents (METs) were measured through the Chester Step Test performed by physicians. Both the nutrition team and physicians were blinded to the participants' group assignments.

The main outcome measures were the isometric muscle strength of the GMAX, QF, and SOL, assessed using a validated digital dynamometer method. The validity coefficients (r) and intraclass correlation coefficients (ICCs) for the digital dynamometer were as follows: GMAX ($r = 0.988$, ICC = 0.998), QF ($r = 0.996$, ICC = 1.000), and SOL ($r = 0.994$, ICC = 0.994). Reliability tests showed ICC values of 0.993, 0.983, and 0.994, respectively. Previous studies have demonstrated a near-perfect correlation between digital and isokinetic dynamometers for measuring isometric strength, with no significant differences reported (Kim *et al.*, 2015; Romero-Franco *et al.*, 2017).

Pre-measurement protocols involved a 5-min jogging warm-up to induce maximal effort. During testing, muscles were placed in a neutral, gravity-aligned posture and secured to the digital dynamometer with adjustable straps. Padding was used between the straps and the body to prevent injury. The dynamometer was positioned perpendicular to the muscle's axis of action (Kim *et al.*, 2015; Romero-Franco *et al.*, 2017). Standardized muscle testing positions were applied. GMAX was tested with the participant in a supine position, hips flexed at 90°, knees relaxed, and resistance applied via a strap placed just above the femoral condyle (Kim *et al.*, 2015). QF was tested in a seated position with both hip and knee flexed at 90°, with the resistance strap placed anteriorly on the calf, just above the ankle joint (Endo *et al.*, 2020). SOL was tested with the participant in a supine position, with hips and knees flexed at 90°. The proximal lower leg rested on an adjustable seat, while the distal part of the lower leg hung freely off the edge, with the ankle dorsiflexed to 15°. Resistance was applied at the metatarsophalangeal joint (Hirano & Yamamoto, 2013).

Participants performed maximal isometric contractions held for 5 s. Three trials per muscle group were averaged. After the eight-week intervention, the experimental group completed a blinded perceptual evaluation survey assessing 1) perceived benefit of the intervention, 2) ease of exercise execution and self-efficacy, 3) safety and absence of adverse effects, and 4) willingness to continue after the study. Responses were rated on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

Statistical Analysis

Data were analyzed using IBM SPSS Statistics (Version 26). The Shapiro–Wilk test was used to assess the normality of baseline demographic and clinical characteristics. Participants' baseline profiles were summarized using descriptive statistics. For in-group comparisons of GMAX, QF, and SOL muscle strength before and after the eight-week intervention, parametric assumptions were assessed. Paired t-tests were used for normally distributed data ($p \geq 0.05$), while Wilcoxon signed-rank tests were applied for non-normal data ($p < 0.05$). Between-group differences in the magnitude of change (Δ) in muscle strength were analyzed using independent t-tests for parametric data and Mann–Whitney U tests for non-parametric data.

Results

All participants successfully completed the Asian squat exercise protocol, with a high average adherence rate of 91.67% (range: 87.5%–100%) and no serious adverse events reported. Statistical analyses included 14 participants in the intervention group and 14 in the waitlist control group who completed the study. Baseline demographic and clinical characteristics for both groups are presented in Table 1.

As shown in Table 2, there were no significant between-group differences in baseline muscle strength (week 0) for the GMAX, QF, or SOL muscles in either lower extremity ($p > 0.05$), confirming initial group homogeneity. At week eight post-intervention, the intervention group demonstrated statistically significant improvements in mean muscle strength across all three muscle groups compared to the waitlist control group ($p < 0.05$). The intervention group exhibited significant within-group changes in muscle strength from baseline to week eight compared to the waitlist control group ($p < 0.05$). Figure 1 shows these significant strength gains in the GMAX, QF, and SOL for both extremities after the eight-week program ($p < 0.05$). In contrast, participants in the waitlist control group showed no significant strength changes in any muscle group or extremity ($p > 0.05$).

