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Relationship between ultrasound measurement of quadriceps muscle and nutritional status in ICU patients in a high-complexity trauma care hospital

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Abstract

Introduction

Muscle mass assessment of critically ill patients is essential to be part of the nutritional diagnosis in hospital care. Thus, the evaluation of more specific techniques for that purpose is needed. The present study aimed to investigate the association of quadriceps muscle thickness (QMT), measured by ultrasound (US), with the nutritional status of critically ill patients in a referral high-complexity trauma care hospital.

Methods

A cross-sectional observational study was conducted in the intensive care units (ICUs) in a tertiary hospital in Brazil. The sample comprised 30 critically ill trauma patients admitted between February and March 2022. The methodology involved evaluating muscle mass and comparing nutritional status through mid-upper arm circumference measurements and US assessments. Specifically, the QMT was quantified using US at a predefined site between the iliac crest and the proximal border of the patella.

Results

The Kruskal-Wallis test indicated variability in QMT between the nutritional status groups, with statistical significance reached after excluding the overweight group ($H(2) = 7.532$, $p = 0.023$). The moderate malnutrition group exhibited notably lower QMT. Sensitivity analyses using bootstrap and Monte Carlo methods showed moderate trends toward significance. A positive correlation was found between QMT and mid-upper arm circumference adequacy ($p < 0.05$), demonstrating fair to moderate correlation ($r_s = 0.531$).

Conclusion

Significant changes in QMT were detected by ultrasound assessment in moderate malnutrition patients compared to patients of other nutritional statuses. Ultrasound may be a valuable technique for monitoring muscle integrity in critically ill patients.

Abbreviations

ANOVA, one-way analysis of variance; ESPEN, European Society for Clinical Nutrition and Metabolism; ICU, intensive care unit; IQR, interquartile range; MUAC, mid-upper arm circumference; MUAC, mid-upper arm circumference adequacy; QMT, quadriceps muscle thickness; RF, rectus femoris; SD, standard deviation; US, ultrasound; VM, vastus medialis; VL, vastus lateralis; VI, vastus intermedius.

Keywords: ultrasonography; muscle mass; quadriceps muscle; critically ill patient; nutritional status; malnutrition.

INTRODUCTION

Critically ill patients admitted to an intensive care unit (ICU) present both physiological instability and a high risk of mortality [1]. These patients typically experience changes in body composition, mainly caused by hypermetabolism resulting from disease-associated inflammation, reduced food intake and mobility, and drug effects. These changes can lead to an intense loss of muscle mass and function [2,3].

A broad scientific literature suggests that malnutrition and reduced muscle mass in hospitalized patients serve as predictors of worsening clinical outcomes, particularly among those receiving intensive care, leading to an increased risk of morbidity, mortality, and impaired long-term functionality [4]. Therefore, it is essential that muscle mass evaluation be part of the nutritional diagnosis [5] and the monitoring muscle losses be used to guide interventions for muscle recovery [6].

Nutritional assessment comprises evaluation of body composition, which can be challenging in critically ill patients since anthropometric measurements can be altered by hemodynamic changes commonly observed during their ICU stay [7]. In addition, trauma injuries can limit or make it impossible to use many instruments and techniques involved in nutritional assessment [8].

Mid-upper arm circumference (MUAC) is a standard protocol in nutritional assessment as it can be used to determine the patient's nutritional status and provides a necessary variable for estimating weight using predictive equations [9,10]. However, MUAC measurements can be affected by edema, a clinical condition commonly present in ICU patients [8], and it does not provide specific information on muscle composition.

Ultrasound (US) is progressively becoming a promising tool for assessing muscle mass in various clinical populations, including critically ill patients. This device confers good reproducibility, reliability, and diagnostic accuracy for both intra and inter-examiners [11,12]. US is a modality that allows measurements in various sections of muscles, organs, and adipose tissue. The resulting images offer a direct visualization of the region under study, enabling the observation of compositional differences in muscular mass or adiposity, among other parameters [13]

The evaluation of quadriceps muscle thickness (QMT) has been reported to have good reliability and validity for the diagnosis and monitoring of acute muscle wasting in critically ill patients, particularly when assessed at the bedside using US [14]. Several authors have highlighted it as an excellent region that is both practical and accessible for the application of US in studying patients admitted to the ICU

[3,15,16].

In the care of critically ill patients who are at high nutritional risk, the need for procedures that specifically monitors muscle mass integrity is paramount to stablish nutritional diagnosis and to guide dietary treatment. Thus, the purpose of this study was to investigate the association of QMT, measured by US, with nutritional status of critically ill patients in a referral high-complexity trauma care hospital.

METHODS

This observational quantitative cross-sectional study was conducted on patients admitted to the ICUs of a highly complex public hospital, which serves as a reference in trauma for the North and Northeastern regions of Brazil, between February and March 2022. The study was carried out with the approval of the hospital's ethics committee (CAAE 41909321.8.0000.5047) and informed consent forms were signed by the legal guardians of the participants. A non-probabilistic convenience sampling method was applied, with inclusion criteria consisting of adult and elderly patients (≥18 years old) of both genders. Exclusion criteria comprised individuals with amputated upper or lower limbs, edema in both arms, burned patients, pregnant women, and those whose condition did not permit access to the quadriceps for US evaluation.

Data collection

The collection of clinical data and identification from the patient's chart was performed through the utilization of a data collection form.

Mid-upper arm circumference (MUAC) measurement

Mid-upper arm circumference was measured to classify patient's nutritional status [17] based on its adequacy, according to Blackburn and Thornton (1979) [18]. The measurement of MUAC was conducted following the method described by

Lohman (1987) [9]. For accurate measurements, an inelastic measuring tape marked in centimeters (cm) and yielding a precision of 0.1 cm was utilized.

Ultrasound measurements

The quadriceps muscle thickness (QMT) quantification was obtained by using a portable Mindray® ultrasound device, Model M6, equipped with a 19" screen, which allowed for obtaining an image in mode B, with a (7L4s) transducer and a sampling frequency of 5-10 MHz. Precise measurements, in centimeters, were taken perpendicularly and transversely on the evaluated muscles. The assessment was performed with the patient in dorsal decubitus, with the elbows and knees in passive extension, to allow examination of the muscle when it is extended and relaxed. Sterile gel was applied to the US transducer to facilitate contact with the skin surface. The transducer was placed on the anterior surface of the thigh, transversely in relation to the muscle length and perpendicularly to the longitudinal axis, at the point corresponding to two-thirds of the distance between the iliac crest and the upper border of the patella (Figure 1) [19-21].

