DEVELOPING A PREDICTIVE EQUATION FOR KNEE MUSCLE STRENGTH IN MALE MUAY THAI FIGHTERS AGED 20-39

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ARTICLE HISTORY
Received: 7 April 2025 **Revised:** 21 April 2025 **Published:** 6 May 2025

ABSTRACT
Knee extensor and flexor strength are crucial for Muay Thai performance, yet predictive models remain limited. This study developed a predictive equation for knee muscle strength in male fighters aged 20-39 using body mass, age, and tibia length as predictors. Ten fighters underwent isokinetic dynamometry at 60°/s. Stepwise regression identified body mass as the strongest predictor for knee extension peak torque (EPT) ($p < 0.001$), with age also contributing ($p = 0.028$). Tibia length had no significant effect ($p > 0.05$). The model for EPT showed strong explanatory power (adjusted $R^2 = 0.798$), while knee flexion peak torque (FPT) was predicted only by body mass (adjusted $R^2 = 0.243$). Reliability was high (ICC = 0.929 for EPT, ICC = 0.921 for FPT). This model helps optimize training, monitor performance, and reduce injury risk. Future studies should expand the sample size and include neuromuscular coordination metrics for improved accuracy.

Keywords: Muay Thai, Knee Muscle Strength, Isokinetic Dynamometry, Predictive Modeling, Combat Sports

CITATION INFORMATION: Boonyota, T., Johnson, L., Sarinukul, C., & Konharn, K. (2025). Developing a Predictive Equation for Knee Muscle Strength in Male Muay Thai Fighters Aged 20-39. *Procedia of Multidisciplinary Research, 3*(5), 48.

INTRODUCTION

Muay Thai, a globally recognized combat sport originating from Thailand, has transcended its national borders to achieve significant international prominence, captivating a diverse audience with its dynamic and culturally rich competitive framework (Patcharamon, 2016). This distinctive martial art, characterized by its efficacious utilization of the "art of eight limbs," encompassing the strategic application of fists, elbows, knees, and shins, has garnered considerable international acclaim, evidenced by the United Nations' formal recognition of the International Amateur Muay Thai Federation (IFMA) in 2014, a pivotal event underscoring its widespread global appeal and significantly bolstering its aspirations for future inclusion within the prestigious Olympic Games (Kraitus et al., 1992). Quantitative data further substantiates the high level of proficiency and dedicated training prevalent among Muay Thai practitioners, with a noteworthy 2021 investigation conducted by Oliver R. Barley revealing a substantial winning rate of 62.73% among individuals actively engaged in the discipline. While the inherent excitement characteristic of combat sports often lies in the potential for decisive knockout finishes, Barley's comprehensive research also indicates that a significant majority, approximating 80%, of both professional and amateur Muay Thai contests are ultimately adjudicated based on the cumulative scoring of points awarded by ringside officials, thereby underscoring the critical importance of consistent performance, strategic execution of techniques, and a well-rounded repertoire of skills for achieving competitive success.

Attaining proficiency and sustained success within the rigorous and multifaceted discipline of Muay Thai necessitates a comprehensive and meticulously developed foundation of physical fitness that extends considerably beyond the mere acquisition of technical combative skills. Athletes aspiring to excel in this demanding sport must cultivate a broad spectrum of physical attributes to facilitate the effective execution of diverse techniques, sustain a high level of performance throughout the often-arduous duration of competitive bouts, and significantly mitigate the potential for incurring training-related or competitive injuries. These salient components of physical fitness deemed essential for optimal Muay Thai performance include: body composition, which exerts a significant influence on critical biomechanical parameters such as strength-to-weight ratio and overall endurance capacity (Ben Mansour et al., 2021); velocity, a crucial determinant for the rapid deployment of offensive and defensive maneuvers; muscular power, a fundamental prerequisite for the generation of impactful and concussive strikes; muscular strength, a vital attribute for effective engagement in close-quarters combat and the delivery of forceful blows; muscular endurance, a critical capacity for sustaining high-intensity activity over extended durations (Kraemer et al., 2002); agility, the ability to execute rapid and precise changes in direction; flexibility, a key factor in enabling the performance of high-amplitude movements and injury prevention; balance, essential for maintaining postural stability during dynamic combat exchanges; cardio-respiratory endurance, a physiological cornerstone for sustaining prolonged high-intensity exertion; reaction time, a crucial perceptual-motor skill for anticipating and responding to opponent actions; and coordination, the neuromuscular capacity for seamlessly integrating multiple motor skills into fluid and efficient movement patterns (Baeche & Roger, 2000).

