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Original Article

Association and forecasting model for leg strength based on physical characteristics and quadriceps muscle thickness in young participants: A preliminary study

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Abstract

Introduction. Leg strength is crucial for overall physical fitness, particularly for young individuals participating in sports such as running or high jumping. However, accurately assessing leg strength is challenging due to reliance on specific equipment and testing methodologies. This initial investigation aims to develop an accurate predictive model for leg strength by considering overall physical attributes and quadriceps muscle thickness. **Methods.** Sedentary participants were included in the study, and six physical characteristics were measured: age, weight, height, body mass index (BMI), leg length, and dominant quadriceps thickness. The Pearson correlation test was used to explore relationships between these variables and leg strength, while linear regression analysis was utilized to identify a predictive model. **Results.** The study included 40 young individuals (21 females and 19 males) with an average age of 20.87 ± 1.28 years, a height of 1.64 ± 0.07 m, a weight of 57.97 ± 13.3 kg, a BMI of 21.21 ± 3.85 kg/m^2, a leg length of 33.77 ± 2.39 inches, a quadriceps muscle thickness of 31.96 ± 8.72 mm, and a leg strength of 28.42 ± 15.11 kg. Significant positive correlations were found between leg strength and various factors: gender ($r = 0.87$), quadriceps muscle thickness ($r = 0.81$), height ($r = 0.45$), weight ($r = 0.59$), leg length ($r = 0.49$), BMI ($r = 0.51$), and age ($r = 0.36$). However, some associations were relatively weak. Linear regression analysis indicated that gender ($t = 4.38$, $p < 0.01$) and quadriceps thickness ($t = 2.72$, $p = 0.01$) were the primary predictors of leg strength. The final predictive model for leg strength was 18.07 (gender) + 0.574 (thickness) − 16.58, with a correlation coefficient of 0.935. Notably, quadriceps muscle thickness strongly correlated with leg strength ($r = 0.935$). **Conclusion.** This study highlights the correlation between leg strength and various physical attributes, particularly gender and quadriceps muscle thickness. These factors are significant predictors of leg strength in individuals aged 19–25.

Keywords: Forecasting model, Leg strength, Physical characteristics, Quadriceps muscle thickness

Introduction

Physical fitness, particularly speed and agility, is crucial for athletes and sports training (Abe et al., 2001). The role of muscle strength in sports performance has been highlighted by Volaklis et al. (2015). A previous investigation on basketball athletes identified physiological elements associated with competitive performance (Delgado-Floody, 2017). High muscular contractility is essential for high-intensity short sprints (Lockie et al., 2015) and continuous running or leaping during competition (Ribeiro et al., 2016). Given the rapid pace and dynamic nature of basketball, tennis, and running, leg strength is crucial (Kozinc et al., 2022) because it directly influences vertical jumping power (Quagliarella et al., 2011). Previous research has shown a positive correlation between muscle strength and muscle circumference and thickness (Kai et al., 2008). Additionally, a study on the muscle structural attributes of short and long-distance cyclists revealed that the rectus femoris fascicle length at the 30% level of the thigh was a significant independent predictor of 20-s cycling power in short-distance cyclists (Lee et al., 2021). This finding aligns with previous research indicating a significant association between isometric maximum voluntary contraction (MVC) and mid-thigh quadriceps thickness in a sample of 140 participants (Freilich et al., 1995). Recent research by Recenti et al. (2021) has also demonstrated a significant relationship between body mass index (BMI) and isometric leg strength. However, limited research has been conducted on equations predicting leg strength. A previous study involving 121 healthy elderly individuals found a correlation between knee extensor strength and factors such as gender, weight, leg length, and time taken to complete the Five Time Sit to Stand Test (FTSST) (Tapanya et al., 2024). Additionally, the association of dominant quadriceps muscle thickness with leg strength is of interest. Therefore, the aim of this preliminary study was to establish the correlation between physical attributes (gender, age, height, weight, BMI, dominant leg length, and quadriceps muscle thickness) and leg strength and to develop a predictive model for leg strength in young, healthy participants.