With the aim of standardizing measurements for all participants, the position of the US transducer was determined after demarcating the midpoint with the aid of an inelastic measuring tape graduated in centimeters (cm) and with a precision of 0.1 cm. To calculate the median, US measurements were performed in duplicate. US images of the region where the measurements were performed were also collected. Figure 2 illustrates one of the ultrasound images obtained in the present study, demarcating the QMT.

Statistical analysis

Data were analyzed using IBM SPSS Statistics 26.0 and sensitivity analyses by R software version 4.3.1. Categorical variables were presented as relative frequencies. The Shapiro-Wilk test assessed the normality of the distribution of continuous variables. Given the non-normal distribution of some variables, measures of central tendency and dispersion were presented as mean ± standard deviation (SD) for normal data and median with interquartile range (IQR) for skewed data.

The Kruskal-Wallis test was utilized to identify differences between more than two independent groups, accounting for the non-normal distribution. Additionally, Spearman's rank correlation coefficient explored associations between quantitative muscle thickness (QMT) with both mid-upper arm circumference (MUAC) and its adequacy (MUACA). The interpretation of the Spearman's correlation coefficients was based on the guidelines provided by Chan et al. (2003) [22]. The significance level was set at $p < 0.05$.

A critical element of the statistical approach was conducting sensitivity analyses using resampling methods, specifically bootstrap and Monte Carlo simulation, to validate the robustness of the findings. These methods were paramount given the small sample size in the Overweight group, raising concerns about the potential bias and the stability of the results. With 2,000 iterations, the bootstrap method was employed to estimate the distribution of the Kruskal-Wallis test statistic under the null hypothesis, providing a confidence interval for this statistic. The models were refitted to each bootstrap sample, and we calculated the mean statistics and their bias-corrected 95% confidence intervals (CI). Monte Carlo simulation, also set at 2,000 iterations, assessed the p-value distribution. Through 2,000 iterations, it assessed the distribution of p-values and test statistics beyond conventional analytical constraints, providing a more nuanced understanding of the data's statistical properties.

RESULTS

Table 1 presents the general characteristics of all study participants. Of the 30 patients evaluated, 28 (93.3%) were male and 2 (6.7%) were female, with a median age of 40.4 years (interquartile range [IQR], 23.75-53 years). The median length of hospital stay was 24 days (IQR, 13.25-68.5 days). Traumatic brain injury and polytrauma were the primary reasons for hospitalization, accounting for 76.7% of the sample. None of the participants were obese, and only two individuals (6.7%) were overweight. For the moderate malnutrition group, the QMT mean ± SD were 1.46 ± 0.46 cm ($p = 0.547$). The eutrophy group showed a QMT mean ± SD of 2.12 ± 0.43 cm ($p = 0.785$). The mild malnutrition group had a QMT median of 2.09 cm (IQR, 2.03-2.23 cm) ($p = 0.032$). The two observed QMT values for the Overweight group were 1.92 cm and 2.11 cm (Figure 3).

Upon applying the Kruskal-Wallis test to all groups (N=30), the statistics were as follows: $H(3) = 7.635$, $p = 0.054$. The moderate malnutrition group had a QMT median of 1.44 cm (IQR, 1.19-1.86 cm). The eutrophy group showed a QMT median of 2.08 cm (IQR, 1.82-2.47 cm). The overweight group, limited in sample size, had a median of 2.01 cm (based on only two observed values). As previously stated, the mild malnutrition group had the reported median and IQR values (Figure 4). Excluding the overweight group (N=28) adjusted the statistics to $H(2) = 7.532$, $p = 0.023$, reaching statistical significance. Sensitivity analyses employing bootstrap and Monte Carlo methods were conducted to examine the stability of these findings, given the potential influence of the small sample size in the overweight group.

The 95% CI for the proportion of significant tests, based on bootstrapped p-values, ranged from approximately 0.00079 to 0.5414, indicating substantial variability in the data. A considerable proportion of these tests (59.95%) yielded significant results ($p < 0.05$) (Figure 5A). Furthermore, the mean p-value derived from the bootstrap method was 0.0898 (Figure 5B). The Monte Carlo simulations demonstrated that in 65.3% of instances, the observed differences were statistically significant ($p < 0.05$) (Figure 6A) and the mean p-value was 0.0649 (Figure 6B). Although these results do not meet the criterion for significance ($p < 0.05$), it denotes a moderate trend toward statistical significance. These findings suggest that while the null hypothesis cannot be categorically rejected based on our data set, there is a preliminary indication of potential effects worthy of future investigation. The decision to include the overweight group was driven by clinical interpretability considerations.

A significant positive correlation was observed between the QMT and the MUAC ($p < 0.05$). The Spearman's correlation coefficient (r_s) was 0.557, indicating a fair to moderate correlation (Figure 7A). Our analysis also revealed a significant positive correlation between QMT and the MUACA ($p < 0.05$). The r_s for this association was 0.531, further establishing a fair to moderate correlation (Figure 7B).

DISCUSSION

Summary of findings

The differences between the groups, particularly the moderate malnutrition group showing a significantly lower QMT, are a cause for concern, highlighting the potential relationship between higher degrees of malnutrition and muscle mass. The discovery that even with a small sample, the overweight group does not follow the trend of the moderate malnutrition group is a valuable discussion point. It reflects the complexity of the relationship between body mass and muscle mass, especially in situations involving the hospitalization of critically ill patients, as in the present study, where the nutritional status of mild malnutrition, eutrophy, and overweight exhibited higher QMT than moderate malnutrition. Therefore, our study's statistically significant positive correlations suggest that as QMT increases, there is a concordant rise in MUAC and its adequacy. This can be vital in clinical and nutritional settings, especially when evaluating an individual's muscle mass and its relation to overall nutritional status.