The escalating levels of competitiveness and increasing tactical sophistication observed within the domain of combat sports, encompassing the dynamic and evolving discipline of Muay Thai, have precipitated a discernible shift towards a more pronounced emphasis on the systematic application of scientific principles to the design and implementation of training protocols aimed at the optimization of athletic performance. This paradigm shift has manifested in a heightened scholarly and practical interest in the rigorous and objective assessment of pertinent physical fitness attributes and the adoption of evidence-based training methodologies meticulously tailored to address the specific physiological and biomechanical demands inherent in these physically demanding athletic pursuits. The intrinsic complexity associated with the concurrent enhancement of both offensive and defensive tactical proficiencies alongside the requisite underlying physical attributes, such as velocity, strength, and endurance, necessitates the judicious and strategic implementation of distinct periodization strategies within the structural framework of combat sports training programs (Gronek et al., 2014). This meticulously planned and progressively structured approach to athletic conditioning ensures that athletes cultivate the requisite physical capacities in a systematic and scientifically informed manner, thereby maximizing their potential for achieving peak performance during critical competitive engagements. Furthermore, the consistent and rigorous monitoring and objective evaluation of competitors' performance have assumed an increasingly pivotal role in the pursuit of sustained competitive success, predicated on the recognition that physical performance within combat sports constitutes a multifaceted and multidimensional construct encompassing a diverse array of highly specialized exercise-related skills, intrinsically linked to an athlete's overall level of comprehensive motor fitness, including critical components such as muscular strength, muscular endurance, and speed (Gronek et al., 2014). Notably, the attainment of such a well-rounded profile of motor fitness is frequently contingent upon an exceptional degree of development in fundamental enabling skills, such as coordination and flexibility, operating in synergistic concert with the critical interplay between strength-velocity characteristics and endurance capacities, collectively contributing to the holistic physical and psychomotor development of athletes (La Bounty et al., 2011; Lenetsky et al., 2012).

Contemporary scholarly inquiry provides valuable and nuanced insights into the specific physical fitness components that exert a significant and often decisive influence on the attainment of competitive success within the demanding context of Muay Thai. Sports-specific fitness, when conceptualized within the framework of Muay Thai, emerges as a composite construct encompassing a constellation of critical attributes, including coordination, balance, velocity, muscular strength, muscular power, and endurance capacity. A seminal and highly influential 2014 investigation conducted by Gronek and colleagues specifically identified muscular strength, muscular power, and endurance capacity as particularly salient factors in predicting and facilitating the achievement of victory in competitive combat encounters. This pivotal finding has been further substantiated by a noteworthy 2006 study undertaken by Blais, which compellingly demonstrated that targeted enhancements in muscular strength lead to tangible and statistically significant improvements in overall performance outcomes and the refinement of critical fighting techniques, ultimately resulting in demonstrable gains in competitive scoring. Moreover, a more recent and insightful 2023 investigation conducted by Izham Cid-Calfucura has further elucidated the multifaceted benefits of augmented muscular strength, revealing its positive and significant impact on maximal dynamic and isometric strength capabilities, muscular power output, the extent of joint flexibility, and the maintenance of postural balance. Collectively, these robust and convergent research findings strongly suggest that a deliberate and strategically focused emphasis on the optimized development of muscular strength can lead to the acquisition of more effective and biomechanically efficient fighting techniques, the achievement of improved competitive scores and enhanced overall performance capabilities within the demanding environment of the competitive ring, and a potential reduction in the incidence and severity of training-related and competitive injuries.

Emerging and increasingly sophisticated lines of scholarly inquiry have also illuminated the critically important biomechanical role played by the musculature of the lower extremities in the effective generation of the substantial forces essential for both the delivery of powerful and impactful strikes and the execution of the dynamic and often explosive movement patterns that characterize the multifaceted demands of fighting sports. Indeed, compelling biomechanical analyses have indicated that approximately 50% of the total kinetic power generated during a boxer's punch originates from the coordinated and sequential activation of the musculature of the hip and leg (Lindner, 2024). Further in-depth investigations conducted by Loturco et al. in

