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ORIGINAL ARTICLE

A Regression Model of Hip Flexion Force of the Dominant Leg Among Malaysian Adults in Standing Posture

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ABSTRACT

Introduction: The disregard for hip flexion force when designing foot-operated equipment poses a potential threat to non-compliance with ergonomics principles, ultimately impacting occupational health. Nevertheless, there is a noticeable lack of studies focusing on the hip flexion strength of Malaysian adults in a standing position. This paper aimed to measure the maximum force of hip flexion strength and formulate a regression model for Malaysian young adults in a standing posture. **Materials and methods:** The experiment invited sixty Malaysian adults aged 20 to 26 years old. A digital force gauge (Mark-10, USA) was used to measure the hip flexion force. A regression model was developed to determine the influence of gender, body mass, body height, thigh length, and thigh circumference on the hip flexion force. **Results:** The results of this study found that the means of hip flexion force for the male and female participants were 192.8 N and 126.0 N, respectively. The regression model concluded that gender is the most significant factor influencing hip flexion force ($p<0.01$). The body mass, body height, thigh length, and thigh circumference positively correlate to hip flexion force. However, these correlations were not statistically significant ($p>0.05$). **Conclusion:** This study concluded that the relationship between anthropometric parameters and hip flexion force is not always straightforward and can be influenced by various factors. To gain a more comprehensive picture of hip flexion, it is essential to consider other potential factors such as muscle mass, neuromuscular control, and joint mechanics.
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INTRODUCTION

The hip is one of the vital human body parts located between the legs and waist. It plays a significant function in the human body, providing body balance and postural stability to allow movement, extension, and flexion of the trunk and legs (1). Hip flexion is the action of lifting or moving the knee towards the chest, commonly referred to as knee-to-chest. The muscles responsible for generating force for hip flexion include the psoas, iliacus, rectus femoris, pectineus, and sartorius (2). Strong hip flexors play esssential roles in activities of daily living and occupational sectors, helping to maintain postural stability and body balance. The hip flexors are interconnected with the muscles, forming a functional unit. They work together to stabilize the spine and pelvis during movements. Strong hip flexors contribute to body stability, which is essential for maintaining an upright posture and preventing excessive swaying or tilting of the torso (3). Adequate hip flexor strength is critical for keeping the body in an upright position. Whether standing or sitting, the hip flexors engage to support the spine and prevent slouching. This is particularly important in occupations that involve prolonged periods of standing, as weak hip flexors can contribute to fatigue and postural issues. The hip flexors play a role in coordinating movements that require balance, such as walking on uneven surfaces or navigating obstacles. They work in tandem with other lower body muscles to ensure controlled weight shifting and adjust the body's center of gravity, reducing the risk of falls or injuries. When lifting objects or carrying loads, the hip flexors work in conjunction with other muscles to provide stability to the spine and pelvis. This is critical for preventing excessive stress on the lower back and maintaining balance while performing lifting tasks.

Even in this day and age of automation, certain work processes or activities in occupational sectors still rely on human efforts, particularly involving hip movements. These activities include walking, pushing or pulling a cart, climbing scaffolding, squatting to lift loads, and soldiers marching with forceful foot stomping. During walking, hip flexion is a fundamental component of the walking cycle. Each step involves a coordinated movement of the hip flexors to lift the leg and advance the foot forward. Adequate hip muscle strength is essential for maintaining efficient and balanced legs (4). When pushing or pulling a cart, the hip flexors engage to stabilize the pelvis and contribute to the generation of force. A strong hip flexion allows for better control and power, making it easier to maneuver carts, especially when dealing with uneven surfaces. Climbing scaffolding requires a combination of strength and coordination. The hip flexors actively lift the legs to ascend and descend. A strong hip flexion force is vital for climbing safely and efficiently, particularly in occupations like construction or maintenance. Squatting is a common posture for lifting heavy loads. Proper hip flexion is essential for achieving a deep squat position (5), enabling the individual to maintain balance and stability. Adequate hip flexion force is crucial for lifting objects from the ground without compromising the spine or lower back. Military drills often involve forceful marching and foot stomping. Hip flexion force contributes to the controlled lifting of the legs, allowing soldiers to maintain a consistent and powerful marching rhythm. Strong hip flexors are essential for endurance and precision in military activities. In summary, hip flexion force is a foundational element for a range of occupational tasks that involve mobility, stability, and force generation. It enhances the efficiency and safety of movements, reducing the risk of musculoskeletal injuries. Incorporating exercises to strengthen the hip flexors into occupational training programs can contribute to overall worker health and performance, especially in jobs that demand physical exertion and varied movement patterns.