Body composition assessment by ultrasound

In the context of nutritional assessment of critically ill patients the need for more accurate and non-invasive method to assess body composition is increasingly on the rise in health research. Ceniccola et al. (2019) reported that US is superior to other anthropometric methods for estimating nutritional status, as it is a practical tool that allows for the non-invasive quantification of tissue composition, without requiring patient mobilization [23]. Reid et al. (2004) demonstrated that US measurements are not affected by fluid accumulation or edema, validating the method for bedside patient monitoring [24].

Another point that has yet to be standardized in the literature is the amount of pressure needed to correctly quantify the muscle mass when using a US transducer [25]. Toledo et al. (2021) point out that among researchers, minimal pressure is preferable for standardization [3]. However, Paris et al. (2017) noted that greater pressure is necessary to facilitate identification of muscle mass when edema is present [26]. In the present study, the analysis was performed by two trained researchers who applied minimal pressure to measure the quadriceps in most patients, although greater pressure was required in the presence of severe edema. It is worth emphasizing that the effectiveness of this technique has been previously demonstrated in edematous patients when accessing the quadriceps muscle [27], as well as in muscles of other limbs of the body [28, 29].

Correlations and implications of MUAC and QMT

In the present study, a positive correlation was established between MUAC and QMT. The MUAC measurement is a simple, practical, and low-cost method that has been validated for many years and widely used in hospitals due to its prognostic value in relation to both nutrition and mortality, particularly in resource-limited situations. Nevertheless, MUAC is not used to monitor specifically muscle composition, an important parameter in the nutritional care of critically ill patient context.

In recent studies, a reduction in the measurements of MUAC and QMT has been observed during illness and hospitalization. El-Liethy and Kamal (2021) conducted a study on sarcopenic patients with and without liver cirrhosis, where the MUAC and QMT values were found to progressively decrease with the severity of the disease [30]. Similarly, Chapple et al. (2020) reported a decrease in both measures in patients between hospital admission and discharge. However, their study was limited to descriptive data, and a correlation between MUAC and QMT was not performed [31].

Sanz-Paris et al. (2021) performed a correlation between MUAC and QMT measurements in 101 sarcopenic patients diagnosed with malnutrition, who were hospitalized for a hip fracture. Using US, they found statistically significant negative and positive correlations between MUAC and QMT echogenicity and thickness, respectively. The QMT mean value was 2.21 ± 0.645 cm, with only the rectus femoris and vastus intermedius muscles used as constituents of the quadriceps [32]. In the present study, we also used only the rectus femoris and vastus intermedius muscles as constituents of the quadriceps.

In the present study, the QMT of critically will patients, which have suffered trauma mostly, was determined and associated with each identified nutritional status in the sample. The findings demonstrated that moderate malnutrition patients tend to exhibit lower QMT, suggesting that adequate nutrition is a crucial factor in maintaining muscle mass. In a previous clinical study, Toledo et al. (2021) examined critically ill yet well-nourished adult patients in relation to BMI and a lower cut-off point (1.64 cm) for quadriceps thickness depletion was reported in mechanically ventilated subjects. However, that lower QMT value compared to our study can be attributed to the fact that most of their patients had developed sepsis, which is known to directly affect muscle loss [3].

The role of ultrasound in nutritional monitoring

The presented studies suggest that several variables could have potentially interfered in the body composition of the participants, thereby influencing the QMT. These variables include disease severity, inflammatory profile, length of stay, nutritional support, associated comorbidities, among others, which could explain the different results observed. In this study, most of the participants suffered from severe trauma and were on respiratory support, requiring a prolonged hospitalization period, all of which indicate a greater muscle depletion in comparison to patients presenting a less accentuated catabolic profile.

Taking into consideration the most recent studies in which ultrasound was employed to assess muscle mass composition, including the present study, it is not the primary objective to determine QMT cutoff points for patient profile. Rather, the relevance of this study is to show that the US can detect differences in muscle integrity, which changes according to nutritional status of critically patients, and can be used as a tool to monitor the progression of patients during hospitalization. By utilizing this technique, periodic evaluation of the QMT could enable a more precise adjustment of protein supply and other nutrients to patients at risk of muscle depletion.

Limitations of the study

Some limitations exist in this study, including the lack of information regarding drugs administered that may be associated with acute muscle loss and random patient selection based on length of stay. The decision-making in our statistical approach was complex, requiring a balance between methodological rigor and interpretative caution due to the small sample size of the Overweight group. While the initial Kruskal-Wallis test suggested a marginal statistical significance when all groups were included, the reanalysis without the Overweight group revealed a clearer statistical significance. The sensitivity analyses provided further insights. The bootstrap results highlighted the potential instability of the findings related to the Overweight group, suggesting its influence could introduce variability. Both the bootstrap method and Monte Carlo simulations presented a significant number of p-values indicating potential statistical significance in the difference between groups, including the Overweight group. The choice was made to proceed with the inclusion of the Overweight group from the primary analyses. This decision was based on following factors: the significant p-values when including the Overweight group in many iterations, and the clinical consideration regarding the interpretability. We suggest more studies in this field to evaluate other variables that could imply in muscle composition changes in ICU patients as well as the monitoring the same patient in different days of hospitalization. Specifically, further research is required to analyze the distinct outcomes in overweight and obese ICU patients compared to those with other nutritional statuses, ensuring a significant data interpretation.

CONCLUSION

The ultrasound (US) assessment of the quadriceps muscle thickness (QMT) revealed changes in muscle mass depending on nutritional status, mainly when moderate malnutrition patients were compared to other nutritional statuses, and may constitute a valuable tool for monitoring muscle wasting in critically ill patients. Also, measurement of QMT using the US may serve as a criterion for defining a more assertive diet therapy plan for recovery and maintaining nutritional status.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

Author contributions

Milton Alves Danziato-Neto: Conceptualization; Methodology; Formal analysis; Investigation; Writing - Original Draft; Writing - Review & Editing; Visualization. **Priscilla Sousa Santos Caldas:** Conceptualization; Methodology; Investigation; Writing - Original Draft. **Juliana Magalhães da Cunha Rêgo:** Methodology; Investigation; Writing - Original Draft. **Antônio Augusto Ferreira Carioca:** Formal analysis; Writing - Review & Editing. **Cristiane Rodrigues Silva Câmara:** Conceptualization; Methodology; Investigation; Writing - Original Draft; Writing -

Review & Editing; Visualization; Project administration.

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Table 1 - Demographic, anthropometric, and clinical characteristics of the participants.

