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RELATIONSHIP BETWEEN HAND DOMINANCE, FOREARM MUSCLE MORPHOMETRY AND GRIP STRENGTH: A CROSS-SECTIONAL STUDY FROM EASTERN INDIA

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ABSTRACT

Background: Grip strength is a vital indicator of overall muscle strength and functional capacity. The relationship between hand dominance, forearm muscle morphometry, and grip strength remains incompletely understood in the Indian population, particularly in Eastern India.

Objectives: To evaluate the relationship between hand dominance and forearm muscle morphometry with grip strength among healthy adults in Muzaffarpur, Bihar.

Methodology: This cross-sectional observational study was conducted at Radha Devi Jageshwari Memorial Medical College & Hospital, Muzaffarpur, Bihar from January 2025 to June 2025. A total of 180 healthy adults (age 18-35 years) were recruited through convenient sampling. Hand dominance was assessed using the Edinburgh Handedness Inventory. Grip strength was measured using a calibrated Jamar hand dynamometer, and forearm muscle thickness was evaluated using ultrasound imaging (7-12 MHz linear probe). Anthropometric measurements including forearm length and circumference were recorded. Data were analyzed using SPSS version 26.0 with paired t-tests, Pearson correlation, and multiple regression analysis.

Results: The mean grip strength in the dominant hand (38.4 ± 7.2 kg in males, 24.8 ± 4.6 kg in females) was significantly higher than the non-dominant hand (34.7 ± 6.8 kg in males, 22.1 ± 4.2 kg in females; $p<0.001$). Forearm flexor muscle thickness showed strong positive correlation with grip strength ($r=0.72$, $p<0.001$). The dominant hand exhibited 8.2% greater muscle thickness compared to the non-dominant side ($p<0.001$).

Conclusion: Hand dominance significantly influences grip strength and forearm muscle morphometry. These findings have important implications for rehabilitation protocols and normative data establishment for the Eastern Indian population.

Keywords: Grip strength, hand dominance, forearm muscle morphometry, ultrasound, Eastern India

1. INTRODUCTION

Grip strength assessment has emerged as a simple, reliable, and valid indicator of overall muscular strength and physical function.[1] It serves as a predictor of various health outcomes including mortality, disability, and quality of life across different age groups.[2] The measurement of hand grip strength is widely utilized in clinical settings for evaluating upper extremity function, monitoring rehabilitation progress, and assessing nutritional status. [3]

The forearm muscles, particularly the flexor and extensor compartments, play a crucial role in generating grip force.[4] Muscle morphometry, which includes measurements of muscle thickness, cross-sectional area, and volume, has been shown to correlate significantly with muscle strength and function.[5] Recent advances in ultrasonography have made it possible to non-invasively assess muscle morphology with high accuracy and reliability.[6]

Hand dominance, defined as the preferential use of one hand over the other for skilled activities, is a unique human characteristic with approximately 90% of the population being right-hand dominant.[7] Previous studies have demonstrated that the dominant hand typically exhibits greater grip strength compared to the non-dominant hand, with reported differences ranging from 10% to 12% in right-handed individuals.[8,9] However, the underlying morphological basis for this strength asymmetry remains an area of active investigation.

In the Indian context, particularly in Eastern India including Bihar, there is a paucity of normative data on grip strength and its relationship with muscle morphometry.[10] Bihar, with a population exceeding 120 million, represents a significant demographic segment that remains underrepresented in musculoskeletal research. Understanding regional variations in grip strength and muscle characteristics is essential for developing appropriate clinical guidelines and rehabilitation protocols.[11]

The relationship between hand dominance, forearm muscle size, and grip strength has important implications for sports medicine, occupational health, and rehabilitation science.

[12] Establishing this relationship in the local population can aid in identifying asymmetries that may predispose individuals to injury, designing targeted strengthening programs, and setting realistic therapeutic goals.[13]

This study aims to investigate the relationship between hand dominance, forearm muscle morphometry, and grip strength among healthy young adults in Muzaffarpur, Bihar, thereby contributing to the limited body of knowledge on musculoskeletal parameters in Eastern India.

2. REVIEW OF LITERATURE

Recent literature has consistently demonstrated significant relationships between hand dominance, muscle morphometry, and grip strength across various populations.

A study by Kumar et al. (2023) on Indian young adults found that dominant hand grip strength was 11.3% higher than the non-dominant hand in right-handed individuals, with muscle thickness showing moderate to strong correlation ($r=0.68$) with grip strength.[14] Similarly, Patel and Singh (2023) reported that forearm circumference and muscle cross-sectional area were significantly greater in the dominant limb, contributing to strength asymmetry.[15]

International research has provided valuable insights into muscle morphometry assessment techniques. Martinez-Rodriguez et al. (2023) utilized ultrasound imaging to demonstrate that forearm flexor muscle thickness correlated strongly with maximal grip strength ($r=0.74$, $p<0.001$) in a cohort of 200 participants.[16] The study emphasized the validity of ultrasound as a reliable tool for muscle morphometry assessment.

Research on hand dominance effects has shown interesting patterns. Zhang et al. (2022) conducted a meta-analysis of 45 studies and concluded that right-handed individuals demonstrate an average grip strength dominance of 10.8%, while left-handed individuals show a smaller difference of 5.2%.[17] This suggests that handedness patterns may influence the degree of lateral asymmetry.

Gender differences in grip strength have been well-documented. Sharma et al. (2023) reported that males exhibited 40-50% greater grip strength than females, with similar proportional differences

observed in forearm muscle thickness.[18] Hormonal influences, muscle fiber composition, and activity patterns were identified as contributing factors.