Table 1. Baseline demographic and clinical characteristics of participants

Variable	Intervention group, <i>n</i> = 14 (50%) Mean $\pm$ SD Median (min–max) ^β	Waitlist control group, <i>n</i> = 14 (50%) Mean $\pm$ SD Median (min–max) ^β	<i>p</i>
Age (years)	15 (15–16) ^β	15 (15–17) ^β	0.907 ^a
Body height (cm)	165.00 $\pm$ 5.25	167.54 $\pm$ 4.64	0.187 ^b
Body weight (kg)	56.0 (48–77) ^β	59.0 (45–100) ^β	0.447 ^a
Body mass index (kg/m ²)	21.73 $\pm$ 3.89	22.19 $\pm$ 4.83	0.784 ^b
Femoral length (cm)	50.50 $\pm$ 2.85	50.29 $\pm$ 2.67	0.839 ^b
Tibial length (cm)	39.64 $\pm$ 1.82	39.36 $\pm$ 2.41	0.726 ^b
Total calorie intake before intervention (kcal)	1263.18 (932.07–1846.50) ^β	1234.64 (1105.25–1867.10) ^β	0.667 ^a
Protein intake before intervention (g)	44.24 (37.40–74.28) ^β	49.89 (32.60–69.50) ^β	0.210 ^a
Fat intake before intervention (g)	45.44 $\pm$ 11.86	50.25 $\pm$ 10.16	0.260 ^b
Carbohydrate intake before intervention (g)	169.67 $\pm$ 45.76	170.03 $\pm$ 42.68	0.983 ^b
METs before intervention	13.75 (9.80–16.80) ^β	12.60 (10.60–20.00) ^β	0.874 ^a

^a)Mann–Whitney U test; significance set at *p* < 0.05^b)Independent t-test; significance set at *p* < 0.05

Table 2. Between-group analysis of GMAX, QF, and SOL muscle strength

Muscle strength	Variable	Intervention group, <i>n</i> = 14 (50%) mean $\pm$ SD (in kg) Median (min–max) ^β	Waitlist control group, <i>n</i> = 14 (50%) mean $\pm$ SD (in kg) Median (min–max) ^β	<i>p</i>	Effect size (Cohen's <i>d</i>)
Right GMAX	Week 0	20.37 $\pm$ 6.05	20.75 $\pm$ 6.99	0.882 ^a	-
	Week 8	26.48 $\pm$ 7.62	20.60 $\pm$ 7.30	0.028 ^{a*}	0.789
	ΔWeek 0–8	5.58 (3.70–10.10) ^β	-0.13 (-2.00–1.23) ^β	<0.001 ^{b*}	4.413
Left GMAX	Week 0	19.70 $\pm$ 5.76	20.57 $\pm$ 7.27	0.727 ^a	-
	Week 8	25.77 $\pm$ 5.82	20.47 $\pm$ 6.91	0.037 ^{a*}	0.830
	ΔWeek 0–8	6.08 $\pm$ 1.65	-0.10 $\pm$ 0.83	<0.001 ^{a*}	4.738
Right QF	Week 0	23.38 $\pm$ 5.98	24.45 $\pm$ 5.93	0.640 ^a	-
	Week 8	30.37 $\pm$ 7.62	24.51 $\pm$ 6.02	0.033 ^{a*}	0.853
	ΔWeek 0–8	6.99 $\pm$ 2.27	0.06 $\pm$ 0.66	<0.001 ^{a*}	4.140
Left QF	Week 0	23.13 $\pm$ 6.89	24.46 $\pm$ 5.86	0.588 ^a	-
	Week 8	30.13 $\pm$ 7.72	24.51 $\pm$ 5.89	0.040 ^{a*}	0.818
	ΔWeek 0–8	6.70 $\pm$ 1.90	0.05 $\pm$ 0.72	<0.001 ^{a*}	4.828
Right SOL	Week 0	9.41 $\pm$ 2.14	10.10 $\pm$ 2.15	0.403 ^a	-
	Week 8	13.23 $\pm$ 2.07	10.20 $\pm$ 2.60	0.002 ^{a*}	1.293
	ΔWeek 0–8	3.82 $\pm$ 1.87	0.10 $\pm$ 0.90	<0.001 ^{a*}	2.539
Left SOL	Week 0	9.07 $\pm$ 1.75	9.92 $\pm$ 2.12	0.254 ^a	-
	Week 8	12.70 $\pm$ 1.85	9.96 $\pm$ 2.51	0.003 ^{a*}	1.244
	ΔWeek 0–8	3.64 $\pm$ 1.37	0.03 $\pm$ 0.98	<0.001 ^{a*}	3.027