Characteristics	**Total (n= 30)**	***p* ***
Sex, %		
Men	93.3	
Women	6.7	
Age in years, median (IQR)	40.5 [23.75-53.0]	0.042
Length of stay in days, median (IQR)	24.0 [13.25-68.5]	< 0.001
Reason for hospitalization, %		
Brain cancer	3.3	
Exogenous intoxication	13.3	
Polytrauma	36.7	
Traumatic brain injury	40.0	
Spinal cord injury	6.7	
Patients on MV > 48h, %	90.0	
MUAC (cm), mean ± SD	28.8 ± 4.19	0.335
MUACA (% ± SD)	91.0 ± 13.5	0.648
Nutritional status (%)		
Moderate malnutrition	23.3	
Mild malnutrition	20.0	
Eutrophy	50.0	
Overweight	6.7	
QMT (cm), mean ± SD	1.97 ± 0.46	0.798
QMT (cm) by nutritional status, mean ± SD or median (IQR)		
Moderate malnutrition	1.46 ± 0.46	0.547

Mild malnutrition	2.09 [2.03-2.23]	0.032
Eutrophy	2.12 ± 0.43	0.785
Overweight	1.92 and 2.11	-

* All continuous variables were tested for normality using the Shapiro-Wilk test, p-value < 0.05. MUAC, mid-upper arm circumference. QMT, quadriceps muscle thickness. MV, mechanical ventilation. SD, standard deviation.

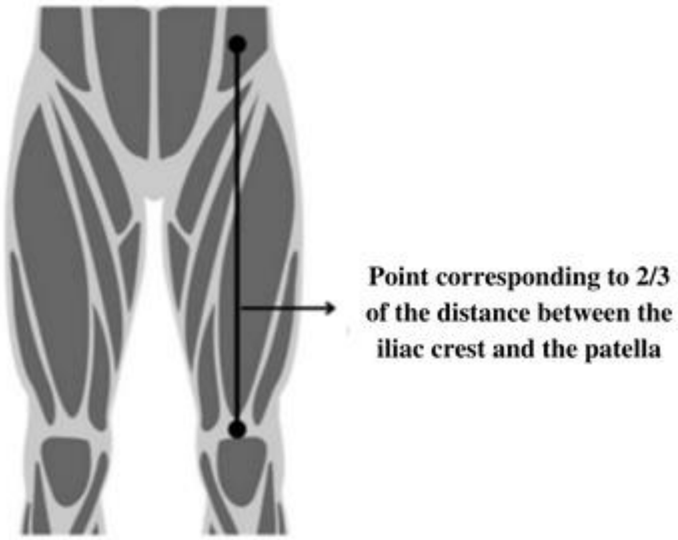


Figure 1. Point corresponding to two-thirds of the distance between the iliac crest and the patella. This image is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

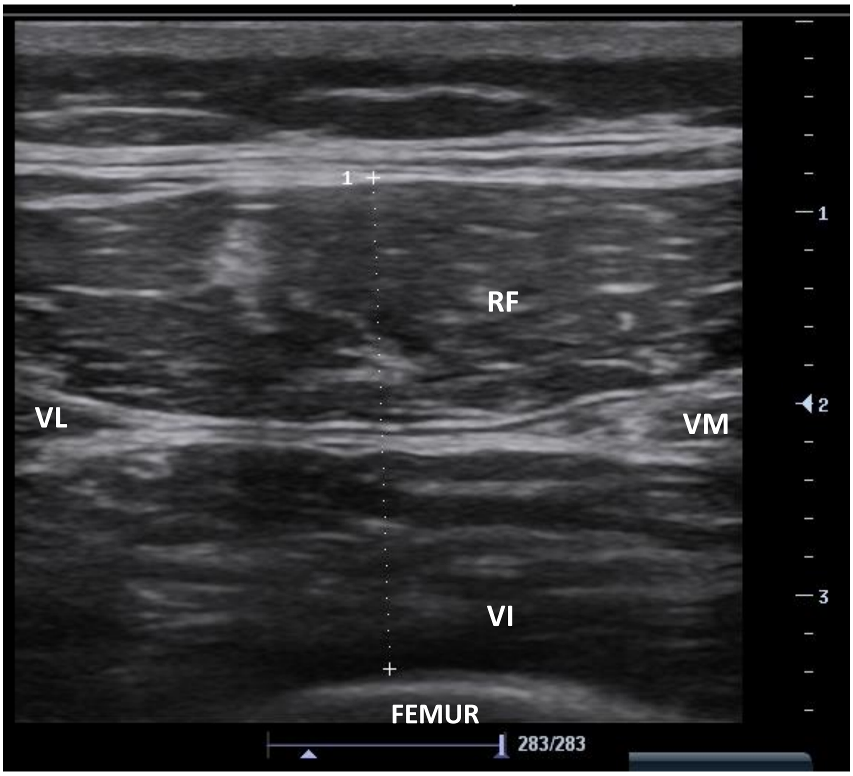


Figure 2. Quadriceps muscle thickness as detected by a participant's ultrasound image. The dotted line represents the full thickness of the quadriceps (rectus femoris and vastus intermedius complex). RF, rectus femoris; VI, vastus intermedius; VL, vastus lateralis; VM, vastus medialis. In the image, only small portions of the VM and VL are visible.