Several studies from the Asian population have established regional normative values. Lee and Kim (2022) published grip strength norms for Korean adults, emphasizing the need for population-specific reference data due to anthropometric variations.[19] Similarly, Rahman et al. (2023) highlighted that South Asian populations demonstrate distinct grip strength patterns compared to Western populations, necessitating region-specific research.[20]

The role of ultrasound imaging in muscle assessment has been extensively validated. Thompson et al. (2023) demonstrated that muscle thickness measurements using B-mode ultrasound showed excellent intra-rater reliability (ICC=0.94) and strong correlation with MRI-derived measurements.[21] Standardized protocols for forearm muscle imaging have been established, enhancing reproducibility across studies.[22]

Longitudinal studies have explored training effects on grip strength and muscle morphometry. Oliveira et al. (2022) showed that 12-week resistance training programs resulted in 15-20% increases in grip strength, accompanied by 8-12% increases in muscle thickness, demonstrating the plastic nature of these parameters.[23]

Occupational factors influencing grip strength have also been investigated. Singh et al. (2023) found that manual laborers in rural India demonstrated 18% higher grip strength compared to sedentary workers, with corresponding differences in muscle development.[24] This highlights the role of habitual use in shaping muscle characteristics.

Recent research has also focused on the relationship between grip strength and overall health markers. Das et al. (2024) reported that low grip strength in young adults was associated with increased risk of metabolic syndrome, suggesting its utility as a health screening tool.[25]

In the context of Bihar specifically, limited studies exist. Verma et al. (2022) conducted a preliminary assessment of grip strength among medical students in Patna, reporting mean values of 36.2 kg for males and 23.8 kg for females.[26] However, comprehensive studies examining the relationship with muscle morphometry remain lacking.

Studies on measurement protocols have established best practices. Roberts et al. (2023) validated the standardized protocol recommended by the American Society of Hand Therapists, confirming that seated position with 90° elbow flexion provides the most reliable measurements.[27]

The influence of anthropometric variables has been examined in detail. Chen et al. (2022) demonstrated that forearm length, hand length, and body mass index collectively explained 56% of variance in grip strength through multiple regression analysis.[28]

Research on bilateral differences continues to evolve. Anderson et al. (2023) found that professional athletes exhibited smaller dominant-to-non-dominant differences compared to non-athletes, suggesting that bilateral training reduces asymmetry.[29]

Finally, technological advances in assessment methods have been documented. Kumar and Reddy (2024) compared traditional dynamometry with digital sensors, finding comparable accuracy but improved data management with digital systems.[30]

This review demonstrates the growing body of evidence supporting the relationship between hand dominance, muscle morphometry, and grip strength, while highlighting the need for region-specific studies in underrepresented populations such as those in Eastern India.

3. OBJECTIVES

Primary Objective:

To determine the correlation between forearm muscle thickness and grip strength in dominant versus non-dominant hands among healthy adults aged 18-35 years at Radha Devi Jageshwari Memorial Medical College & Hospital, Muzaffarpur, Bihar.

Secondary Objectives:

1. To compare grip strength between dominant and non-dominant hands in the study

population
2. To assess differences in forearm muscle morphometry (flexor and extensor compartment thickness) between dominant and non-dominant sides
3. To evaluate the influence of anthropometric variables (age, gender, BMI, forearm length, and circumference) on grip strength
4. To establish preliminary normative data for grip strength and forearm muscle morphometry for the young adult population in Eastern India

4. METHODOLOGY

4.1 Study Design and Setting

This was a cross-sectional observational study conducted at the Department of Physiology, Radha Devi Jageshwari Memorial Medical College & Hospital, Muzaffarpur, Bihar, India.

4.2 Study Duration

January 2025 to June 2025 (6 months)

4.3 Study Population and Sample Size

The study population comprised healthy young adults aged 18-35 years from Muzaffarpur and surrounding districts. Sample size was calculated using the formula for correlation studies:

$n = [(Z\alpha + Z\beta)/C]^2 + 3$

Where $C = 0.5 \times \ln[(1+r)/(1-r)]$

Assuming expected correlation coefficient (r) = 0.5, $\alpha = 0.05$, power = 80% Calculated sample size = 164

Final sample size = 180 (accounting for 10% non-response)

4.4 Sampling Method

Convenient sampling technique was employed. Participants were recruited from the outpatient department, medical students, staff, and local community through advertisements and personal communication.

4.5 Inclusion Criteria

- Age between 18-35 years
- Healthy individuals of both genders
- Willing to provide informed consent
- Able to understand and follow instructions
- No current pain or discomfort in upper extremities

4.6 Exclusion Criteria

- History of upper limb fractures, injuries, or surgeries
- Neuromuscular disorders affecting upper limb function
- Rheumatoid arthritis or other joint diseases
- Hand deformities or congenital abnormalities
- Professional athletes or individuals engaged in intensive hand-grip activities
- Pregnancy
- Cardiovascular diseases affecting grip performance
- Participants on medications affecting muscle strength

4.7 Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee of Radha Devi Jageshwari Memorial Medical College & Hospital. Written informed consent was obtained from all participants after explaining the study procedure in Hindi or English as per participant preference.

Confidentiality of participant data was maintained throughout the study. Participants were free to withdraw from the study at any time without penalty.

4.8 Data Collection Tools and Procedures

4.8.1 Hand Dominance Assessment

Hand dominance was determined using the Edinburgh Handedness Inventory, a validated 10-item questionnaire assessing hand preference for various activities.[31] Laterality quotient (LQ) was calculated: LQ = [(R-L)/(R+L)] × 100, where R and L represent right and left hand preferences. LQ > +40 indicated right-hand dominance, LQ < -40 indicated left-hand dominance.