^a) Independent t-test; *Significance set at *p* < 0.05^b) Mann–Whitney U test; *Significance set at *p* < 0.05

Participant feedback showed strong acceptance of the intervention. Specifically, 92.9% agreed or strongly agreed on its perceived benefits, 100% endorsed its simplicity and feasibility for independent practice, 100% reported no serious side effects, and 92.9% expressed willingness to continue after the study.

Perceived exertion, assessed using the Borg scale, averaged 10–11 across sessions, peaking at 11 during sessions 13, 14, 19, and 20. Mild exercise-induced pain (WBS scores 0–1) occurred briefly in sessions 7, 13, 14, 19, and 20, resolving within 24–48 h with conservative treatments such as cold compresses, light stretching, and rest. These episodes were attributed to delayed onset muscle soreness (DOMS) and did not interfere with subsequent training.

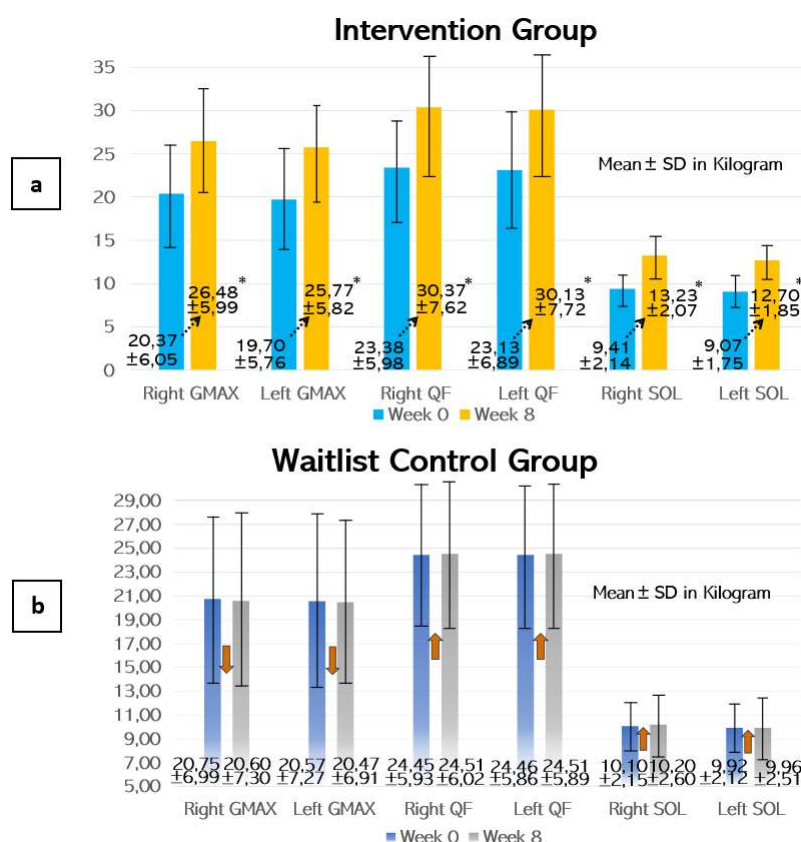


Figure 1. Analysis of gluteus maximus, quadriceps femoris, and soleus strength after eight weeks of Asian squat exercise. a) Intervention group; b) waitlist control group. *Significance set at $p < 0.05$

Discussion

To our knowledge, this study is the first systematic analysis of Asian squat exercise interventions aimed at improving muscle strength in sedentary male adolescents, identified through an extensive literature search of English and Indonesian databases, including PubMed, Embase, Cochrane Library, ScienceDirect, EBSCO, Web of Science, and ClinicalTrials.gov.