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Materials and Methods

This study involved 40 healthy, non-smoking individuals aged 19–26, comprising 21 females and 19 males. The participants were not athletes and did not exercise more than three times per week. None had documented medical histories of conditions such as hypertension, diabetes, cardiopulmonary diseases like pneumonia, post-COVID-19 complications, or musculoskeletal disorders, as reported or recorded in hospital data. Before the evaluation began, all participants provided their consent by signing a consent form.

Study protocol design

The Ethics Committee at the Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai, Thailand approved this preliminary investigation (Investigation Code: AMSEC-67EX-017). The aim of the study was to identify the associations and develop a potential predictive model for dominant leg strength based on physical factors such as gender, age, weight, height, BMI, and dominant leg length. The researchers used the G*Power tool (version 3.0.10) to determine the appropriate sample size, employing correlation and t-tests. The investigation by Ogawa et al. (2023) reported an effect size of 0.44, an α error probability of 0.05, a power (1-β error probability) of 0.80, and a correlation coefficient (r) of 0.20. Based on these parameters, a minimum sample size of 34 healthy individuals aged 19–26 was recommended. An additional 6 participants (10%) were included to ensure an adequate sample size, resulting in a total recruitment of 40 participants.

Physical characteristic evaluation

All parameters were collected in a controlled laboratory environment with a temperature range of 24–26°C. Before the anthropometric assessment, participants were instructed to wear lightweight clothing and remove their footwear. Body weight was measured using a digital scale from TANITA Corporation, Tokyo, Japan. Height was measured with a stadiometer (Health O meter® Physician, AD Medical, Inc., USA) with a scale in inches. BMI was calculated by dividing weight by the square of height (kg/m^2). Leg length was measured on the dominant side following the methodology of Tan et al. (2013). According to Morrissy et al. (2006), the established procedure for determining leg length involved measuring from the anterior superior iliac spine (ASIS) through the lateral femoral condyle to the lateral malleolus.

Quadriceps muscle thickness

The thickness measurement process followed the protocol established by Sai et al. (2021). Quadriceps thickness was measured using a B-mode ultrasound device (Dwell, China) to image the rectus femoris and vastus intermedius muscles. A solitary proficient examiner positioned a linear transducer, operating at a frequency of 6–7 MHz, perpendicular to the anterior aspect of the thigh. The transducer was placed at the midpoint between the greater trochanter and the lateral epicondyle of the femur, and ultrasound gel was used.

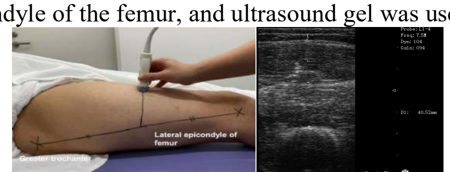

Figure 1. Measurement of quadriceps muscle thickness using B-mode ultrasound (Sai et al., 2021)

Leg strength evaluation

In this study, the assessment of leg strength, specifically isometric quadriceps strength, was performed using a back and leg dynamometer. Although this device can assess both leg and back strength, it is recommended to focus primarily on measuring quadriceps muscle strength, as suggested by Eyuboglu et al. (2019). Participants assumed an upright position with their knees flexed at a 60-degree angle (Risberg et al., 2018). They stood on the base of the dynamometer with feet shoulder-width apart, arms extended downward, holding the center of the bar with both hands, and palms facing the body. Knee extension was achieved through gradual and intense contraction of the quadriceps muscles, avoiding any external force exerted by the back and shoulders. Maximum force, measured in kilograms, was recorded from three consecutive attempts, with rest intervals of 20–30 s between each attempt.