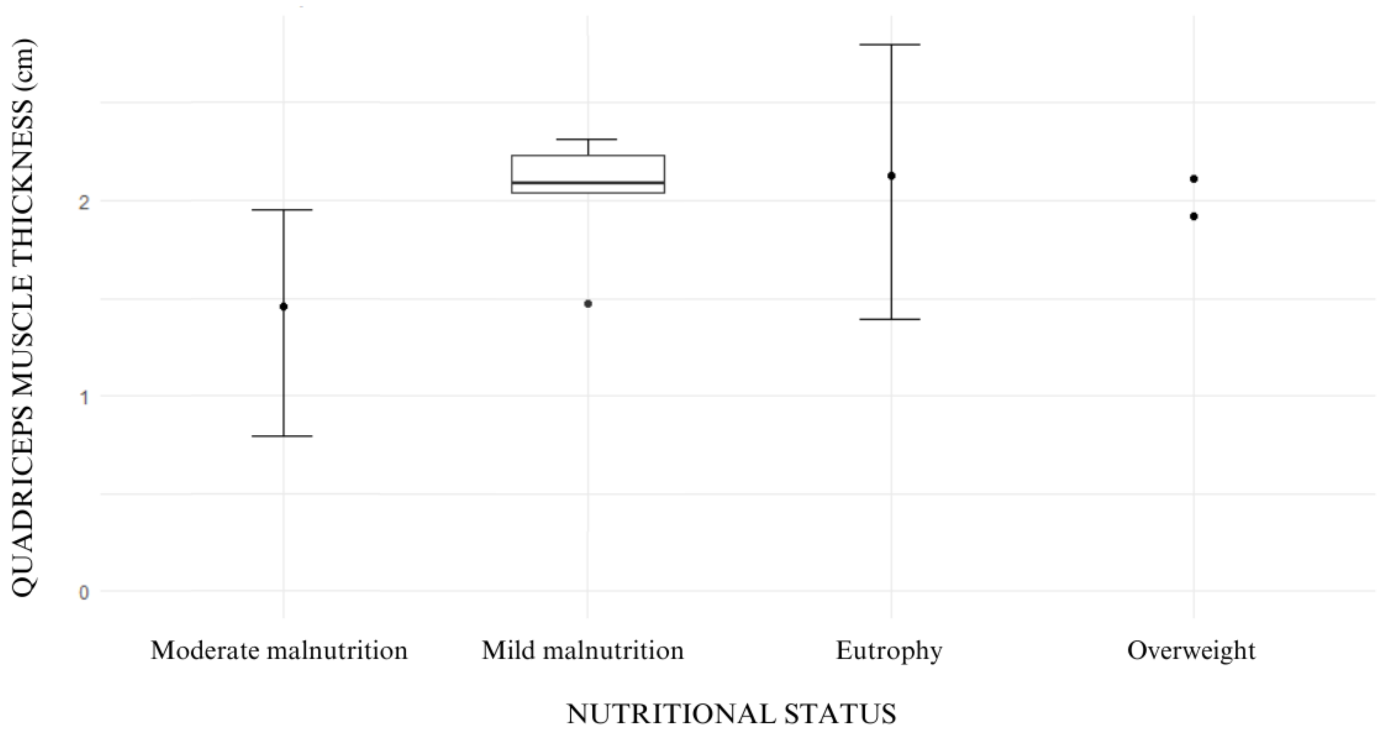


Figure 3. Distribution of quadriceps muscle thickness (cm) in relation to nutritional status classified based on mid-upper arm circumference adequacy (%). The groups Moderate malnutrition and Eutrophy are represented by error bars, displaying the mean and the