Jobs that require frequent lifting, especially with poor lifting mechanics, can strain the hip flexors. Lifting heavy loads without proper engagement of the hip flexors and other supporting muscles can lead to overexertion and increased susceptibility to strains. Additionally, heavy machinery operation, or tasks requiring forceful movements can contribute to hip flexor strain. Sudden and forceful actions, such as pushing, pulling, or lifting heavy objects, may put excessive stress on the hip flexors, leading to strain (6). Occupations that involve regular stair climbing or descending, such as those in construction or maintenance, can strain the hip flexors. The repetitive lifting of the legs and engagement of the hip flexors during stair navigation may lead to overuse and potential strain.

The etiological pathways linking hip injuries to hip flexion force are crucial to understanding and preventing work-related musculoskeletal issues. Jobs requiring prolonged periods of sitting, especially in flexed hip positions, may lead to muscle imbalances and tightness in the hip flexors (7). Sedentary work environments, common in office settings, contribute to weakened and shortened hip flexor muscles. Over time, this imbalance can result in increased susceptibility to strains and discomfort. Occupations involving frequent lifting, bending, or squatting tasks place additional stress on the hip flexors (8). Workers in industries like construction, healthcare, or manual labor may be prone to hip injuries due to the repetitive nature of these movements. High-force hip flexion during lifting or bending activities can lead to muscle strains, tendonitis, or even more severe injuries such as labral tears. Certain occupational tasks may require workers to maintain awkward postures or perform activities that involve forceful hip flexion (8). For instance, individuals in professions like agriculture, where prolonged stooping or bending is common, may be at an increased risk of hip injuries. The continuous stress on the hip joint in these positions can contribute to the development of structural issues and impingement, potentially leading to chronic pain and discomfort. Moreover, occupations that demand dynamic and forceful hip flexion, such as those in the service industry where workers are required to lift and carry loads, can contribute to stress fractures or overuse injuries. The repetitive loading on the hip joint, combined with forceful flexion, may result in microtrauma to the bones and soft tissues around the hip, increasing the risk of stress-related injuries.

By studying the hip flexion force of the dominant leg, sports professionals, therapists, and ergonomists can develop a more profound understanding of the hip's functional capacity and its implications for diverse aspects of movement, performance, and health. In sports, understanding the hip flexion strength, specifically the force generated by the dominant leg (9), can provide valuable insights for players and coaches to optimize training programs, such as cycling, kicking balls and packing closely in the rugby scrummage. Therapists have the capability to create individualized rehabilitation programs for patients who are recuperating from hip injuries or surgeries, aiming to strengthen and restore functionality to the affected hip. For specific industrial job processes that require repetitive hip flexion movements, understanding the force exerted by the dominant leg can help ergonomists to design and implement ergonomic solutions to minimize the risk of musculoskeletal injuries.

In an industrial setting, improper ergonomics practices at work place can lead to hip flexor strain. Hip flexor strain typically occurs when the hip flexor muscles are pulled and sprained (10). This condition reduces

the range of motion and mobility of the lower limbs, resulting in discomfort and pain. In the construction and agricultural industries, workers often experience muscle strain when they overuse their hip flexors while pulling their legs and boots out of muddy areas. Office workers and computer programmers who spend most of their time sitting are at a high risk of hip flexor strain because their muscles are constantly shortened. Consequently, this health effect can result in poor work performance.
Overexertion of the muscles (e.g., hip flexors) is the primary cause of musculoskeletal disorders. Unfortunately, statistics from the United States Bureau of Labor Statistics reported 47,280 cases of musculoskeletal disorders treated in emergency rooms in 2019 (11). Hip injuries are one of the common occupational health issues faced by industrial workers and are increasingly prevalent in Malaysia. According to the Social Security Organization of Malaysia (SOCSO) annual reports, from 2015 to 2019, the total cases of hip injuries and disability payments were 3644 cases and RM 4507, respectively (12–16). In light of this, an empirical study on hip flexion strength is a necessity to overcome the abovementioned issues.

The rationale behind this suggestion lies in the potential of such a study to unveil critical insights into the factors contributing to hip injuries. By examining hip flexion strength, this study aims to identify individual factors (e.g. gender and body mass) that influence hip flexor muscles, providing a foundation for targeted injury prevention strategies. This may involve the development of strength training programs, ergonomic interventions in relevant industries, and educational initiatives promoting proper body mechanics during occupational tasks. Furthermore, insights from this study could inform rehabilitation and treatment approaches for individuals who have already suffered hip injuries, potentially enhancing recovery outcomes and reducing the likelihood of recurrent injuries. The findings of this study may also contribute to the establishment of occupational health guidelines that emphasize the importance of maintaining adequate hip flexion strength in specific work settings. Ultimately, this study on hip flexion strength was envisioned as a crucial step toward mitigating the prevalence and impact of hip injuries, addressing both the immediate concerns reflected in the annual reports and the broader goal of promoting musculoskeletal well-being among Malaysian workforces.

