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Variation of Grip Strength and Wrist Range of Motion with Forearm Rotation in Healthy Young Volunteers Aged 23 to 30

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Abstract

Background Grip strength and wrist range of motion (ROM) are important metrics used to evaluate hand rehabilitation and outcomes of wrist interventions. Published normative data on these metrics do not recognize the contribution of forearm rotation. This study aims to identify and quantify variations in grip strength and wrist ROM with forearm rotation in healthy young individuals.

Materials and Methods Wrist ROM and grip strength were measured in 30 healthy volunteers aged 23 to 30. Participant demographics, grip strength, and wrist ROM (wrist flexion and extension, ulnar and radial deviation) at three forearm positions (full supination, neutral, and full pronation) were measured using a digital dynamometer and standard goniometers. Data analysis was conducted using a one-way repeated measure ANOVA. Forearm position values were compared using post hoc analysis.

Results Grip strength in males was greatest in neutral position (males: nondominant 51.4 kg, dominant 56.1 kg) followed by supination (males: nondominant 46.6 kg, dominant 51.7 kg) and weakest in pronation (males: nondominant 40.1 kg, dominant 42.9 kg). Grip strength in females was similar between supination (nondominant: 26.1 kg, dominant: 28.5 kg) and neutral (nondominant: 27.4 kg, dominant: 29.1 kg) positions, but both were greater than in pronation (nondominant: 22.3 kg, dominant: 24.1 kg). Wrist flexion in males was significantly reduced in supination compared with neutral and pronated positions (nondominant: supination 63.1°, neutral 72.6°, pronation 73.3°; dominant: supination 62.4°, neutral 70.2°, pronation 70.3°), whereas not significant wrist flexion in females was also weaker in supination (supination 74.4°, neutral 79.9°). Wrist extension in males was greater in pronation (supination 64.6°, pronation 69.5°) whereas females showed no significant difference in any of the forearm positions. Ulnar deviation in males did not differ with forearm position, but females demonstrated greater ulnar deviation in supination on the nondominant hand (supination 44.6°, pronation 33.2°). Whereas there was no difference in radial deviation with forearm position in females, it was markedly greater in pronation versus supination on both sides in males (nondominant: supination 16.3°, pronation 24.6°; dominant: supination 15.4°, pronation 23.9°).

Keywords
► wrist motion
► grip strength
► functional range
► rehabilitation

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Conclusion This study characterizes variations in grip strength and wrist ROM in three forearm positions in healthy young individuals. All measurements differed with forearm rotation and were not influenced by hand dominance. These results suggest that wrist ROM and grip strength should be evaluated in different positions of forearm rotation, rather than a fixed position. This has functional implications particularly in patients involved with specialized activities such as sports, instrument-playing, or work-related activities.

Introduction

Hand grip strength and wrist range of motion (ROM) are two measurements commonly used to assess clinical progress during rehabilitation after hand and wrist injury. These measurements are made by dynamometry and goniometry, respectively. Typically, the contralateral limb is used as a standard of comparison in assessing the wrist undergoing rehabilitation. However, it has been shown that there are side-to-side discrepancies between measurements even in the absence of injury or intervention, and therefore the contralateral side often may not serve as a reliable control.[1] Consequently, normative values of these parameters have been measured and published by several authors in a variety of populations to provide a more consistent reference.[2,3] It has also been shown that wrist ROM is significantly affected by forearm rotation, yet most of the current ROM data available were measured with the forearm in neutral position.[4] It has been demonstrated that the functional ROM of the wrist required to perform activities of daily living (ADLs) is actually quite minimal; however, specialized tasks such as playing musical instruments, playing sports, or performing work-related activities requires a much greater range, often with the wrist in either full pronation or supination.[5,6] It is therefore important to understand the functional abilities of the wrist throughout the full range of forearm rotation to relate its assessment in rehabilitation to its ability to perform tasks. The objective of this study is to characterize the variation in grip strength and wrist ROM (flexion, extension, ulnar and radial deviation) in healthy volunteers with respect to forearm rotation. We hypothesize that both grip strength and wrist ROM vary between limbs and in different forearm positions. Characterization of these parameters in healthy patients may allow hand therapists and surgeons to better understand how progress in therapy relates to patients' ability to perform specific tasks and activities.

Materials and Methods

The study was approved by the Western University Research Ethics Board (REB #109595). This study utilized a convenience sample of 30 healthy male and female volunteers between 23 and 30 years of age. Equal numbers of females and males comprised the cohort. Individuals with a history of upper limb injury, diabetes mellitus, peripheral neuropathies, arthritis, cumulative trauma disorders (e.g., tendonitis), or significant illness affecting daily function were excluded from the study. None of the participants had previous injury, fractures, or surgery to the upper extremities. Participant demographics (including age, sex, hand dominance, and occupation) were recorded.