range between minimum and maximum values. Box and whisker plot illustrates Mild malnutrition, indicating median, interquartile range, and outliers. Overweight is depicted by isolated points due to the low sample size.

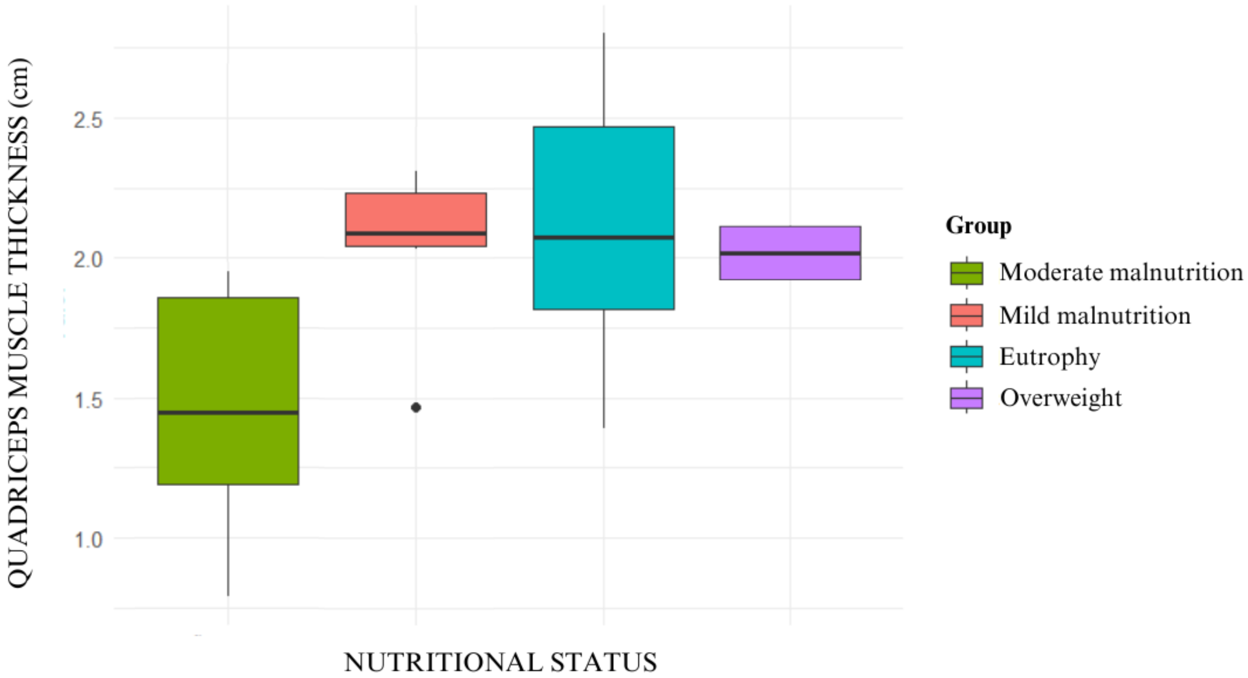
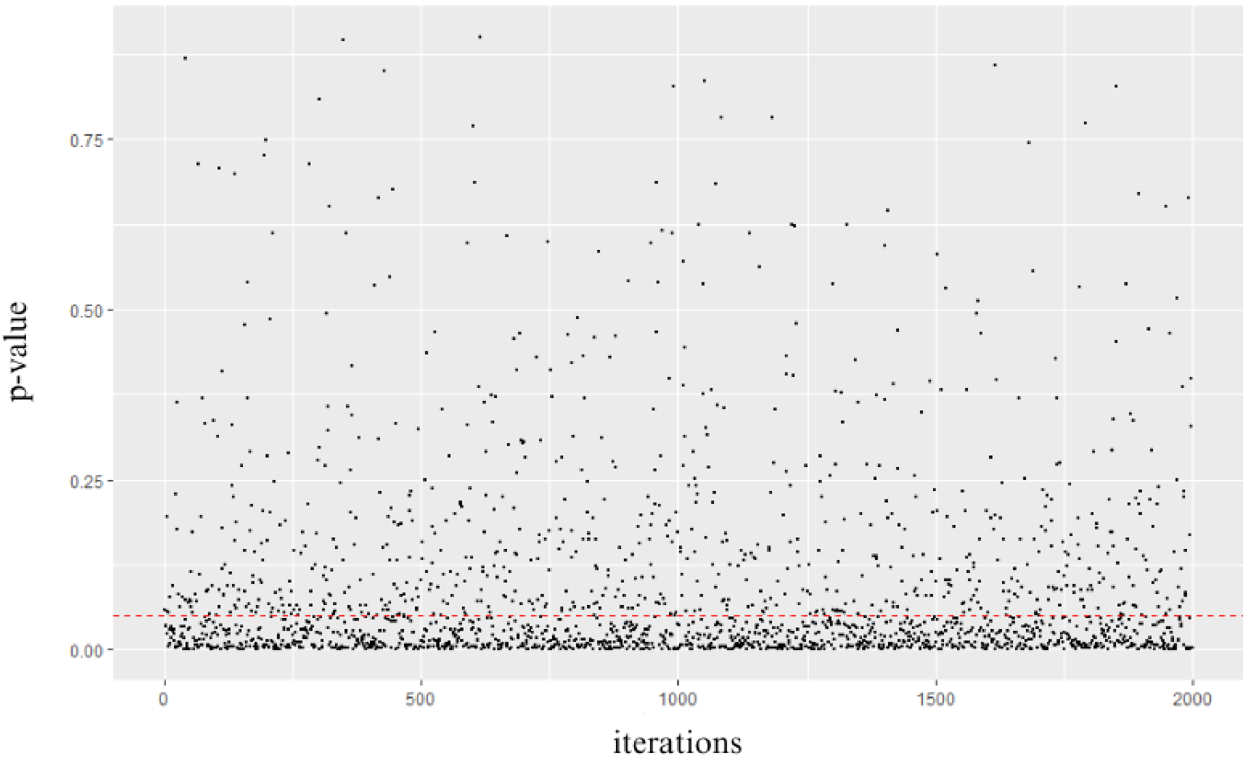