Many ergonomics studies relating to Malaysian population have concentrated on anthropometry (17), pushing and pulling forces (18). However, there appear to be very few studies on the hip flexion strength of Malaysian adults in the standing position. Recently, (19) studied the hip's range of motion among Malaysian adolescents. The hip flexion force of Malaysian male juniors in a supine position was measured in a study published in (20). The studies may have a limited scope, focusing specifically on certain age groups (e.g., adolescents, male juniors) or positions (e.g., supine position). This limited scope may not provide a comprehensive understanding of hip flexion force across diverse age ranges and genders. However, the magnitude of hip flexion force generated by Malaysian adults in a standing position remains unquantified. Negligence of this biomechanical factor in the workplace and task designs is a potential threat to the ergonomics principles of human-work interaction, thus affecting the safety of the workers. Therefore, this paper aimed to measure the maximum force of hip flexion strength and formulate a regression model for Malaysian young adults in a standing posture. This study focused on the dominant leg because it influences motor skills, body balance, and movement in occupational activities, sports, and daily routines. The dominant leg is the leg that an individual naturally prefers to use for starting various physical activities, such as walking, and kicking. This research addresses a critical need in the existing knowledge of ergonomics by presenting quantitative data and statistical analysis of hip flexion force in relation to the lower limb strength of Malaysian adults. The findings of this research will undoubtedly be invaluable for engineers and ergonomists in designing foot-operated machines, personal protective equipment, and industrial tasks that demand reduced muscle activation to prevent discomfort and fatigue in the hip and lower back. Moreover, occupational therapists can utilize the quantitative data on hip flexion forces to assess both healthy individuals and symptomatic workers concerning their hip flexion capability. This information will aid in identifying potential issues and providing appropriate interventions to ensure better occupational health and performance.

Furthermore, the significance of hip flexion force data lies in its potential to offer valuable insights into musculoskeletal health, injury prevention, and rehabilitation strategies (21,22). Understanding the force exerted during hip flexion is crucial, especially in contexts such as occupational tasks or physical activities, where repetitive or forceful hip flexion may contribute to injuries (23,24). By collecting and analyzing hip flexion force data, researchers and healthcare professionals can identify patterns, risk factors, and thresholds that may be associated with hip injuries (25,26). The need for a regression model becomes evident in the quest for a quantitative understanding of the relationships between hip flexion force and injury outcomes. A regression model can help establish predictive relationships, enabling the identification of key factors influencing injury risk and providing a foundation for evidence-based interventions. Ultimately, the integration of hip flexion force data into a regression model holds the potential to inform targeted interventions, personalized rehabilitation strategies, and preventive measures aimed at optimizing musculoskeletal health and reducing the incidence of hip injuries.

MATERIALS AND METHODS

Participants

A convenience sample of sixty participants Malaysian adults aged between 20 to 26 years old involved as experimental subjects. The sample size used in this study was determined to be adequate for detecting a moderate effect size in the variables of interest, with a statistical power of 0.85 and a significance level (α) set at 0.05. The participants were healthy undergraduate and postgraduate students of Universiti Teknikal Malaysia Melaka, Malaysia. These participants constitute a significant age group of the active labor force engaged in various industries in Malaysia (27). They were recruited through personal invitations and social networking channels, including WhatsApp groups and Facebook. The screening process involved a self-reporting interview to assess their eligibility for participation in the hip flexion force experiment. Specific inclusion and exclusion criteria were used to recruit participants for the experiment. The criteria were as follows:

[1] Health status and fitness level: Participants were required to be in good health and free from any medical conditions that could significantly affect hip flexion force. They should not have a history of low back pain, neurological disorders, or recent physical injuries. Their body mass index (BMI) should fall within the range of 18.5 to 24.9, and they should have a reasonable baseline of muscle strength.

[2] Recent activity and strength tests: Individuals who had engaged in rigorous activities such as rock climbing, rugby tournament, or participated in muscle strength tests within two weeks before the experiment day were excluded. This was to avoid potential confounding effects that could arise from recent intense physical activity or testing.

[3] Sufficient sleep: Participants were required to have had six to eight hours of sleep on the night before the hip flexion force experiment. Ensuring adequate sleep duration aimed to prevent feelings of fatigue and reduced energy levels during the experiment.

[4] Mental stress level: Participants were selected to have a very minimal level of mental stress to mitigate the impact of muscle tension and physical exhaustion. To further minimize distractions during the experiment, the researchers provided participants with a clear experiment schedule, reducing waiting time. To ensure that the participants were free from significant mental stress, the researchers employed a self-reporting technique. The participants were informed that the experiment was voluntary and depended on their willingness and readiness to participate. Before performing the experiment, researchers verbally interviewed each participant, asking if they were experiencing mental stress. Participants who responded affirmatively were excluded from the experiment. Additionally, to support the claim that the participants were free from mental stress, the experiment was scheduled on days when the participants did not have lecture classes or tests. This self-reporting method, combined with careful scheduling, was used to assess and ensure the mental stress level of the participants.