Statistical analysis

Before reporting the mean, standard deviation (SD), and the categorical variable "gender" (specified as 1 for female and 2 for male), all attributes (age, gender, weight, height, BMI, and leg length) were checked for normal distribution using the Kolmogorov–Smirnov test. Linear regression (LR) analysis was employed to develop the predictive model for leg strength based on these variables (Ismail & Manjula, 2016). Following confirmation of normal distribution, Pearson's correlation test was used to assess the relationship between all variables and leg strength. Correlation coefficients were interpreted according to the following guidelines: very weak (0.00–0.19), weak (0.20–0.39), moderate (0.40–0.59), high (0.60–0.79), and very high (0.80–1.00) (Hung et al., 2017). The analysis of linearity and heteroscedasticity was performed using a P–P plot of standardized residual regression. The Durbin–Watson statistic test (Andy, 2005) was also used to check for autocorrelation. Daoud (2017) analyzed the variation inflation factor (VIF) and tolerance values to examine multicollinearity among the factors influencing the predictive model. Pearson's correlation test also determined the relationship between quadriceps muscle thickness and actual leg strength and the predictive models. All data analyses were conducted using IBM's Statistical Package for the Social Sciences (SPSS) software, version 10.0 (SPSS Inc., Chicago, IL, USA) for the Windows operating system.

Results

Data from all 40 healthy subjects, consisting of 21 females and 19 males, were analyzed. Table 1 presents the mean ± SD (min-max) values for physical parameters, quadriceps muscle thickness, and leg strength for all participants. Pearson correlation analysis results for these individuals are also provided, including the correlation coefficient (r). The findings indicated a significant positive association between leg strength and both gender and quadriceps muscle thickness ($p > 0.8$).

Table 1. Characteristics of 40 participants and correlation analysis

Variables	Min–Max	Mean ± SD	Correlation
Gender (female:male)	21:19		r = 0.87*
Age (years old)	19–25	20.87 ± 1.28	r = 0.36*
Height (meter)	1.49–1.80	1.64 ± 0.07	r = 0.45*
Weight (kg)	35–97	57.97 ± 13.3	r = 0.59*
Body mass index (BMI)	14.69–29.94	21.21 ± 3.85	r = 0.51*
Leg length (in)	29.5–38.0	33.77 ± 2.39	r = 0.49*
Quadriceps muscle thickness (mm)	19.07–49.46	31.96 ± 8.72	r = 0.81*
Leg strength (kg)	10.00–56.00	28.42 ± 15.11	

Note: * $p < 0.05$ with Pearson's correlation test

Table 2 presents the linear regression model analysis results conducted using the entry approach to predict leg strength. The prescreening model showed an R^2 value of 0.847, indicating a statistically significant association with gender (t = 4.977, p = 0.000) and thickness (t = 2.779, p = 0.000). Subsequently, the linear regression model was analyzed, incorporating gender and thickness variables, resulting in higher regression coefficients (0.935) and an improved R^2 value of 0.874. Furthermore, the assessment of collinearity or multicollinearity in the final model is crucial. Tolerance values close to 1.0 and variance inflation factor (VIF) values ideally below 10.0 indicate the absence of multicollinearity. In this study, the VIF of 2.67, below 10.0, suggests no multicollinearity between the variables of gender and quadriceps muscle thickness. The F value in model 2 demonstrated statistical significance ($p < 0.05$), indicating that both models effectively capture the influence of all factors on leg strength through linear regression analysis. Additionally, the Durbin–Watson test resulted in a final analytical result of 1.87, within the range of 1.5–2.5, suggesting independence in the observed variances.

Table 2. Summary of the model, coefficients, and collinearity statistics (n = 40)

Model		Unstandardized coefficients		Standardized coefficients			Collinearity statistic	
		β	Standard error	Beta	t	Sig.	Tolerance	VIF
Prescreen	(constant)	24.678	87.659		0.282	0.780		
	gender	18.96	4.328	0.759	4.382	0.000	0.218	4.596
	age	0.345	1.103	−0.265	0.313	0.758	0.569	1.757
	high	−54.148	54.701	−0.056	−0.990	0.330	0.069	14.462
	weight	−0.064	0.810	0.081	−0.079	0.938	0.012	85.378
	BMI	−0.316	2.258	0.207	−0.140	0.890	0.019	51.732
	length	1.307	1.123	1.164	1.154	0.253	0.171	5.863
	thickness	0.750	0.276	0.433	2.721	0.010	0.217	4.518
	R = 0.92, R^2 = 0.847, Adjusted R^2 = 0.843, SEE = 5.56, F = 20.658, Sig. = 0.000 Durbin–Watson = 1.616							
Final model	(constant)	−16.583	4.306		−3.851	0.000		
	gender	18.069	3.630	0.605	4.977	0.000	0.382	2.617
	thickness	0.574	0.210	0.332	2.7729	0.010	0.382	2.617
	R = 0.935, R^2 = 0.874, Adjusted R^2 = 0.870, SEE = 4.93, F = 70.114, Sig. = 0.000 Dubin–Watson = 1.871							