The Asian squat, a form of deep squatting, engages a wide range of lower-extremity muscles through a multisegmental movement pattern involving all muscles of the lower limbs (Hoa, 2022; Luna & Dominick, 2023). Compared to other squat variations, the Asian squat effectively increases lower-extremity muscle strength owing to significant neuromuscular and functional adaptations (Pallarés *et al.*, 2019). This exercise predominantly activates the GMAX, SOL, hamstrings, and vastus muscle group, which are primarily uniaxial muscles responsible for generating joint torque against inertial loads (Hoa, 2022). Our eight-week intervention (3 sessions per week) aligns with adolescent resistance training guidelines, which recommend at least 2–3 weekly sessions to support neuromuscular development (Stricker *et al.*, 2020; American College of Sports Medicine, 2022). The observed strength improvements confirm that a minimum of 6–8 weeks of resistance training is necessary to elicit noticeable neuromuscular adaptations (Garcia *et al.*, 2020), while maximal gains generally require more than 23 weeks (Lesinski *et al.*, 2016; Stricker *et al.*, 2020). Regular training programs lasting 6–24 weeks have been shown to increase contractile force production and increase muscle mass (Aguilar-Agon *et al.*, 2019), while 8–16 weeks of training may lead to a 5%–30% increase in muscle cross-sectional area (Jorgenson *et al.*, 2020). Resistance training during or after puberty in adolescents promotes muscle growth mainly through hypertrophy (Stricker *et al.*, 2020). Beyond muscular changes, it also improves motor unit recruitment, autonomic nervous system activity, and muscle power by triggering both acute and chronic neural adaptations. These neural adaptations are especially important in the early phases of resistance training, before muscular adaptations become dominant and lead to substantial muscle hypertrophy (Faigenbaum *et al.*, 2020).

The eight-week Asian squat exercise intervention in the treatment group led to a significant increase in GMAX muscle strength. GMAX activation is strongly affected by squat depth, with deeper squats involving greater knee flexion angles that correlate with higher muscle activity (Schoenfeld, 2010; Ribeiro *et al.*, 2023). During the descent phase of the squat, the GMAX contracts eccentrically to maintain balance and control movement, while concentric contractions predominate during the ascent phase to overcome body weight (Caterisano *et al.*, 2002; Schoenfeld, 2010). The Asian squat, characterized by its maximal depth, aligns with

findings of Muyor *et al.* (2020), who reported increased GMAX activity during squats, as measured by electromyography (EMG).

Quadriceps femoris (QF) muscle strength in the intervention group showed a significant increase after the Asian squat exercise program. This is consistent with findings of Muyor *et al.* (2020) and Lee *et al.* (2022), who reported high EMG activity in the vastus lateralis, vastus medialis, and rectus femoris during the concentric phase of squat movements. Moreover, the vastus medialis generated significant knee torque during the maintenance phase of the Asian squat (Hoa, 2022). These findings are consistent with those of Kojic *et al.* (2022), who observed significant improvements in QF strength, measured by one-repetition maximum (1RM), after back/parallel squat training, with moderate effect sizes. Additionally, Robertson *et al.* (2008) reported increased EMG activity in the rectus femoris during the descent phase before reaching maximal squat depth, highlighting its function as a hip flexor and stabilizer for the hip and knee during squat movements. However, among the QF muscles, the vastus muscles played a more prominent role, producing approximately 30%–90% greater force than the rectus femoris during squat exercises (Escamilla *et al.*, 2001). This difference is explained by the bi-articular nature of the rectus femoris, which experiences minimal or negligible changes in muscle length during deep squat movements such as the Asian squat, leading to lower force output compared to the uni-articular vastus muscles (Hoa, 2022).

The SOL muscle strength in the treatment group significantly increased after the Asian squat training program. As an ankle plantarflexor, the SOL co-contracts with the tibialis anterior during the maintenance phase and is mainly activated at the beginning of the ascent phase in the Asian squat (Hoa, 2022). These findings align with Toutoungi *et al.* (2000), who found that the SOL shows greater activity than the gastrocnemius during deep squat movements such as the Asian squat, owing to its role as a pure plantarflexor. Conversely, the gastrocnemius, being a bi-articular muscle involved in both plantarflexion and knee flexion, functions mostly isometrically during squats, with little to no change in fiber length during the movement (Schoenfeld, 2010; Hoa, 2022). The waitlist control group showed a non-significant increase in the average strength of the bilateral QF and SOL muscles. This slight improvement may be attributed to activities outside the Asian squat intervention because participants' daily routines were not restricted by the study protocol. Additionally, a small, non-significant decrease in the mean delta strength of the bilateral GMAX muscles was observed. These results are consistent with Huang *et al.* (2022), who reported that sedentary behavior could cause venous pooling in the lower limbs, potentially reducing muscle blood flow and impairing effective muscle contraction. Moreover, decreased physical activity is a well-known risk factor for sarcopenia (Jung *et al.*, 2023).