The participants received detailed information about the experiment, including its potential benefits and risks, assurance of confidentiality, the voluntary nature of participation, and the experimental procedures. Throughout the experiment, participants were required to wear loose pants or track bottoms (tight jeans were not allowed) to ensure that their attire would not disrupt the ability of the hip flexor muscles to contract. Furthermore, the participants conducted the experiment either barefoot or wearing thin socks to minimize the impact of gravitational acceleration on the legs. After thoroughly informing the participants about the experiment and obtaining their consent, they were required to sign a consent form.

Measurement of Relevant Anthropometry

The measurement of participants' anthropometry adhered to the guidelines outlined in MS ISO 7250-1:2008 (28). Four relevant anthropometric parameters (body mass, body height, thigh length and thigh circumference) of the participants were measured to investigate the effects of the body dimensions on the hip flexion force. Body mass was assessed without shoes, utilizing an electronic weight scale. The Harpenden standard anthropometer measured body height and thigh length, with the latter measured from the midpoint of the inguinal ligament to the proximal edge of the patella (29). Thigh circumference was measured at the thickest part of the thigh near the crotch, employing a Realmet anthropometric tape. All measurements were recorded in centimeter (cm). Rigorous quality control measures were applied, involving three repetitions of each measurement, and the mean value was documented. Participants wore light clothing, such as fitted tracksuits, and were barefoot during measurements (17).

A graduate research assistant (GRA) conducted the anthropometric measurements. To evaluate the consistency and agreement of readings, an intra-rater reliability test was executed. The GRA performed repeated measurements of the same anthropometric parameter (e.g., body height) on the same participant across three separate days. The resulting intra-rater correlation coefficient of 0.8 indicated good reliability and consistency in the measurements conducted by the GRA.

Instrument and test rig

The hip flexion force was measured using a Mark-10 Series 5 handheld digital force gauge (manufactured by Copiague, New York, USA), similar to previous studies (30,31). Throughout the experiment, the gauge was securely attached to a rigid test rig to ensure accurate measurements. The test rig was fabricated using high-strength aluminum to ensure it is sturdy. As shown in

Fig. 1 (A), the test rig was placed on a flat floor surface and supported by a rigid wall to prevent it from the overturn. The test rig was designed with adjustable height to ensure the force gauge and the participant's thigh can be aligned perpendicularly.

Prior to initiating the experiments, a comprehensive examination and calibration of the force gauge were conducted. The calibration procedure meticulously followed the standards established by the National Institute of Standards & Technology (NIST) of USA, ensuring the instrument's accuracy and reliability. To validate the accuracy of the force gauge, the authors employed known standard weights or loads with certified masses adhering to recognized standards. These loads were systematically applied to the force gauge, and the resulting readings were meticulously compared with the expected values. The authors confirmed the accuracy of the force gauge by ensuring that any errors or deviations between the two sets of readings were minimal or negligible.

Furthermore, a thorough assessment of the precision of the force gauge was conducted through repeatability testing. This involved applying the same load multiple times and scrutinizing whether the force gauge consistently provided readings. The precision of the force gauge was deemed satisfactory when the variations in readings were found to be within acceptable limits. These rigorous procedures collectively attest to the meticulous calibration, accuracy, and precision of the force gauge, thereby establishing a solid foundation for the experimental procedures outlined in this study. The measurement unit was set to Newton (N) for consistency and standardization. The display mode is real-time of compression force of the hip flexion. As shown in Fig. 1 (B), the force gauge was reset to zero before the measurements were taken.

Safety and experimental procedures

The experimental procedures underwent a thorough review and received approval from the University's Research Ethics Committee (UTeM.11.02/500-25/1/4JILID 2(45)). The hip flexion force experiment took place at the Laboratory of Ergonomics in UTeM, with a controlled temperature of 22°C. Before data collection began, stringent safety measures were put in place to ensure the well-being of participants. Firstly, participants were instructed to maintain a neutral standing posture throughout the experiment to minimize the risk of strain or injury. The laboratory floor was regularly cleaned to eliminate any potential hazards, such as water or oil spillages, that could lead to slips or falls. Additionally, participants were encouraged to perform the experiment at their own pace and to engage in voluntary muscle contractions to prevent overexertion and reduce the likelihood of muscle injury. Prior to the experiment, participants received thorough instructions on proper technique and were closely monitored by the researchers throughout the data collection process to ensure their safety and well-being at all times.