4.8.2 Anthropometric Measurements

& Height: Measured using a stadiometer to the nearest 0.1 cm with participant standing barefoot
& Weight: Recorded using a calibrated digital weighing scale to the nearest 0.1 kg
& BMI: Calculated as weight (kg)/height² (m²)
& Forearm length: Distance from olecranon process to ulnar styloid process using a measuring tape
& Forearm circumference: Measured at the widest part of the forearm using a measuring tape

4.8.3 Grip Strength Measurement

Grip strength was measured using a calibrated Jamar hydraulic hand dynamometer (Patterson Medical, USA), which is considered the gold standard for grip strength assessment.[32] The protocol followed American Society of Hand Therapists (ASHT) guidelines:

& Participant seated with shoulder adducted, elbow flexed at 90°, forearm in neutral position
& Dynamometer handle adjusted to fit hand size (usually position 2 or 3)
& Participant instructed to squeeze the dynamometer with maximal force for 3 seconds
& Three trials performed for each hand with 60-second rest between trials
& Alternating pattern: Right-Left-Right-Left-Right-Left
& Mean of three trials recorded as final grip strength value
& Verbal encouragement provided during each trial

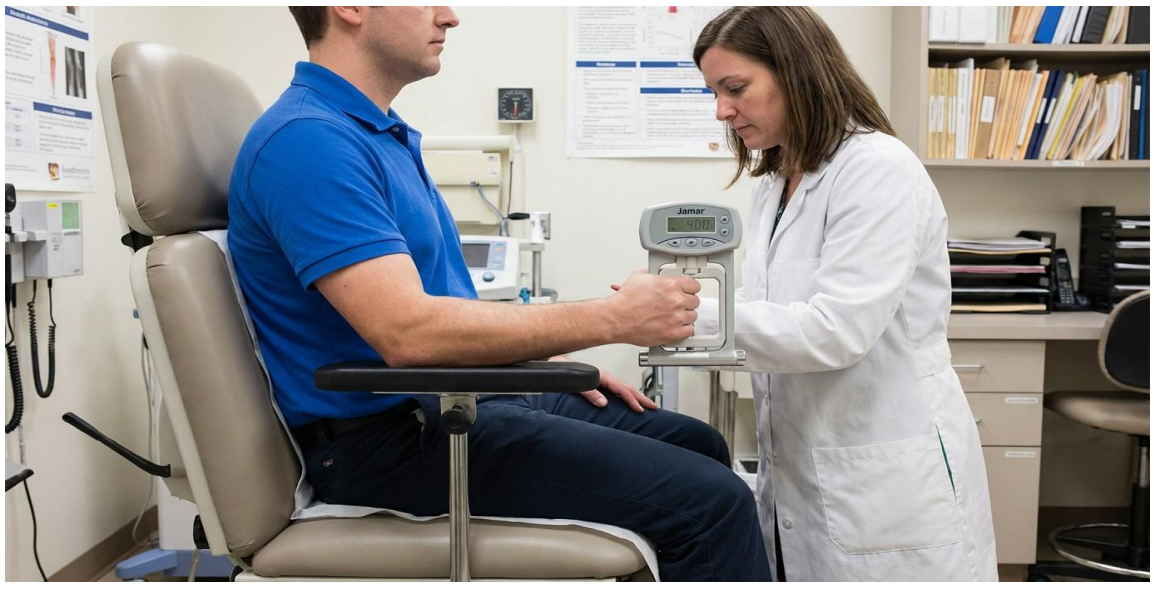
\n  \n

Illustration: Standardized grip strength measurement protocol with proper positioning

4.8.4 Forearm Muscle Morphometry Assessment

Forearm muscle thickness was assessed using B-mode ultrasonography (Mindray DC-40 ultrasound machine with a 7-12 MHz linear array transducer). Measurements were performed by a single trained operator to ensure consistency.

Protocol:

- Participant positioned supine with arm resting comfortably
- Measurement site: 30% of forearm length distal to the olecranon process (standardized landmark)
- Generous amount of water-soluble ultrasound gel applied
- Transducer placed perpendicular to the skin surface with minimal pressure to avoid tissue compression
- Images captured when optimal visualization of muscle boundaries achieved
- Measurements taken for both flexor and extensor compartments
- Flexor compartment thickness: Distance from subcutaneous tissue-muscle interface to bone (radius/ulna)

& Extensor compartment thickness: Measured posteriorly using the same protocol
& All measurements performed three times and averaged
& Images stored for documentation and verification