Abbreviations: *R*, multiple correlation coefficient; R^2, multiple coefficients of determination; SEE, standard error of the estimate; and VIF, variation inflation factor (VIF). All models were analyzed using multiple linear regression and the enter method. *F* and significance values were determined from the ANOVA assay.

Furthermore, the final predictive model for leg strength involved assessing linearity, skewness, and normality using the Shapiro–Wilk test. Figure 1 illustrates a linear trajectory in both genders, as evidenced by the P–P heteroscedasticity test results in the regression normalized residual plot. The scatter plot depicts random residuals across the expected values of variables related to leg strength, with no discernible systematic trend and values ranging from −0.5 to 5.0. This indicates statistically significant normality of errors, with p-values exceeding 0.05 for females (p = 0.567) and males (p = 0.869). The result of the final model is used to predict leg strength. As shown in Table 2, gender exerted a significant influence of 87.1%, while quadriceps muscle thickness accounted for 12.9%. Therefore, according to the forecasting equation, changing gender from female (1) to male (2) and increasing quadriceps muscle thickness by 1 mm can lead to an average increase in leg strength (kg) by 18.07 (b1) and 0.574 (b2), respectively, at a statistical significance level of 0.05.

Forecasting equations summary

The two equations for predicting leg strength are summarized from the linear regression analysis in Table 2. In this study, we investigated the correlation between leg strength and quadriceps muscle thickness in a sample of 40 participants. The findings revealed a strong correlation coefficient of 0.785 in the actual values (Figure 3A), 0.92 in the prescreen model (Figure 3B), and 0.935 in the final forecasting model. These correlation coefficients were deemed significant for both females ($r = 0.87$) and males ($r = 1.0$) (Figure 3C).

$$\text{Leg strength (kg)} = 24.678 + 18.96\,(\text{gender}) + 0.345\,(\text{age}) - 54.148\,(\text{height}) - 0.064\,(\text{weight}) - 0.316\,(\text{BMI}) + 1.307\,(\text{length}) + 0.750\,(\text{thickness}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

$$\text{Leg strength (kg)} = 18.069\,(\text{gender}) + 0.574\,(\text{thickness}) - 16.583 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