Before commencing the experiment, the researchers conducted a pilot study to establish the best procedures for the participants and to ensure that the force gauge and test rig functioned as intended, generating accurate and consistent data on hip flexion force. Participants maintained a neutral body posture and remained attentive during the experiments. Initially, the participant stood in front of the test rig and firmly held its handle. The participant was asked to actively flex his/ her hip of the dominant leg. Meanwhile, the non-dominant leg remains in upright position. The researchers ensured participant's thigh touched the rubber pad of the force gauge. To acquire the maximum hip flexion force, the force gauge and the thigh should be aligned perpendicularly (90°), as shown in Fig. 1 (C). The hip flexion force was measured through 60° range of motion of the hip flexion by referring to the protocol in the studies (32,33). Prior to the attempt, the participants were allowed to familiarize themselves with the experiment's protocol and correct their posture if needed. The attempt was then initiated when the participant is ready. A researcher gave instruction to the participant to push the thigh against the force gauge and speak, "Go ahead-push-push-push-push and relax". Maintain the maximum force for 5 seconds, and the researcher recorded the force data. The participants were asked to perform three attempts. Interval breaks of 5 minutes were given between the attempts to eliminate the effects of muscle fatigue. The maximum value of the hip flexion force from the three attempts was chosen for statistical analysis. The experimental setup of the hip flexion force experiment is illustrated in Fig. 1, depicting the test rig, force gauge, and range of motion used.

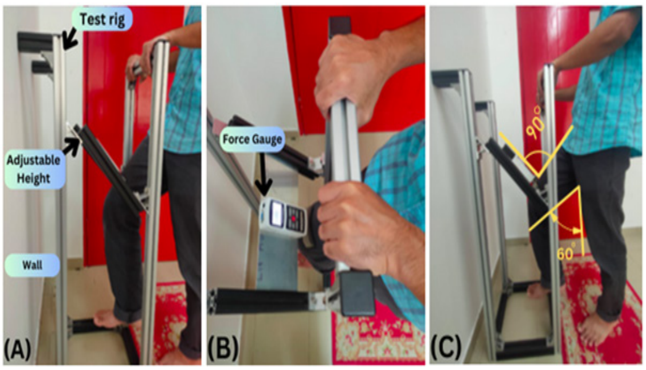

Fig. 1: Setup of test rig, force gauge, and range of motion in hip flexion force experiment

Statistical Analysis

Statistical analysis, which involved descriptive statistics, analysis of variance (ANOVA), Pearson correlation, and linear regression, was conducted using Microsoft Excel 2016 and Minitab. The significance level for all statistical tests was set at $\alpha = 0.05$.

RESULTS

Anthropometric Parameters of Participants
Out of the 60 participants recruited, 38 were male and the rest were female. Descriptive statistics of the participants' age, body mass, body height, thigh length, and thigh circumference were tabulated in Table I. It clearly showed that body dimensions of the male (body mass, body height, thigh length, and thigh circumference) were greater than those of the female. The age range for both genders was between 20 to 26 years.

Table I: Anthropometric parameters of participants

	Male participant (n = 38)				Female participant (n = 22)			
Anthro-pometric parameters	**Min**	**Mean**	**Max**	**St-Dev**	**Min**	**Mean**	**Max**	**St-Dev**
Age	20	23.9	26	1.9	21	23.6	26	1.4
Body mass (kg)	45	69.9	120	16.5	38	60.7	89	14.5
Body height (cm)	160	168.4	179	4.4	151	158.9	168	4.6
Thigh length (cm)	27	34.5	42	4.1	25	33.2	45	5.8
Thigh cir-cumference (cm)	41	57.1	97	11.8	42	54.4	66	7.0

Hip Flexion Force of Participants
Table II shows the descriptive statistics of the hip flexion force of the dominant leg in standing position generated by both genders of experiment participants. The force data for males and females were considered to be normally distributed, based on their skewness and kurtosis. In general, this study observed that male participants generated greater hip flexion force than the female participants. The mean of hip flexion force of the male participants was 192.8 N (SD = 65.7). Meanwhile, the female participants recorded the mean hip flexion force of 126 N (SD = 39.7). In male participants, the minimum and maximum forces were 64.8 N and 347.8 N, respectively. Meanwhile, the female participants recorded the maximum force of 211.8 N and the minimum force was 59.2 N.