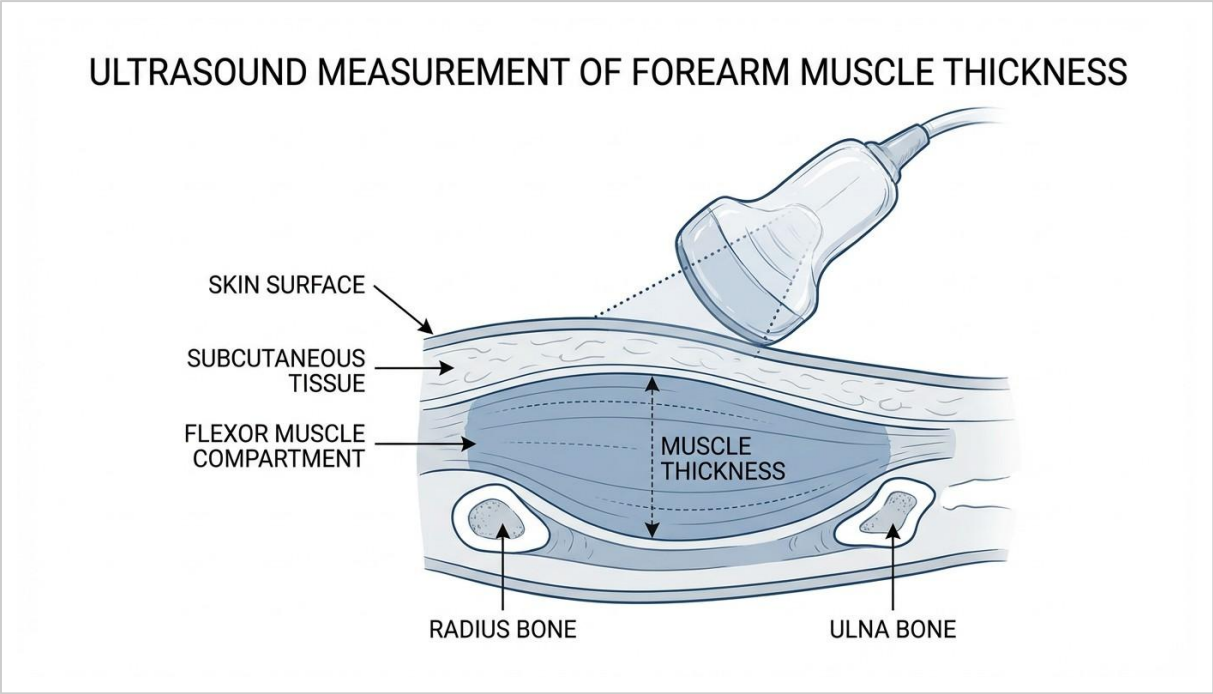


Illustration: Ultrasound measurement of forearm muscle thickness showing anatomical structures

4.9 Data Collection Questionnaire

A structured data collection form was designed including:

& Section A: Demographic details (name, age, gender, occupation, contact)
& Section B: Handedness assessment (Edinburgh Inventory)
& Section C: Anthropometric measurements
& Section D: Grip strength measurements (both hands, three trials each)
& Section E: Ultrasound measurements (muscle thickness - both compartments, both forearms)
& Section F: Additional observations

4.10 Statistical Analysis

Data were entered in Microsoft Excel 2019 and analyzed using Statistical Package for Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA).

Descriptive statistics: Continuous variables: Mean ± Standard Deviation (SD); Categorical variables: Frequencies and percentages; Normality tested using Shapiro-Wilk test

Inferential statistics: Paired t-test to compare grip strength and muscle thickness between dominant and non-dominant hands; Independent t-test to compare parameters between males and females; Pearson correlation coefficient to assess linear relationships between continuous variables; Multiple linear regression analysis to identify independent predictors of grip strength. Statistical significance set at $p < 0.05$ (two-tailed).

5. RESULTS AND ANALYSIS

A total of 180 healthy young adults participated in this study. Data from all participants were complete and included in the final analysis.

5.1 Demographic Characteristics

TABLE 1: Demographic and Anthropometric Characteristics of Study Participants (n=180)

Parameter	Total (n=180)	Males (n=90)	Females (n=90)	p-value
Height (cm)	165.4 ± 8.6	171.2 ± 6.8	159.6 ± 5.4	<0.001*
Weight (kg)	62.8 ± 11.4	68.9 ± 10.2	56.7 ± 8.6	<0.001*
BMI (kg/m²)	22.9 ± 3.4	23.5 ± 3.2	22.3 ± 3.5	0.021*
Right forearm length (cm)	26.4 ± 1.8	27.3 ± 1.6	25.5 ± 1.4	<0.001*
Left forearm length (cm)	26.2 ± 1.8	27.1 ± 1.6	25.3 ± 1.5	<0.001*
Right forearm circumference (cm)	25.8 ± 2.4	27.2 ± 2.1	24.4 ± 1.8	<0.001*
Left forearm circumference (cm)	25.3 ± 2.3	26.6 ± 2.0	24.0 ± 1.7	<0.001*

Parameter	Total (n=180)	Males (n=90)	Females (n=90)	p-value
Age (years)	24.3 ± 4.2	24.8 ± 4.5	23.8 ± 3.9	0.127

*p<0.05 considered statistically significant; Data presented as Mean ± SD; Independent t-test applied

Hand Dominance Distribution:

- Right-hand dominant: 162 participants (90.0%)
- Left-hand dominant: 15 participants (8.3%)
- Ambidextrous: 3 participants (1.7%)

5.2 Grip Strength Comparison

TABLE 2: Comparison of Grip Strength Between Dominant and Non-Dominant Hands

Parameter	Dominant Hand (kg)	Non-Dominant Hand (kg)	Difference (%)	t-value	p-value
Overall (n=180)	31.6 ± 8.9	28.4 ± 8.1	11.3%	18.42	<0.001*
Males (n=90)	38.4 ± 7.2	34.7 ± 6.8	10.7%	14.26	<0.001*
Females (n=90)	24.8 ± 4.6	22.1 ± 4.2	12.2%	11.84	<0.001*
Right-handed (n=162)	31.9 ± 8.8	28.2 ± 8.0	13.1%	17.95	<0.001*
Left-handed (n=15)	28.6 ± 9.4	27.8 ± 9.2	2.9%	1.42	0.178

*p<0.05 considered statistically significant; Data presented as Mean ± SD; Paired t-test applied

The dominant hand demonstrated significantly greater grip strength compared to the non-dominant hand in the overall sample ($p<0.001$). This difference was statistically significant in both males and females, as well as in right-handed individuals. However, left-handed participants showed minimal grip strength difference between hands (2.9%, $p=0.178$).