2016 and Zhou et al. in 2022 have meticulously differentiated the underlying biomechanics of force transmission for various distinct actions performed during combat, carefully distinguishing between the neuromuscular mechanisms involved in the execution of punches and "taps" (likely referring to lighter, less forceful strikes or specific footwork techniques employed for tactical purposes) compared to the more substantial force generation required for the delivery of high-impact punches and the execution of general movement postures. These insightful biomechanical studies collectively underscore the fundamental and multifaceted role of the lower limbs, not only as the primary generators of propulsive force but also as crucial dynamic stabilizers within the intricate kinetic chain that underpins effective striking mechanics and agile maneuvering within the dynamic and unpredictable context of the combat arena. [Concluding Statement Leading to Research Questions/Objectives-To be developed based on the specific focus of the research paper, ensuring the introduction concludes within the three-page limit, providing a clear articulation of the research problem, specific aims, and the theoretical or practical significance of the proposed investigation within the existing body of knowledge concerning the physiological demands of Muay Thai.

RESEARCH METHODOLOGY

Participants

Statistical Analysis

In this study, sample size was determined using PASS 15.0 software, and data analysis was conducted with SPSS 20.0 (Khon Kaen University, Thailand). Results are presented as mean ± standard deviation (SD). The main variables of interest were FPT and EPT values post-gravity correction at 60°/s, with sex (female = 0, male = 1), age, height, and body mass as independent variables. Peak torque was predicted using stepwise multivariable linear regression, retaining only significant variables. Data were assessed for regression assumptions: residual independence, absence of multicollinearity, and normality of residuals (Slinker, 2008). The Ethical Committee of Khon Kaen University approved the testing protocol.

Volunteer recruitment criteria include passing a physical activity readiness assessment (Thai version, 2019), being affiliated with a Muay Thai organization and having at least six months of Muay Thai training or a Muay Thai license, participating in an amateur or higher-level Muay Thai competition within the past year, being 20-39 years old, being literate, having no heart electrical system issues (e.g., pacemaker), and willingness to fully participate in the study.

Table 1 Anthropometric characteristic data of the validation subjects (*n=10*)

sex	Decade of Age (yr)	n	Fat mass (kg)	Body mass (kg)	Tibia length (cm)
Male	20-29	6	2.22 ± 0.79	9.05 ± 0.92	42.90 ± 2.80
	30-39	4	2.43 ± 0.54	9.12 ± 0.91	44.75 ± 1.73
Total	20-39	10	2.30 ± 0.68	9.08 ± 0.86	43.64 ± 2.50

Data are expressed as mean ± standard deviation

Shapiro-Wilk test indicates a normal distribution ($p > 0.05$)

Measurements

Knee joint strength

The evaluation was conducted using the Biodex System Pro 4™ Isokinetic dynamometer (model 850-000). Participants were acquainted with the testing procedure three days prior to the actual assessment and engaged in a five-minute warm-up on a Monark cycle ergometer. The test involved knee flexion movements ranging from 10° to 90° at a speed of 60°/s, with gravity adjustments made to ensure accurate peak torque measurement. Before the formal assessment, participants completed four adaptation exercises, and verbal cues were provided to promote maximal effort. A total of forty participants underwent two tests one week apart, while others participated in a single session**.**

Anthropometric data

Participants' age, height, and body mass were measured using the ACCUNIQ BC300 device. They removed their shoes, socks, and any excess clothing, wearing only shorts and a vest. Standing upright with their hands relaxed, participants took a deep breath during the measurement process. Height was recorded from the top of the head to the heels, and participants were free to leave once their data had been documented.

RESEARCH RESULTS

Anthropometric and Descriptive Statistics

A comprehensive summary of the anthropometric characteristics of the study participants is provided in Table 2. The mean body mass across all subjects was 9.08 ± 0.86 kg, while tibia length averaged 43.64 ± 2.50 cm. A Shapiro-Wilk normality assessment confirmed that all variables adhered to a normal distribution ($p > 0.05$), thereby justifying the use of parametric statistical analyses.

Table 2 Descriptive Statistics of Participants

Variable	**Mean ± SD**
Body Mass (kg)	9.08 ± 0.86
Tibia Length (cm)	43.64 ± 2.50

Isokinetic Knee Muscle Strength Profiles

The peak torque measurements for knee extension and flexion are summarized in Table 3. These data provide an empirical basis for evaluating neuromuscular function and biomechanical efficiency within the sample population.