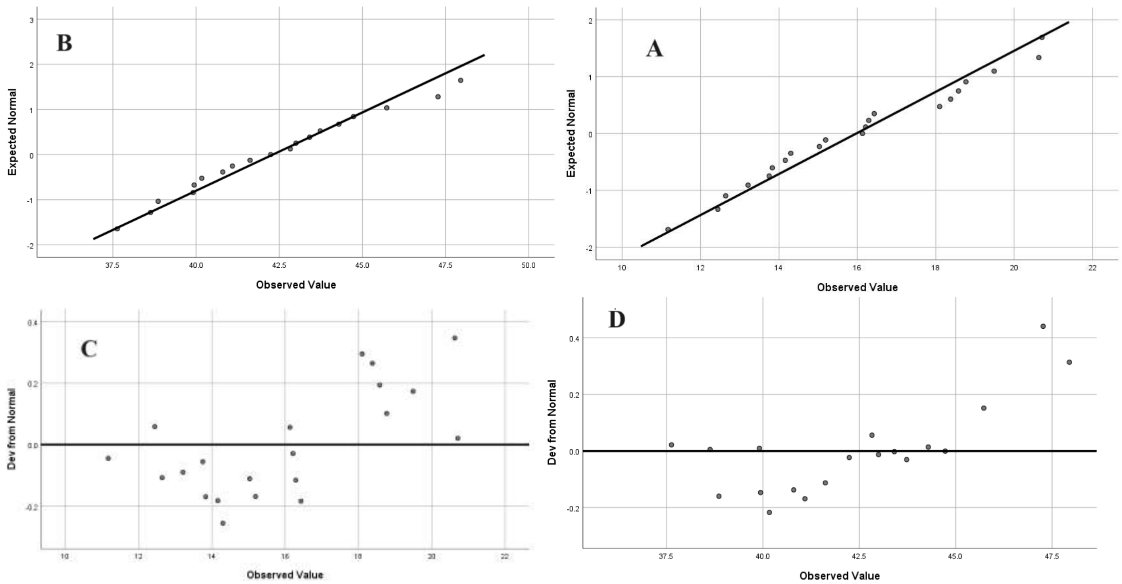

Figure 2. The linearity and normality skewness of the final forecasting model in females (A & C) and males (B & D)

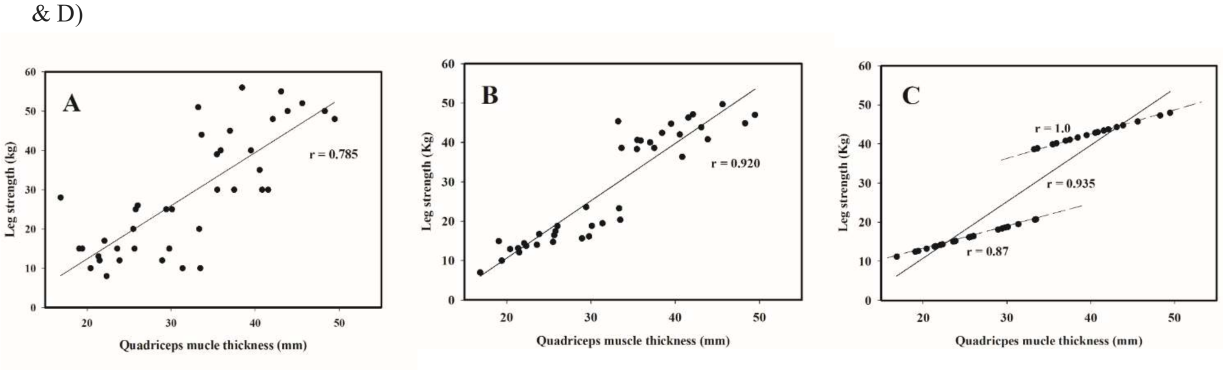

Figure 3. Scatter plots depicting the relationship between quadriceps muscle thickness and leg strength from actual data (A), the prescreen model (B), and the final forecasting model (C)

Discussion

In this preliminary investigation, we assessed the potential physical attributes, including gender, age, height, weight, BMI, and dominant leg length, in relation to leg strength among a sample of healthy individuals aged 19–26 years. Our pilot study with 40 participants revealed a significant association between all variables and leg strength. To ensure the robustness of our findings, we followed stringent inclusion criteria similar to those employed by Strollo et al. (2015) for healthy participants, considering conditions such as cardiovascular disease, diabetes mellitus, or osteoarthritis, which could affect lower leg power. Additionally, we included non-athletes in our study based on previous research suggesting a positive correlation between muscle size disparity and longer fascicle lengths in the dominant leg among soccer players (Kearns et al., 2001). This approach aimed to mitigate potential confounding influences on the results. The assessment of leg strength was performed using a back–leg dynamometer, a straightforward device used for quadriceps muscle evaluation. Following Eyuboglu et al. (2019), leg strength measurements were obtained with participants standing erect, knees flexed at a 60-degree angle, feet shoulder-width apart, and arms straight down without exerting effort from the shoulder and back (Risberg et al., 2018).

Nunes et al. (2018) strongly recommended evaluating leg strength using an isokinetic Cybex dynamometer. Their findings revealed a highly significant correlation coefficient (r = 0.81) between quadriceps thickness and leg strength, indicating a significant influence on the final forecasting model. Furthermore, preprocessing before evaluation was validated using ICC (3:1), demonstrating strong internal consistency of the assessor. Specifically, the assessor's ICC values for leg length (1.0), leg strength (0.96), and quadriceps muscle thickness (0.91) all fell within the acceptable range. These results were derived from a previous assessment conducted on a back–leg dynamometer, which showed a notable level of test–retest repeatability in previous investigations (ICC's > 0.92) (Hoor et al., 2016).