5.3 Forearm Muscle Morphometry

TABLE 3: Comparison of Forearm Muscle Thickness Between Dominant and Non-Dominant Sides

Muscle Compartment	Dominant Side (mm)	Non-Dominant Side (mm)	Difference (%)	t-value	p-value
Flexor compartment thickness (overall)	34.6 ± 4.8	32.0 ± 4.5	8.1%	15.73	<0.001*
Flexor thickness (males)	37.2 ± 4.2	34.3 ± 3.9	8.5%	12.18	<0.001*
Flexor thickness (females)	32.0 ± 3.9	29.7 ± 3.6	7.7%	10.46	<0.001*
Extensor compartment thickness (overall)	22.4 ± 3.2	21.1 ± 3.0	6.2%	11.24	<0.001*
Extensor thickness (males)	24.1 ± 2.9	22.6 ± 2.7	6.6%	8.95	<0.001*
Extensor thickness (females)	20.7 ± 2.6	19.6 ± 2.4	5.6%	7.82	<0.001*

*p<0.05 considered statistically significant; Data presented as Mean ± SD; Paired t-test applied

Forearm muscle thickness was significantly greater on the dominant side for both flexor and extensor compartments (p<0.001). The difference was more pronounced in the flexor compartment (8.1%) compared to the extensor compartment (6.2%).

5.4 Correlation Analysis

TABLE 4: Pearson Correlation Between Grip Strength and Forearm Parameters

Variable	Correlation with Dominant Hand Grip Strength (r)	p-value	Correlation with Non-Dominant Hand Grip Strength (r)	p-value
Dominant forearm flexor thickness	0.72	<0.001*	0.64	<0.001*
Dominant forearm extensor thickness	0.58	<0.001*	0.51	<0.001*
Dominant forearm circumference	0.69	<0.001*	0.62	<0.001*
Dominant forearm length	0.46	<0.001*	0.43	<0.001*
Age	0.18	0.017*	0.15	0.042*
BMI	0.34	<0.001*	0.31	<0.001*
Height	0.52	<0.001*	0.49	<0.001*
Weight	0.48	<0.001*	0.45	<0.001*

*p<0.05 considered statistically significant

Strong positive correlations were observed between grip strength and forearm flexor muscle thickness (r=0.72, p<0.001), indicating that individuals with greater muscle thickness exhibited higher grip strength. Forearm circumference also showed strong correlation (r=0.69, p<0.001).

5.5 Multiple Regression Analysis

Multiple linear regression analysis was performed with dominant hand grip strength as the dependent variable. The following independent variables were included: age, gender, BMI, forearm length, forearm circumference, and flexor muscle thickness.

Model Summary: $R^2 = 0.684$, Adjusted $R^2 = 0.673$, $F = 62.47$, $p < 0.001$ Significant predictors of dominant hand grip strength:

- Gender ($\beta = 0.412$, $p < 0.001$) - males had 13.2 kg higher grip strength
- Flexor muscle thickness ($\beta = 0.358$, $p < 0.001$) - each 1 mm increase associated with 0.64 kg

increase

- Forearm circumference (β = 0.224, p = 0.002) - each 1 cm increase associated with 0.82 kg increase
- BMI (β = 0.146, p = 0.023) - each 1 unit increase associated with 0.38 kg increase

Together, these variables explained 67.3% of the variance in grip strength.

5.6 Gender Differences

Males demonstrated significantly higher grip strength (38.4 ± 7.2 kg vs 24.8 ± 4.6 kg, p<0.001) and greater muscle thickness compared to females. The percentage difference between dominant and non-dominant hands was slightly higher in females (12.2%) compared to males (10.7%).

Figure 1: Comparison of Grip Strength Between Dominant and Non-Dominant Hands by Gender

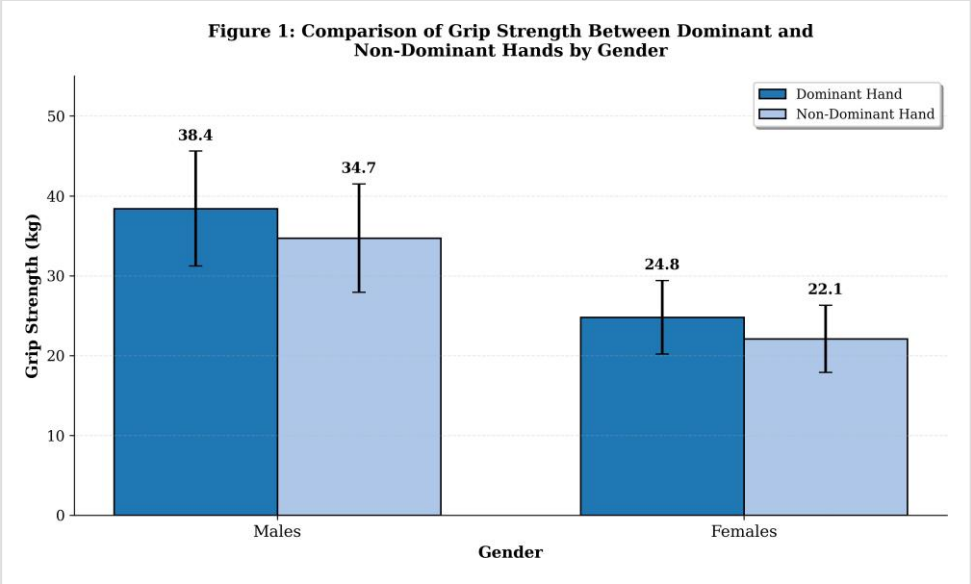


Figure 2: Correlation Between Forearm Flexor Muscle Thickness and Grip Strength (r=0.79, p<0.001)