Figure 4. Box and whisker plots illustrate the quadriceps muscle thickness (QMT) (cm) across four nutritional status groups classified based on mid-upper arm circumference adequacy (%). Mild malnutrition displays the highest median QMT, followed by Eutrophy, Overweight and Moderate malnutrition. An outlier, represented by a dot, is evident below Mild malnutrition box. The interquartile range (IQR) provides the distribution dispersion about the median. The Overweight group demonstrates an absence of IQR, indicating a limited data set comprising two observed values.

A


p-value
0.00
0.25
0.50
0.75
0
500
1000
1500
2000
iterations

B

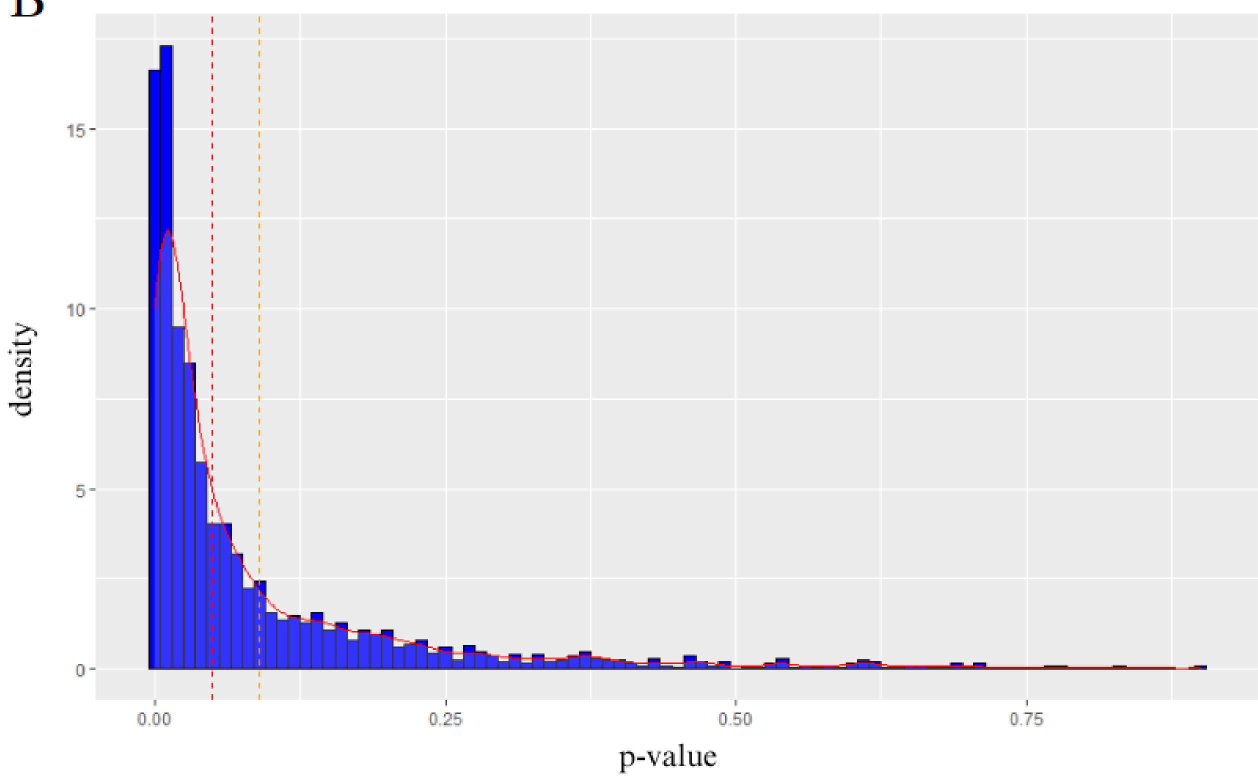
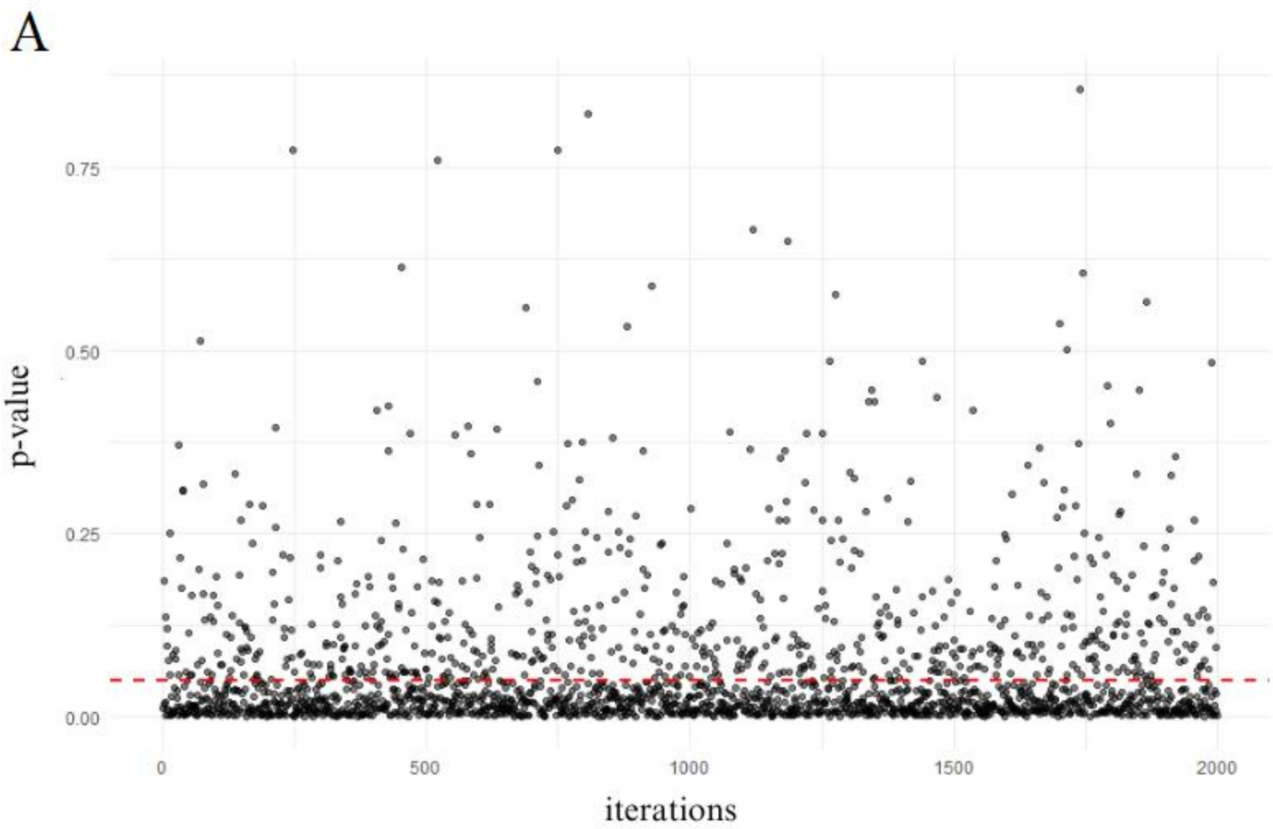

density
0
5
10
15
0.00
0.25
0.50
0.75
p-value

Figure 5. Scatter plot (**Figure A**) and histogram overlayed with a density curve (**Figure B**) illustrating the distribution of p-values derived from Kruskal-Wallis test based on bootstrap resampling on quadriceps muscle thickness across four distinct nutritional statuses: Moderate malnutrition, Mild malnutrition, Eutrophy, and Overweight. The data distribution was bootstrapped with 2000 iterations. **Figure A:** Further dispersion of points across the entire p-value range indicates variability in the results. A significant proportion (59.95%) of these tests yielded results with p-values less than 0.05. A dashed red line, marking p = 0.05, serves as a reference point for statistical significance. **Figure B:** Two dashed lines of significance are evident on the graph: a red line marking the adopted significance threshold of p = 0.05 and an orange line indicating the mean p-value of 0.0898 for our data.