Table II: Hip flexion force of participants (unit in Newton, N)

Gender	Min	Mean	Max	St-Dev	Skew-ness	Kur-tosis
Male	64.8	192.8	347.8	65.7	0.29	0.51
Female	59.2	126.0	211.8	39.7	0.56	0.52

Regression Model of Hip Flexion Force
This study formulated a regression model (Equation 1) to estimate the magnitude of the hip flexion force of the dominant leg in standing position, corresponding to gender, body mass, body height, thigh length, and thigh circumference. The regression statistics, analysis of variance (ANOVA), and the coefficient values of factors are presented in Table III. A significant regression equation was found ($F(5, 54) = 7.095$, $p<0.01$), with an R-Square of 0.396. Note that gender is a categorical factor, with 0 and 1 representing male and female, respectively. Furthermore, the regression model explained the relationship between the independent factors (gender, body mass, body height, thigh length, and thigh circumference) and the response (hip flexion force). Based on the established regression model (Equation 1), gender emerges as the foremost influential factor on hip flexion force, as indicated by its coefficient of -54.40 (indicating an inverse relationship). This signifies that a lower gender value (specifically level 0 = male) is associated with the highest degree of hip flexion strength. In addition to that, this study found that gender was a significant predictor to the hip flexion force ($p< 0.01$). This study observed that, the thigh circumference (coefficient of 1.23) and the thigh length (coefficient of 1.20) have a positive correlation with the hip flexion force. The interpretation is that, greater thigh circumference and thigh length contribute to utmost hip flexion force. Moreover, this study has unveiled that body mass, body height, thigh length, and thigh circumference are correlated with hip flexion force. However, it is important to note that these relationships were found to be statistically insignificant ($p>0.05$).

Table III: Regression analysis summary for hip flexion force model

Multiple R	0.630				
R-Square	0.396				
Adjusted R Square	0.341				
Standard Error	53.407				
Observations	60				
	df	SS	MS	F	Significance F
Regression	5	101192	20238.3	7.095	3.66E-05
Residual	54	154027	2852.36		
Total	59	255219			
	Coefficients		**P-value**		
Intercept	-56.62		0.84		
Gender	-54.40		0.01		
Body mass	0.63		0.38		
Body height	0.56		0.75		
Thigh length	1.20		0.48		
Thigh circumference	1.23		0.25		

The regression model of the hip flexion force is expressed in Equation 1:

FORCE = -56.62 – 54.4 (GENDER) + 0.63 (BODY MASS) + 0.56 (BODY HEIGHT) + 1.20 (THIGH LENGTH) + 1.23 (THIGH CIRCUMFERENCE) … Equation 1
Where gender is coded as male = 0 and female = 1.

Relationship between Anthropometry and Hip Flexion Force
To facilitate additional statistical analysis, this study calculated a Pearson correlation. This calculation aimed to examine the correlation between the anthropometric

parameters and the hip flexion force produced by the participants' dominant leg while standing. Among the male participants, there was a moderately positive correlation (r = 0.45) observed between body mass and hip flexion force, as presented in Table IV. This result suggests a correlation between greater body mass and higher hip flexion force. Similar patterns were observed for thigh length, thigh circumference, age, and body height.

Among female participants, a moderate positive correlation (r = 0.48) was found between age and hip flexion force, as detailed in Table IV. This outcome suggests that as age increases, there is a corresponding increase in hip flexion force. Similar patterns were identified for body mass and thigh circumference.

Table IV: Correlation coefficient, *r* of anthropometric and hip flexion force

Anthropometric parameters	Male	Female
(1) Body mass	0.45	0.27
(2) Body height	0.33	0.10
(3) Thigh length	0.17	0.07
(4) Thigh circumference	0.43	0.32
(5) Age	0.31	0.48

DISCUSSION

The experimental work in this study was conducted with the aim of measuring the maximum force of the hip flexion strength of the dominant leg among Malaysian adults in a standing posture. Statistical analysis associated with descriptive statistics, ANOVA, and regression model were developed pertaining to the hip flexion force. The regression model to predict the magnitude of hip flexion force is only valid for the Malaysian adult population and the body posture should be standing. It is intriguing to note that the descriptive statistics of the hip flexion forces observed in this study diverge from the findings of previous researches, as presented in Table V. These variations can be attributed to the influence of several individual factors, namely gender, anthropometry (e.g. body mass and height), posture, population, and occupation.

Table V: Individual factors and hip flexion forces of past and current studies

Studies (countries)	Gender	Body mass, height	Posture	Hip flexion force (N)
(34) (Korea)	*Not specify*	70.4 kg, 173.2 cm	Supine	246.8
(35) (Korea)	Male and female	67.6 kg, 174.2 cm 54 kg, 159.4 cm	Supine	145. 8 (Male) 131.1 (Female)
(36) (Hong Kong)	Male and female	65.77 kg	Supine	167.4
(22) (Australia)	Male and female	83.7 kg, 174 cm 70.7 kg, 160 cm	Sitting	342 (Male) 200 (Female)

CONTINUE

Table V: Individual factors and hip flexion forces of past and current studies. (CONT.)