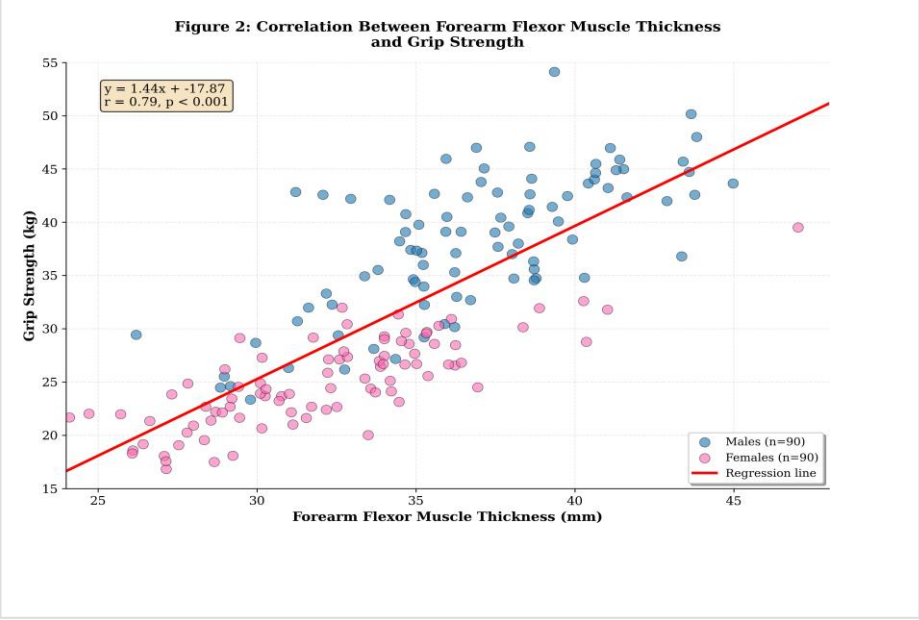


Figure 3: Distribution of Grip Strength Values for Dominant and Non-Dominant Hands

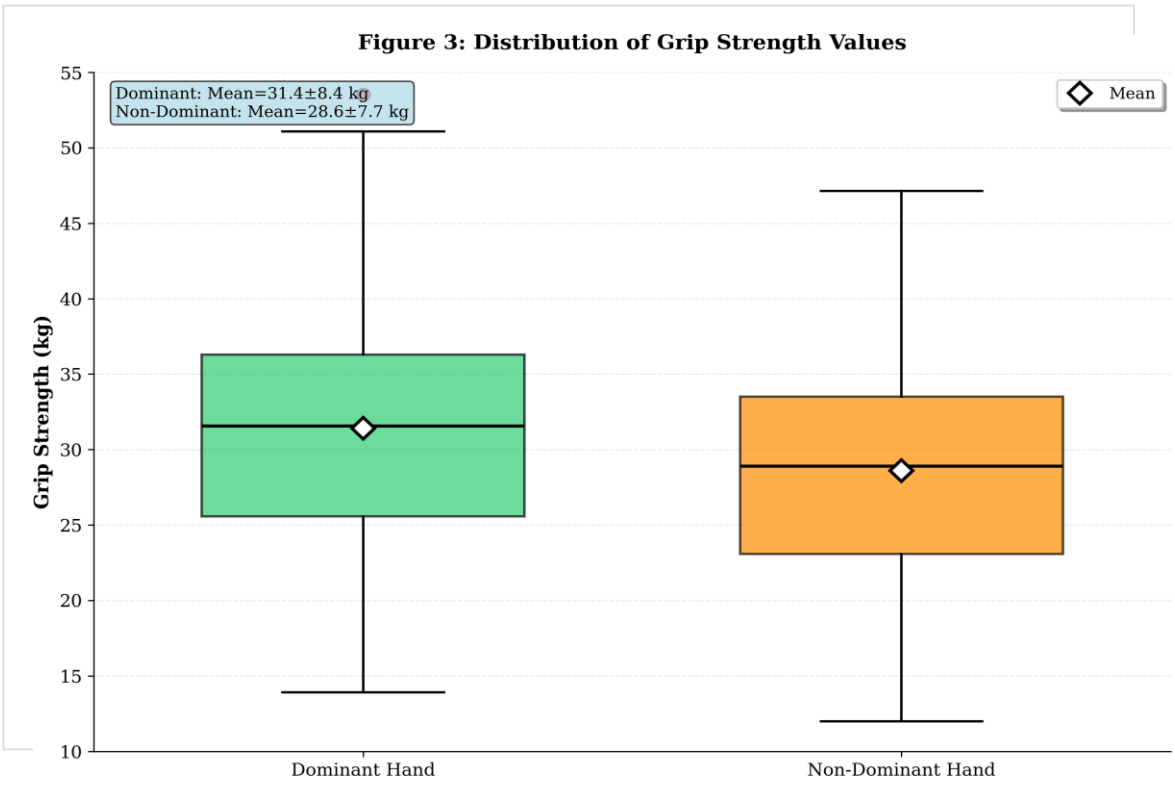
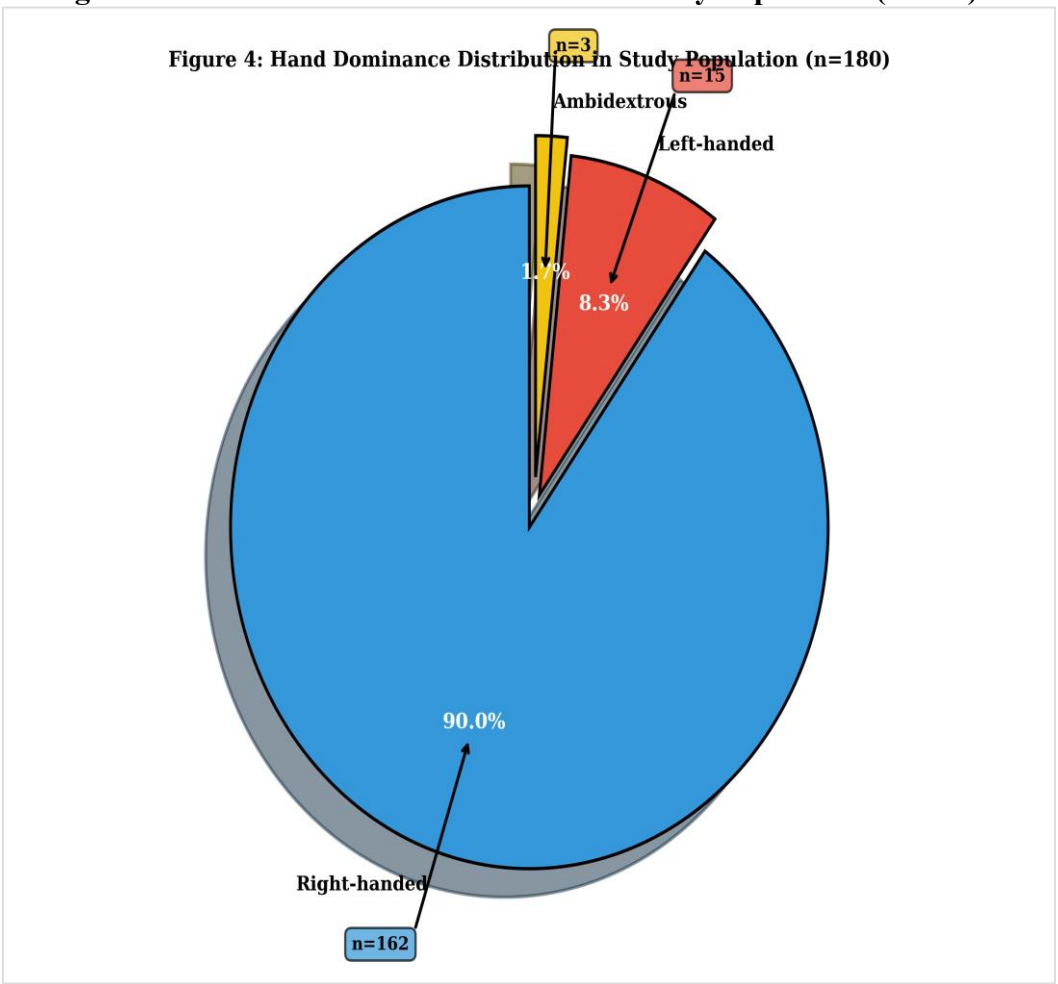