The study's findings on the relationship between physical attributes and leg strength revealed a statistically significant positive correlation, particularly regarding the strength of the quadriceps muscle in both genders. The relatively low association observed with age could be attributed to the limited sample size of 40 participants. Research attention on the association between features and leg strength has been limited. These findings indicate that certain variables, namely height and leg strength (r = 0.45), body weight (r = 0.54), and BMI (r = 0.51), show a correlation with leg strength. These results are consistent with previous research conducted on Japanese adolescents aged 15–17, which also reported a correlation between height and leg strength (r = 0.534), body weight (r = 0.459), and BMI (r = 0.35) (Miyatake et al., 2012). Additionally, a previous investigation with 121 individuals in the healthy aging population demonstrated a correlation between knee extensor strength and factors such as gender, weight, and leg length (Tapanya et al., 2024).

The purpose of this study was to perform linear regression analysis to predict leg strength. All factors were analyzed using the enter approach. A slight increase in quadriceps muscle thickness resulted in a statistically significant result ($p < 0.01$). Subsequently, the leg strength prediction model was iteratively executed using the enter approach. The equation representing leg strength (kg) is 18.069 (gender) + 0.574 (thickness) − 16.583. Evaluation of the collinearity statistic revealed tolerance and VIF values of 0.382 and 2.617 for gender and thickness variables, respectively. According to a previous report by Daoud (2017), a VIF score below 5 indicates the absence of autocorrelation between gender and thickness. Furthermore, the ultimate model exhibited Durbin–Watson test values of 1.871, below the threshold of 2.0, indicating the absence of autocorrelation (Smith, 1983). The study produced model equation summaries, including multiple R^2, multiple R, and adjusted R^2, as well as F-value and significant data. These findings are consistent with a previous report by Cameron et al. (1997) suggesting that a higher R^2 indicates a robust model.

The assessment conducted with the back–leg dynamometer provided data on leg strength, which was particularly indicative of prospective quadriceps muscle strength. This assertion is supported by previous research conducted by Hoor et al. (2016), which involved 45 healthy adults aged 18–35 years and 58 healthy adolescents aged 12–15 years. According to Hoor et al. (2016), a stepwise linear regression analysis demonstrated that the dominant knee extensor was the most significant predictor of back–leg–chest strength ($R^2 = 0.86$). Additionally, Hoor et al. (2016) showed in a previous investigation that isometric knee-extensor strength was the primary and statistically significant predictor of back–leg–chest strength ($R^2 = 0.86$) among individuals in good health. The evaluation methodology with the back–leg dynamometer is promising in indicating quadriceps muscle strength. Moreover, the ultimate predictive model for leg strength consistently validates the linear relationship and independence between gender and thickness using P–P plots and scatter plots.

The scatter plot illustrates random residuals in the expected values of variables dependent on leg strength. No consistent trend is evident, and values range from −0.5 to 5.0. This suggests that errors were significantly larger than 0.05, indicating normal distribution. The results do not show a consistent pattern or higher power of test compared to lower powers of curvature pattern, as observed by Mosteller and Tukey (1977). Therefore, the leg strength prediction models can be continuously performed without requiring data transformation.

Conclusion

This preliminary study demonstrates a positive association between leg strength and various factors, including gender, quadriceps muscle thickness, height, weight, muscle length, BMI, and age. Moreover, the predictors of muscle strength reveal gender and quadriceps muscle thickness, represented by the equation 18.07 (gender) + 0.574 (thickness) − 16.58.