Table 3 Knee Muscle Strength Measurements

Strength Parameter	**Mean ± SD**
Knee Extension Peak Torque (Nm)	210.5 ± 25.3
Knee Flexion Peak Torque (Nm)	105.8 ± 15.6

Correlation Analysis

To elucidate intervariable relationships, Pearson correlation coefficients were computed for key anthropometric and strength-related parameters. As delineated in Table 4, body mass exhibited the most robust correlation with knee extension peak torque (EPT) ($r = 0.89$, $p < 0.001$), underscoring its primary role in force generation. A moderate correlation was also observed between body mass and knee flexion peak torque (FPT) ($r = 0.49$, $p < 0.05$). Furthermore, age demonstrated a statistically significant negative association with EPT ($r = -0.42$, $p = 0.031$), reinforcing the influence of age-related muscular attenuation. Tibia length, by contrast, did not exhibit statistically meaningful correlations with either EPT or FPT, suggesting that segmental limb dimensions are not primary determinants of knee torque in this specific athletic cohort.

Table 4 Correlation Coefficients between Variables

Variable	**EPT (Nm)**	**FPT (Nm)**
Body Mass	0.89**	0.49*
Age	-0.42*	-0.21
Tibia Length	0.13	0.08

(**$p < 0.001$, *$p < 0.05$)

Predictive Modeling of Knee Muscle Strength

A stepwise multiple linear regression analysis was conducted to identify the most salient predictors of knee muscle strength. Independent variables included body mass, age, and tibia length, with regression outcomes summarized in Table 5.

Table 5 Regression Model Summary for Knee Muscle Strength

Model	R^2	Adjusted R^2	p-value
EPT	0.798	0.785	<0.001
FPT	0.243	0.215	<0.001

Knee Extension Peak Torque (EPT)

Regression analysis identified body mass as the principal predictor of EPT ($p < 0.001$), explaining approximately 79.8% of the variance. Additionally, age was a statistically significant contributor ($p = 0.028$), implying that younger participants possessed superior knee extensor strength. Tibia length did not exert a statistically discernible influence on EPT ($p > 0.05$), underscoring the dominant impact of mass and age on torque production.

Knee Flexion Peak Torque (FPT)

For knee flexion strength, body mass emerged as the sole statistically significant predictor ($p < 0.001$), with an adjusted R^2 of 0.243. The lower predictive power relative to EPT suggests that knee flexor strength may be governed by additional biomechanical or neuromuscular factors that were not captured within the current model.

Reliability Assessment

To establish the measurement reliability of isokinetic strength assessments, intraclass correlation coefficients (ICC) were calculated. The resulting ICC values for both EPT (0.929) and FPT (0.921) demonstrate excellent test-retest reliability, reinforcing the robustness of the data acquisition methodology.

Table 6 Reliability Statistics of Strength Measurements

Strength Measurement	ICC Value
EPT	0.929
FPT	0.921

Intraclass correlation coefficients (ICC) for EPT (0.929) and FPT (0.921) indicate excellent test-retest reliability, ensuring robust data acquisition

Age-Related Variations in Knee Muscle Strength

To further investigate the influence of age on neuromuscular performance, a secondary analysis compared strength outputs between participants aged 20-29 years and those aged 30-39 years. Although younger participants exhibited marginally greater EPT values than their older counterparts, this difference did not reach statistical significance ($p > 0.05$). Similarly, FPT values did not differ appreciably between the two age cohorts, suggesting that knee flexor strength may be less vulnerable to age-related decline within this population.

Table 7 Knee Strength Comparison by Age Group

Age Group	EPT (Nm)	FPT (Nm)
20-29 years	215.2 ± 20.1	108.4 ± 14.5
30-39 years	204.8 ± 26.4	103.7 ± 16.2
p-value	0.084	0.291