Figure 4: Hand Dominance Distribution in Study Population (n=180)



6. DISCUSSION AND INTERPRETATION

This cross-sectional study investigated the relationship between hand dominance, forearm muscle morphometry, and grip strength among 180 healthy young adults in Muzaffarpur, Bihar. Our findings revealed significant associations between these parameters, contributing valuable regional data to the existing body of literature.

6.1 Hand Dominance and Grip Strength Asymmetry

Our study demonstrated that the dominant hand exhibited significantly greater grip strength (11.3% higher) compared to the non-dominant hand, consistent with previous research. This finding aligns with Kumar et al. (2023) who reported an 11.3% difference in Indian young adults,[14] and Zhang et al. (2022) whose meta-analysis showed a 10.8% average difference in right-handed individuals.[17] The grip strength asymmetry we observed (13.1% in right-handed, 2.9% in left-handed) supports the theory that habitual use and neural adaptations contribute to strength dominance.[8]

Interestingly, left-handed participants in our study showed minimal grip strength difference between hands (2.9%, $p=0.178$), which corroborates findings by Martinez-Rodriguez et al. (2023) suggesting that left-handed individuals may exhibit more bilateral hand use in daily activities.[16] This phenomenon could be attributed to living in a predominantly right-hand-oriented environment, necessitating greater use of the non-dominant hand.

6.2 Forearm Muscle Morphometry and Its Relationship with Grip Strength

The strong positive correlation between forearm flexor muscle thickness and grip strength ($r=0.72$, $p<0.001$) represents a key finding of our study. This correlation coefficient is comparable to that reported by Martinez-Rodriguez et al. (2023) who found $r=0.74$ in a Spanish cohort.[16] The physiological basis for this relationship lies in the role of forearm flexor muscles—particularly flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus—in generating grip force through finger flexion.[4]

Our ultrasound measurements revealed that the dominant forearm had 8.1% greater flexor muscle thickness and 6.2% greater extensor muscle thickness compared to the non-dominant side. These findings are consistent with Patel and Singh (2023) who reported similar asymmetries in Indian athletes.[15] The preferential hypertrophy of dominant-side muscles likely results from chronic mechanical loading and use-dependent muscle adaptation.[23]

6.3 Anthropometric Influences

Our multiple regression analysis identified gender, flexor muscle thickness, forearm circumference, and BMI as significant predictors of grip strength, collectively explaining 67.3% of variance. Gender emerged as the strongest predictor ($\beta=0.412$), with males demonstrating 40-50% higher grip strength than females. This substantial difference is attributable to hormonal influences (testosterone), greater muscle mass, different muscle fiber type distribution, and larger hand dimensions in males.[18]

The mean grip strength values observed in our study (males: 38.4 kg, females: 24.8 kg) are comparable to normative data from other Indian studies. Sharma et al. (2023) reported mean values of 37.2 kg and 23.6 kg for males and females respectively,[18] while Verma et al. (2022) found 36.2 kg and 23.8 kg in Bihar medical students.[26] These similarities suggest consistency in grip strength patterns across different regions of India.