The limitation of this study

This study did not include leg length and leg strength measurements on the non-dominant side, potentially impacting the accuracy of the forecasting model. This aligns with the previous suggestion by Lanshammar and Ribom (2010) that variations in leg muscle strength exist between the two sides. Future research should explore distinct forecasting models for dominant and non-dominant limbs, similar to those used for athletes. Moreover, it is worth noting that the age range of 19–25 years may not exhibit the same degree of complete maturation as the age range of 13–17 years (Malina, 2006). Consequently, the application of the ultimate predictive model for leg strength in this study may not be generalizable to other age groups.

Conflicts of interest

No conflicts of interest.

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References

Abe, T., Kumajai, K., & Brechue, W.F. (2000). Fascicle length of leg muscles is greater in sprinters than distance runners. *Medicine and Science in Sports and Exercise*, 32(6), 1125-1129.

Andy F. Discovering Statistics Using SPSS: (And Sex, Drugs and Rock "n" Roll). SAGE; 2005.

Cameron, A.C., & Windmeijer, F.A.G. (1997). An R-squared measure of goodness of fit for some common nonlinear regression models. *Journal of Economics*, 77, 329-342.

Eyuboglu, E., Aslan, C.S., Karakulak, I.K., Sahin, F.N. (2019). Is there any effect of non-suitable pull technique in back & leg dynamometers on the leg strength test results?. Acta Medica Mediterranea, 35, 1373.

Daoud, J.I. (2017). Multicollinearity and regression analysis. *Journal of Physics: Conference Series*, 949, 012009.

Delgago-Floody, P., Caamano-Navarrete, F., Carter-Thuillier, B., Gallardo-Fuenters, F.,Ramirez-Campillo, R., Barria, M.C., Latorre-Roman, P., Garcia-Pinillos, F., Martinez-Salazar, C., & Jerez-Mayorga, D. (2017). Comparison of body composition and physical performance between college and professional basketball players. *Archivos de Medicina del Deporte*, 34(6), 332-336.

Freilich, R.J., Kirsner, R.L.G., & Byrne, E. (1995). Isometric strength and thickness relationship in the human quadriceps muscle. *Neuromuscular Disorders*, 5(5), 415-422.

Hoor, G.A.T., Much, K., Meijer, K., & Plasqui, G. (2016). Test-retrest reproducibility and validity of the back-leg-chest strength measurements. *Isokinetics and Exercise Science*, 24, 209-216.

Hung, M., Bounsanga, J., Voss, M.W. (2017). Interpretation of correlations in clinical research. *Postgraduate Medicine*, 129 (8), 902-906.

Ismail, B., & Manjula, S. (2016). Estimation of linear regression model with correlated regressors in the presence of autocorrelation. *International Journal of Statistical Application*, 6, 35-39.

Kai, Y., Jujino, H., Murata, S., & Takei, K. (2008). Relationship between lower limb circumferences and muscle strength and thickness. *Rigakuryoho Kagaku*, 23(6), 785-788.

Kearns, C.F., Isokawa, M., & Abe, T. (2001). Architectural characteristics of dominant leg muscles in junior soccer players. *European Journal of Applied Physiology*, 85, 240-243.

Kozinc, Z., Zitnik, J., Smajla, D., & Sarabon, N. (2022). The difference between squat jump and countermovement jump in 770 male and female participants from different sports. *European Journal of Sport Science*, 22(7), 985-993.

Lanshammar, K., & Ribom, E.L. (2001). Differences in muscle strength in dominant and non-dominant leg in females aged 20-39 years- A population-based study. *Physical Therapy in Sport*, 12(2), 76-79.

Lee, H.J., Lee, K.W., Takeshi, K., Lee, Y.W., & Kim, H.J. (2021). Correlation analysis between lower limb muscle architectures and cycling power via ultrasonography. *Scientific Reports*, 11, 5362.

Lockie, R.G., Schultz, A.B., Callaghan, S.J., Jordan, C.A., Luczo, T.M., & Jeffriess, M.D. (2015). A preliminary investigation into the relationship between functional movement screen scores and athletic physical performance team sport athletes. *Biology of Sport,* 32(1), 41-51.

Malina, R. M. (2006). Weight training in youth-growth, maturation, and safety: An evidence-based review. *Clinical Journal of Sports Medicine*, 16(6), 478.