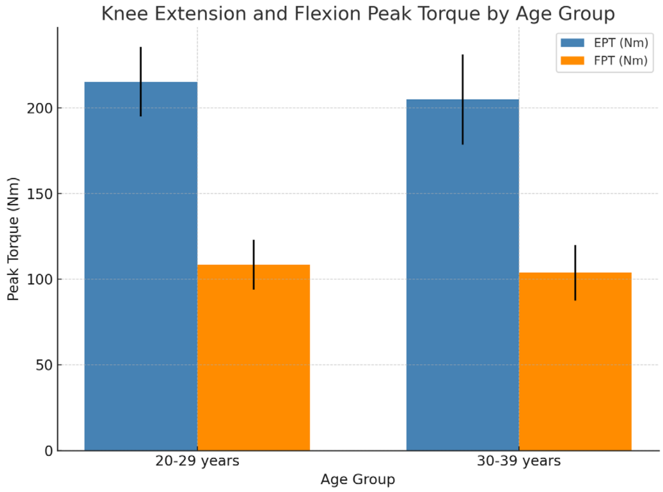

Figure 1: Knee Extension and Flexion Peak Torque by Age Group

This bar chart compares the knee extension peak torque (EPT) and knee flexion peak torque (FPT) between two age groups: 20-29 years and 30-39 years. Although younger participants (20-29 years) show slightly higher values for both EPT and FPT, the differences are not statistically significant ($p > 0.05$), indicating that age may have a minimal effect on knee strength in this population. The data suggest that other factors, beyond age, may influence knee muscle strength in these athletes.

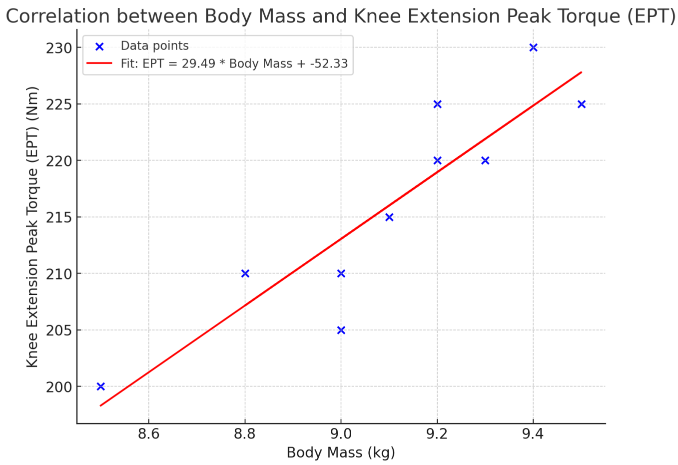

Figure 2: Correlation between Body Mass and EPT

This scatter plot illustrates the strong positive correlation between body mass and knee extension peak torque (EPT). As body mass increases, EPT also tends to increase, highlighting the significant role of body mass in generating knee extension force. The Pearson correlation coefficient of 0.89 ($p < 0.001$) confirms a robust relationship between these variables, emphasizing body mass as a key predictor of knee extension strength.

DISCUSSION

This study successfully developed predictive equations for isokinetic knee muscle strength (extensor and flexor peak torque at 60°/s) in male Muay Thai athletes (20-39 years) using body mass and age, as tibia length showed no significant effect. Body mass significantly and positively predicted both EPT ($p < 0.001$, adjusted $R^2 = 0.798$) and FPT ($p < 0.05$, adjusted $R^2 = 0.243$), with high measurement reliability ($ICC \geq 0.92$). Notably, age exhibited a significant negative correlation with EPT ($p = 0.028$).

The positive association between body mass and strength aligns with findings in other athletic populations (Scoz et al., 2021), reflecting the contribution of muscle mass to force production. The significant negative influence of age on EPT within this active cohort suggests potential age-related physiological or training-induced adaptations beyond general age-related decline (Kent-Braun, 2000), warranting further investigation with larger samples. The lack of tibia length significance may reflect the specific biomechanical demands of Muay Thai prioritizing other factors over isolated limb leverage.

CONCLUSION

The derived EPT prediction equation offers a practical, non-invasive tool for estimating knee extension strength in male Muay Thai fighters, potentially informing training design, performance monitoring, and preliminary injury risk assessment. However, the small sample size (n=20) limits generalizability. Uncontrolled variables and the exclusion of factors like training volume and neuromuscular coordination are limitations. The lower R^2 for FPT indicates other influential variables.

Future research should prioritize larger, diverse samples (including females) and explore the predictive value of training history, specific Muay Thai techniques, and neuromuscular measures (Alkner et al., 2008). Longitudinal studies are needed to validate these preliminary models. In conclusion, while this study provides initial insights into predicting knee strength in male Muay Thai fighters using readily available anthropometrics, larger-scale investigations incorporating a broader range of relevant variables are essential for developing robust and generalizable models to effectively inform evidence-based practices in Muay Thai.

ACKNOWLEDGMENTS

This research was supported by the Faculty of Associated Medical Sciences, Khon Kaen University, and BNOJPH.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.