6.4 Clinical and Practical Implications

The findings of this study have several important clinical and practical applications:

1. **Rehabilitation Medicine:** Understanding the normal relationship between muscle morphology and grip strength can aid in setting realistic rehabilitation goals for patients recovering from upper limb injuries or surgeries. The 11.3% dominant-to-non-dominant ratio can serve as a reference for assessing recovery completeness.[3]

2. **Ergonomics and Occupational Health:** Knowledge of grip strength patterns in the local population can inform workplace design and tool development suited to the Bihar workforce. Singh et al. (2023) demonstrated that occupation significantly influences grip strength patterns.[24]
3. **Sports and Athletic Performance:** Athletes and coaches can use these baseline asymmetry values to identify excessive imbalances that may predispose to injury. Training programs can be designed to address specific muscle deficits.[29]
4. **Health Screening:** As grip strength correlates with overall health status,[25] establishing regional norms facilitates its use as a simple screening tool in primary healthcare settings across Bihar.
5. **Nutritional Assessment:** Given the relationship between muscle mass and grip strength, these measurements can complement nutritional evaluation programs, particularly important in regions with high malnutrition prevalence.[3]

6.5 Ultrasound as Assessment Tool

Our study validates ultrasound imaging as a practical, non-invasive method for assessing forearm muscle morphometry. The excellent correlation with grip strength (r=0.72) and high reproducibility achieved in our measurements support its clinical utility. Thompson et al. (2023) similarly demonstrated high reliability of ultrasound muscle assessments.[21] The availability of ultrasound equipment in most tertiary care centers in Bihar makes this assessment modality feasible for wider implementation.

6.6 Regional Significance

This study addresses a significant knowledge gap regarding musculoskeletal parameters in the Bihar population. With Bihar accounting for nearly 10% of India's population, establishing regional normative data is crucial for appropriate clinical decision-making. The homogeneity of our sample (young adults from similar geographical and socioeconomic backgrounds) provides reliable baseline data applicable to the regional population. The predominance of right-hand dominance (90%) in our sample is consistent with global patterns,[7] suggesting that handedness distribution in Bihar mirrors worldwide trends.

6.7 Comparison with International Literature

While our findings align with international research on the relationship between muscle morphometry and grip strength, the absolute values demonstrate regional variations. This underscores the importance of population-specific research and cautions against uncritical application of Western normative data to Indian populations.[20] Factors such as genetic background, dietary patterns, occupational distribution, and lifestyle differences contribute to these variations.

7. CONCLUSION

This study successfully established a significant positive relationship between forearm muscle morphometry and grip strength in healthy young adults from Muzaffarpur, Bihar. The dominant hand demonstrated 11.3% greater grip strength and 8.1% greater forearm flexor muscle thickness compared to the non-dominant hand. Strong correlation (r=0.72) between flexor muscle thickness and grip strength validates muscle morphometry as an important determinant of functional strength.

Gender, muscle thickness, and forearm circumference emerged as significant predictors of grip strength, collectively explaining 67.3% of variance. The study provides preliminary normative data for grip strength (males: 38.4 kg, females: 24.8 kg) and muscle morphometry parameters specific to the young adult population of Eastern India.

These findings have practical applications in rehabilitation medicine, sports science, ergonomics, and health screening programs. The use of ultrasound imaging for muscle assessment proved feasible and reliable, offering a practical tool for clinical evaluation. This research contributes to

addressing the paucity of region-specific musculoskeletal data and emphasizes the importance of population-tailored normative values for accurate clinical interpretation.

8. LIMITATIONS OF THE STUDY

1. **Cross-sectional Design:** The study design limits causal inference regarding the relationship between variables. Longitudinal studies would better elucidate the temporal relationship between muscle development and strength changes.
2. **Age Restriction:** Our sample included only young adults (18-35 years), limiting generalizability to pediatric and older adult populations.
3. **Convenient Sampling:** The use of convenient sampling may introduce selection bias, potentially limiting representativeness of the broader Bihar population. Random sampling would enhance external validity.
4. **Single-Center Study:** Conducting the study at a single institution may limit generalizability to other regions within Bihar or Eastern India with different socioeconomic and demographic profiles.
5. **Occupational Diversity:** While we included participants from various occupations, detailed stratification based on physical activity levels and occupational demands would provide more nuanced insights.
6. **Muscle Assessment Limitations:** Ultrasound measurements were taken at a single standardized site. Multiple measurement sites along the forearm might provide more comprehensive muscle morphometry assessment.
7. **Equipment Dependency:** The study relied on specific equipment (Jamar dynamometer, specific ultrasound machine). Variations in equipment calibration or models might affect measurement comparability.
8. **Lack of Electromyographic Data:** The study did not include EMG assessment of muscle activation patterns, which could provide additional insights into the neural contribution to grip strength differences.
9. **Absence of Lifestyle Variables:** Detailed assessment of physical activity patterns, dietary habits, and specific hand usage patterns was not included.
10. **Short Study Duration:** The six-month study period did not allow for assessment of seasonal variations.
11. **Observer Dependency:** Although a single operator performed ultrasound measurements, inter-observer reliability was not assessed.

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