B

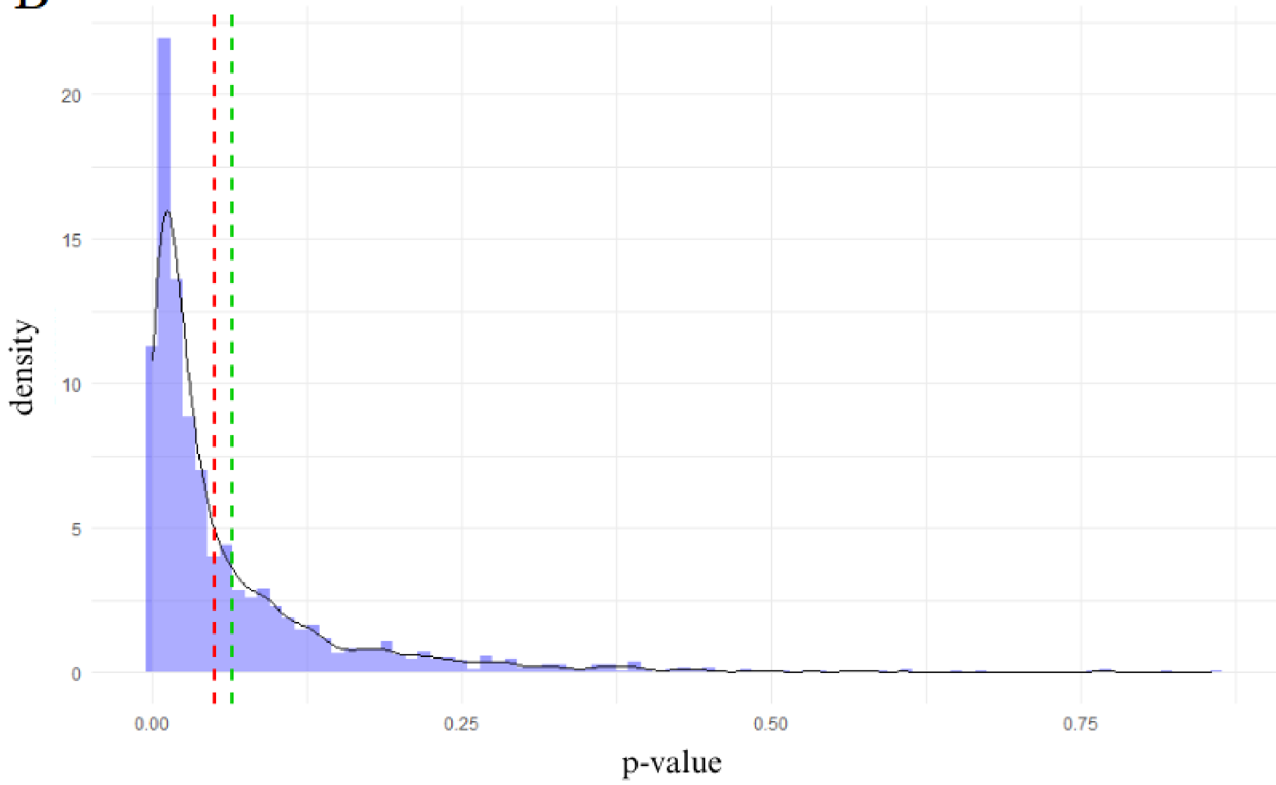


Figure 6. Scatter plot (**Figure A**) and histogram overlayed with a density curve (**Figure B**) illustrating the distribution of p-values derived from Kruskal-Wallis test based on Monte Carlo simulation on quadriceps muscle thickness across four distinct nutritional statuses: Moderate malnutrition, Mild malnutrition, Eutrophy, and Overweight. The assessment utilized 2,000 iterations, consistent with the Monte Carlo simulation parameters. **Figure A:** A significant proportion (65.3%) of these tests yielded results with p-values less than 0.05. A dashed red line, marking p = 0.05, serves as a reference point for statistical significance. **Figure B:** Two dashed lines of significance are evident on the graph: a red line marking the adopted significance threshold of p = 0.05 and a green line indicating the mean p-value of 0.0649 for our data.

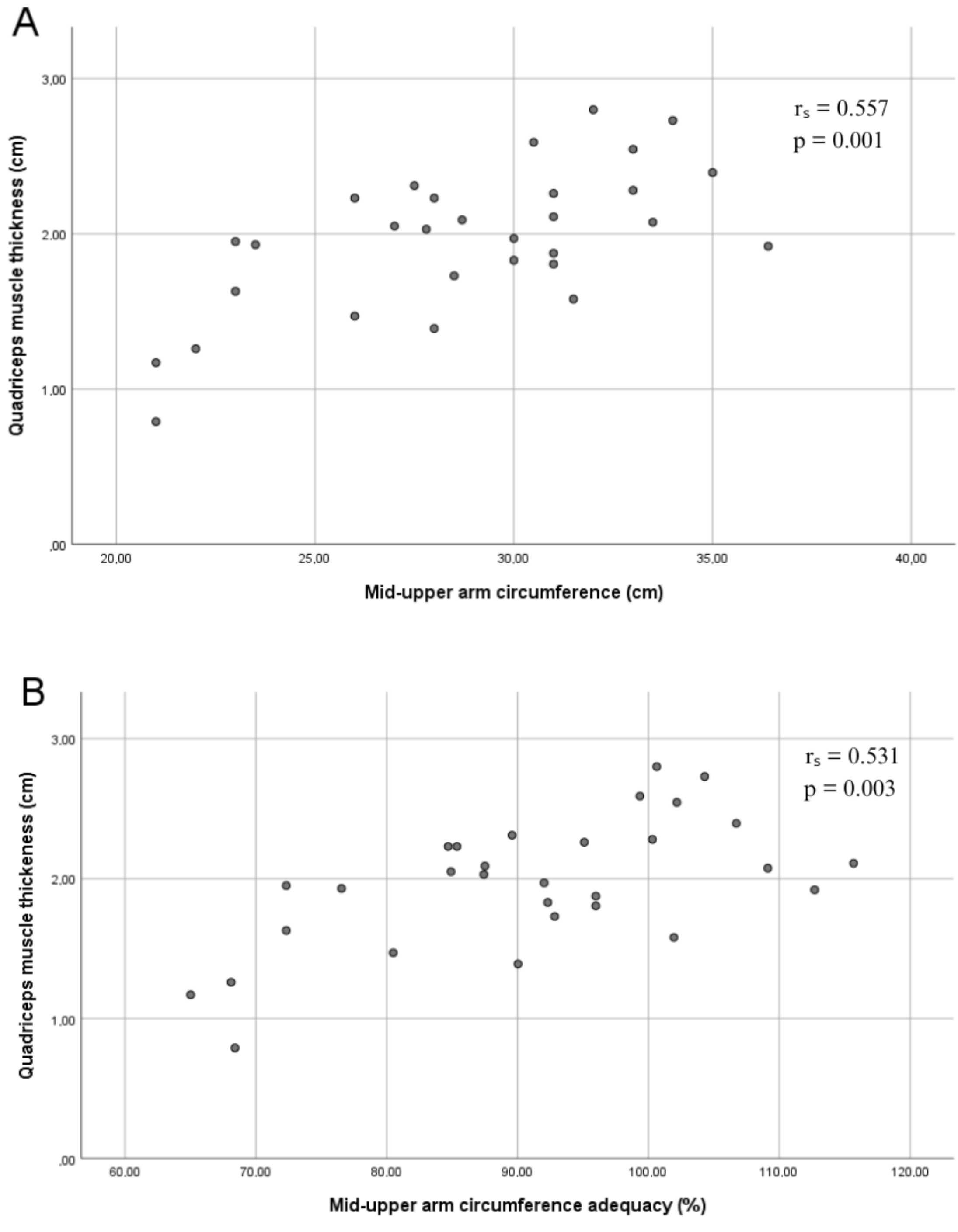


Figure 7. **Figure A:** Scatter plot illustrating the relationship between quadriceps muscle thickness (cm) and the mid-upper arm circumference (cm). **Figure B:** Scatter plot illustrating the association between quadriceps muscle thickness (cm) and the mid-upper arm circumference adequacy (%). Each data point represents an individual measurement. The significance level was set at $p < 0.05$.