Muscle soreness, particularly DOMS, is common in individuals after intense or unaccustomed exercise (Wilke & Behringer, 2021). Research by Gokce *et al.* (2019) indicates that sedentary individuals are more prone to DOMS, especially after exercises that involve eccentric contractions. Consistent with the American College of Sports Medicine (2022) guidelines, the Asian squat exercise was implemented gradually to reduce the risk of excessive muscle soreness and post-exercise fatigue.

Numerous studies emphasize the benefits of resistance training for adolescents in reducing injury risk. Resistance training is recognized as a protective factor against injuries rather than a cause (Schoenfeld & Williams, 2012). Recent evidence indicates that squat exercises, even at advanced or competitive levels, present minimal risk of knee injuries, including ligament and tendon damage (Stone *et al.*, 2024). Full squat movements, such as the Asian squat, do not increase harm in individuals with healthy knees and no pre-existing anatomical issues (Schlegel & Fialová, 2021). Additionally, no significant differences in knee ligament stability have been found between those performing full squats and those doing half squats (Schoenfeld & Williams, 2012).

Extensive research confirms that adolescents can safely improve muscle strength through resistance training with minimal risk of injury, as long as exercises emphasize proper technique and are performed under appropriate supervision (Stricker *et al.*, 2020; Straub & Powers, 2024). In this study, participants in the treatment group completed a one-week familiarization phase before the intervention, performing the Asian squat twice weekly with three sets of five repetitions to ensure correct form and reduce injury risk. The exercises were closely supervised by a physician, and vital signs, along with oxygen saturation, were monitored before, after, and between sets to ensure participant safety during the training.

The American Academy of Pediatrics recommends at least 1–2 rest days per week from competitive sports and physical training to support both physical and psychological recovery. For beginners, rest intervals of 1 min between sets are advised, increasing to 2–3 min as training intensity increases (Stricker *et al.*, 2020). Similarly, the American College of Sports Medicine (2022) guidelines suggest that adolescent resistance training can use body weight as resistance, performing 8–15 submaximal repetitions with proper form. In this study, the Asian squat was performed three times weekly on non-consecutive days, allowing 1–2 rest days between sessions, with 2 min rest intervals between sets. The exercise intensity was increased gradually every two weeks, beginning with 8–15 repetitions, to promote gradual adaptation and reduce injury risk.

This study has several limitations. First, the eight-week duration of the Asian squat exercise is the minimum time needed to observe significant muscle strength improvements. However, the long-term safety and potential side effects, especially regarding maximal strength gains, remain unknown. Second, the study included only sedentary male adolescents. Thus, the effects on other groups—such as female adolescents, pre-pubertal children, older adults, athletes, and active adults—were not examined. Third, participants' daily activities outside

the intervention were not controlled because they continued their usual routines; therefore, the intervention's functional benefits in everyday life were not evaluated. Lastly, participant feedback was collected blindly, limiting the researchers' ability to explore the reasons behind their responses in depth.

Conclusions

The eight-week Asian squat intervention improved the strength of the GMAX, QF, and SOL muscles in sedentary adolescent males, with no serious adverse events reported. This indicates that the Asian squat is a safe, accessible, and equipment-free exercise for improving lower-extremity musculoskeletal strength in this population. By incorporating familiar daily movement patterns, the Asian squat promotes better adherence and sustainability among Indonesian adolescents. For public health policy, these results support the integration of Asian squat exercises into school-based programs or national physical activity guidelines to help combat sedentary lifestyles. Future studies are needed to assess the longitudinal effects of Asian squat exercise across diverse demographic groups, enabling broader application of this training to varied populations.

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Conflict of interest

The authors declare no conflicts of interest related to the publication of this study.

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