Studies (countries)	Gender	Body mass, height	Posture	Hip flexion force (N)
(37) (USA)	Male and female	*Not specify*	Supine	201.8 (Male) 134.6 (Female)
(38) (Denmark)	Male and female	73.9 kg, 174.2 cm	Sitting	321.9 (Male and female)
(39) (Brazil)	Female	58.4 kg, 162 cm	Sitting	220. 8
(33) (USA)	Female	57.6 kg, 163.9 cm	Standing	273.0
(20) (Malaysia)	Male junior	55 kg, 165 cm	Supine	162.7
This study (Malaysia)	Male and Female	69.9 kg, 168.4 cm 60.7 kg, 158.9 cm	Standing	192.8 (Male) 126.0 (Female)

Gender

This study tested the muscle strength of the hip flexion among male and female participants. The hip flexion force of male participants was greater than that of female participants and statistically significant when the two genders were compared. This finding was consistent with the previous studies in (40) which successfully pointed out that gender difference is one of the significant factors in hip flexion. The statistically significant influence of the gender on hip flexion force can attributed to inherent physiological and hormonal differences between males and females (41). The explanation behind this finding is that, in general, body size of men is larger than women. Large body size contains greater muscle mass. Consequently, the men acquire larger muscle fibers (type I and type II fibers), which makes males are physically stronger than females (42). Thus, a strong hip flexion is pronounced in men. Despite physiological differences, hormonal factors play a significant role in muscle strength and force production. Testosterone is an anabolic hormone that promotes muscle growth and strength, and it is found in higher levels in males. On the other hand, estrogen, which is present in higher levels in females, affects muscle tissue differently (43).

Anthropometry

Anthropometrics parameters of the participants such as body mass, body height, thigh length, and thigh circumference were measured and they had a noticeable impact on the hip flexion force. It was observed that the body mass has a moderate positive correlation with the hip flexion strength, meaning that heavier body mass contributes greater hip flexion force. The explanation behind this finding is that, heavy participants are likely to have larger muscle mass (44), thus capable of generating greater force in hip flexion compared to participants with lighter body mass. This finding aligns well with a recent study (45), which also highlighted that body mass was the primary determinant of muscle strength in hip flexion. The lean body mass is strongly correlated to body height (46); therefore, body height also affects muscle strength (47). Early publication in 1966 (48) showed that body mass and body height were highly correlated to hip flexion strength with correlation coefficients of 0.629 and 0.479, respectively. Additionally, the circumference and length of the thigh were positively related to hip flexion force. Greater circumference of the thigh is related to bigger muscle, which produces greater force. The anterior of the thigh is composed of the rectus femoris muscle. Individuals with longer thighs will have longer femoris muscle. Hence, an increase in the length of thigh and femoris muscle will increase the hip flexion strength (49).

Despite the correlations observed between body mass, body height, thigh length, and thigh circumference with hip flexion force, it is crucial to highlight that these relationships were not statistically significant. The relationship between these anthropometric parameters and hip flexion force is not always straightforward and can be influenced by various reasons. For instance, participants with the same body mass may possess different proportions of muscle and fat. Since muscle is more metabolically active and contributes more to force production, it can have a more direct impact on hip flexion strength compared to fat. Additionally, while body height can influence overall body proportions, the length of the hip flexor muscles relative to body height may not vary significantly among the participants. Consequently, the biomechanics of the hip joint and the length-tension relationship of the hip flexor muscles might not be strongly correlated with body height in the context of hip flexion. Likewise, the relationship between thigh length and thigh circumference, and hip flexion force can be complex and may vary among participants due to factors like muscle fiber type composition, neuromuscular control, and muscle architecture, all of which can influence force production. Thus, these multifaceted factors should be considered when investigating the influence of body mass, body height, thigh length, and thigh circumference on hip flexion force.

Posture

In this study, the participants performed the experiments in a standing posture to represent the major work position in manufacturing industry. Interestingly, the compilation of previous studies in Table V illustrates that the magnitude of hip flexion forces varies with the body postures (e.g. standing, sitting, and supine). A comparison of the magnitude of hip flexion force among Malaysian participants between this study and (21) demonstrated that standing posture generated a greater force than supine. This finding confirms that the body posture influences the hip flexion force. There are three potential explanations for the variation of hip flexion force in the perspective of body posture.

Firstly, standing in a neutral posture and symmetrical body-weight distribution minimizes stress on the surrounding muscles and supports musculoskeletal structures (50). Additionally, neutral standing posture provides greater body balance and control, which is beneficial for maximum hip flexion strength. A study in (51) demonstrated that hip flexion torques were 28% greater in a standing position compared to supine.

The second explanation, the hip flexion muscles are in a flexed position and not active in a sitting posture. This position results in muscle shortening. When the muscles are in flexed, shortened, and not active, they become tight and weaken compared to active and normal or full-length conditions. Tightness and weakness of the muscles worsen when sitting for a prolonged period of time (52).