Morrissy, R.T., Weinstein, S.L. Lovell and Winter's Pediatric Orthopedics. Philadelphia, Lippincott Williams & Wilkins, 2006.

Mosteller, F., & Tukey, J.W. (1977). Data Analysis and Regression: A Second Course in Statistics. Addison-Wesley.

Miyatake, M., Miyachi, M., Tabata, I., Sakano, N., Hirao, T., & Numata, T. (2012). Relationship between muscle strength and anthropometric, body composition parameters in Japanese adolescents. *Scientific Research*, 4(1), 16989.

Nunes, R.F.H., Dellagranna, R.A., Nakamura, F.Y., Buzzachera, C.F., Almeida, F.A.M., Flores, L.J.F., Guglielmo, L.G.A., & da Silva, S.G. (2018). Isokinetic assessment of muscular strength and balance in Brazilian elite futsal players. *International Journal of Sports and Physical Therapy*, 13(1), 94-103.

Ogawa, M., Hashimoto, Y., Mochizuki, Y., Inoguchi, T., Kouzuma, A., Deguchi, M., Saito, M., Homma, H., Kikuchi, N., & Okamoto, T. (2023). Effects of free weight and body mass-based resistance training on thigh muscle size, strength and intramuscular fat in healthy young and middle-aged individuals. *Experimental Physiology*, 108(7), 975-985.

Quagliarella, L., Sasanelli, N., Belgiovine, G., Accettura, D., Notarnicola, A., & Moretti, B. (2011). Evaluation of counter movement jump parameters in young male soccer players. *Journal of Applied Biomaterials and Biomechanics*, 9(1), 40-46.

Recenti, M., Ricciardi, C., Monet, A., Jacob, D., Ramos, J., Gislason, M., Edmunds, K., Carraro, U., Gargiulo, P. (2021). Predicting body mass index and isometric leg strength using soft tissue distributions from computed tomography scans, *Health and Technology*, 11, 239-249.

Ribeiro, M. B. T., Carvalho, M. M., Prestes, J., Almeida, J. A., Pereira, G. B., Pereira, E. C. L. (2016). A session of stretching can reduce muscle strength in the lower limb: a randomized study. *Brazilian Journal Exercise Physical and Prescription*, 10 (57), 104-11.

Risberg, M.A., Steffen, K., Nilstad, A., Myklebust, G., Kristianslund, E., Moltubakk, M.M., and Krosshaug, T. (2018). Normative quadriceps and hamstring muscle strength values for female, healthy, elite handball and football players. *Journal of Strength and Condition Research,* 32(8), 2314–2323.

Sai, A., Tanaka, K., Ohashi, Y., Kushiyama, A., Tanaka, Y., Motonishi, S., Sakai, K., Hara, S., & Ozawa, T. (2021). Quantitative sonographic assessment of quadriceps muscle thickness for fall injury prediction in patients undergoing maintenance hemodialysis: an observational cohort study. *BMC Nephrology*, 22, 191. https://doi.org/10.1186/s12882-021-0 2347-5.

Smith, D.P. (1983). Durbin-Watson statistics for model life tables. *Asian and Pacific Census Forum*, 9, 7-9.

Strollo, S.E., Caserotti, P., Ward, R.E., Glynn, N.W., Goodpaster, B.H., Strotmeyer, E.S. (2015). A review of the relationship between leg power and selected chronic disease in older adults. *Journal of Nutrition and Health Aging*, 19(2), 240-248.

Tapanya, W., Sangkarit, N., Amput, P., & Konsanit, S. (2024). Lower extremity muscle strength equation of older adults assessed by Five Time Sit to Stand Test (FTSST). *Hong Kong Physiotherapy Journal*, 44(1), 1-10.

Tan, C.W., Coutts. F., & Bulley, C. (2013). Measurement of lower limb volume: Agreement between the vertically oriented perimeter and a tap measure method. *Physiotherapy*, 99, 247-251.

Volaklis, K.A., Halle, M., & Meisinger, C. (2015). Muscular strength as a strong predictor of mortality: a narrative review. *European Journal of Internal Medicine*, 26, 303–310.