Thirdly, the effect of gravity influences the generation of hip flexion forces. In standing and sitting postures, the resistance of gravity acting on the thigh is low during the early phase of hip flexion but the influence of gravity increases through the range of motion of the hip. The more resistance to gravity, the lower the force generation. In contrast, the effect of gravity is reduced when the participants/ subjects of the experiment are in the supine position. In supine, the participants gained an advantage because their thighs did not have to overcome the full effect of gravity (51).

Ethnicity

Another factor that influences hip flexion strength is the ethnicity of the participants involved in the hip flexion force experiment. According to a study (53), ethnicity played a significant role in influencing the muscle-strengthening capacity of the participants in the experiment. In this particular study, Malaysian adults were chosen as the participants, and it became apparent that the hip flexion force they generated differed from that of individuals from other ethnic backgrounds or countries. The variations in the mean values of hip flexion forces among participants from different countries are presented in Table V. These variations can be attributed to differences in the anthropometric body sizes of the populations, with Australian, European, and American populations generally being larger compared to Asian countries such as Malaysia, Korea, and Hong Kong.

Moreover, varying genetic backgrounds among different ethnicities can also impact muscle strength. Certain genetic traits may be more prevalent in specific ethnic groups, influencing their muscle development and overall performance (54). Additionally, differences in dietary habits across ethnicities can also play a role in muscle strength. Adequate protein, vitamins, and minerals intake is crucial for muscle development and overall muscle health.

Occupation
Professionals such as military, rugby and football players need muscle strength and power to meet the demands of the job activities and sports. These professionals are regularly performing muscular resistance trainings to improve their muscle size and strength. Due to continuous resistance training, their muscles are bigger and stronger than those of non-regular exercise individuals. This is proven by comparing the hip flexion force obtained from this study (recruited university students as participants) to a past study (55), which invited football players as participants. The football players have a stronger hip flexion force of 464 N than the university's students (192.8 N), which is 2.4 times stronger than the non-regular exercise individuals.

CONCLUSION

In conclusion, this study aimed to quantify the maximum force of hip flexion strength in the dominant leg among Malaysian adults in a standing posture, with a specific focus on undergraduate students from a public university. A force gauge (Mark 10, USA) attached to a sturdy test rig measured the hip flexion force. Based on the regression model developed in this study, the authors concluded that gender is the most significant factor influencing hip flexion force. Furthermore, anthropometric parameters such as body mass, body height, thigh length, and thigh circumference are positively correlated with hip flexion strength. Although correlations were found between body mass, body height, thigh length, and thigh circumference with hip flexion force, it is essential to emphasize that these relationships were not statistically significant.

Implications of study
The findings of this study carry significant implications, spanning both biomechanics and practical applications in ergonomics and occupational health. Specifically, data on hip flexion strength can serve as a crucial metric for predicting muscle weakness, evaluating functional capabilities, assessing the efficacy of hip or back treatments, and determining the readiness of injured workers to return to work. Furthermore, the factors influencing hip flexion force identified in this study offer valuable insights for optimizing workplace ergonomics and enhancing occupational health outcomes. By integrating ergonomics principles informed by gender and anthropometric considerations, such as body mass and dimensions, safety and health engineers can design workspaces that effectively minimize strain on the hip flexor muscles, thereby reducing the risk of musculoskeletal injuries. Additionally, the identification of factors influencing hip flexion force informs worker selection and placement programs, ensuring that individuals are assigned tasks commensurate with their strength capabilities, thus preventing overexertion and injury. By leveraging these findings, organizations can enhance workplace safety, productivity, and overall employee well-being.

Limitation of study and recommendation for future research
This study encourages future research endeavours to expand sample sizes, explore additional influential factors, and address the broader implications of these findings for ergonomics and occupational health practices. A limitation that nuances the regression model developed in this study is its ability to explain only a portion of the variance in hip flexion force. Participants in the study were recruited from sixty Malaysian university students, aged 20 to 26 years old, potentially limiting the generalizability of the regression model. Future studies are suggested to recruit larger sample sizes to reveal statistically significant associations of the variables.

The association between these anthropometric parameters and hip flexion force is not always straightforward and can be influenced by various factors. Therefore, taking into account other potential factors that might influence hip flexion force, such as muscle mass, neuromuscular control, and joint mechanics, can contribute to a more comprehensive understanding of hip movement. Consideration of biomechanical factors, such as the length-tension relationship and the moment arm of hip flexor muscles, can contribute to a deeper understanding of the mechanics involved in hip flexion force.

While the study focused on Malaysian adults, it is essential to consider possible reasons for differences in hip flexion force among various ethnicities. Factors such as genetics and dietary habits may contribute to variations, warranting further investigation in future studies.

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