Two examiners (J.C. and S.F.) evaluated the patients. Participants were positioned with their shoulders in neutral position and elbows flexed to 90°, in accordance with the American Society of Hand Therapists' recommendations.[7] Hand grip strength was measured using a manufacturer-calibrated dynamometer (Jamar Smart Hand Dynamometer, Patterson Medical, Nottinghamshire, United Kingdom). The dynamometer handle was set at the second smallest notch for all measurements, as this has been shown to generate maximal grip strength.[8] Standard manual goniometers were used to measure wrist ROM (flexion, extension, ulnar, and radial deviation) and the angle of pronation and supination relative to neutral. Measurements for wrist flexion and extension were made between the forearm and the third metacarpal on the dorsal and palmar surfaces of the hand, respectively. Ulnar and radial deviation was measured relative to the neutral position of the wrist using the capitate as an approximate center of rotation at which to position the goniometer. Forearm rotation measurements were taken with the horizontal arm of the goniometer positioned across the distal palmar wrist crease with the forearm in supination, and across the radiocarpal joint with the wrist in pronation. Grip strength was measured to the nearest 0.1 kg, wrist ROM to the nearest 2.5°, and forearm rotation to the nearest 0.5°.

A one-way analysis of variance (ANOVA) with repeated measures was performed to test the null hypothesis that there is no difference in each measurement of grip strength, flexion, extension, and ulnar and radial deviation with respect to position of forearm rotation (full supination, neutral, full pronation) in males and females. Statistics were computed using SPSS version 23 (IBM SPSS Statistics for Windows, Armonk, New York, United States). Normality of the means of the data was assured by the central limit theorem. The Bonferroni post hoc test was used to identify which values differed with respect to forearm rotation. The level of significance (α) was set to 0.05.

Results

Participants

Total 30 volunteers (15 female, 15 male) participated in the study. The majority (97%, 29/30) of participants were right-hand dominant, and 3% (1/30) were left hand dominant. All

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participants were students. The mean age of participants was 25.4 ± 1.5 years (mean ± standard deviation [SD]), with ages ranging from 23 to 30. All participants met the inclusion criteria.

Forearm Rotation

The measurements of maximal forearm supination and pronation are summarized in ►**Table 1**. In females, pronation was similar between nondominant and dominant sides (87.1°± 6.9 and 82.4°± 7.5, respectively). Supination, however, was significantly greater on the dominant side (89.3°± 8.6 compared with 88.5°± 5.7; $p = 0.024$, two-sided paired *t*-test). In males, pronation was greater on the nondominant side (83°± 8 compared with 78.9°± 9.3; $p = 0.021$), whereas supination was greater on the dominant side (87.7°± 9.2 compared with 87.2°± 9.7; $p = 0.011$).

Grip Strength

The results of grip strength testing in dominant and nondominant hands are summarized in ►**Table 1**. On the nondominant side in females, grip strength was significantly greater in supination (26.1°± 3.6) and neutral (27.4°± 4.3), in comparison to pronation (22.3°± 3.7) ($p = 0.11$ and $p = 0.001$, respectively). The same trend was seen on the dominant side (supination 28.5°± 3.8, neutral 29.1°± 4, pronation 24.1°± 3.3; $p = 0.001$ and $p < 0.001$, respectively). Females showed a grip strength that was similar between sides in all three positions. In males, grip strength was significantly different between all combinations of forearm positions (supinated vs. neutral, supinated vs. pronated, neutral vs. pronated) for both nondominant and dominant hands (dominant: supination 51.7°± 8.7, neutral 56.1°± 8.9, pronation 42.9°± 7.5; nondominant: supination 46.6°± 7.5, neutral 51.4°± 9.3, pronation 40.1°± 7.9). In both sexes, grip strength was greatest in neutral position, followed by supination and pronation. These results are shown graphically in ►**Fig. 1**.

Flexion and Extension

The results of wrist flexion and extension measurements are summarized in ►**Table 1**. In females, the only significant difference in wrist flexion occurred on the nondominant side in supination compared with pronation (74.4°± 6.5 and 78.1°± 5.8, respectively; $p = 0.007$). In males, wrist flexion was significantly greater in neutral (nondominant: 72.6°± 9.4, dominant: 70.2°± 11.2) and pronation (nondominant: 73.3°± 8.6, dominant: 70.3°± 8.9) in comparison to supination (nondominant: 63.1°± 15, dominant: 62.4°± 12.6) on both the nondominant ($p = 0.01$ and $p = 0.041$, respectively) and dominant sides ($p = 0.011$ and 0.021, respectively). Wrist flexion was consistently similar between nondominant and dominant sides in both sexes. The results are shown graphically in ►**Fig. 2**.

Table 1 Summary of mean measurements of forearm supination, forearm pronation, grip strength, wrist flexion and extension, ulnar deviation, and radial deviation on nondominant and dominant sides in females and males

		Females		Males	
		Nondominant	Dominant	Nondominant	Dominant
Forearm supination (degrees ± standard deviation [SD])		88.5 ± 5.7	89.3 ± 8.6	87.2 ± 9.7	87.7 ± 9.2
Forearm pronation (degrees ± SD)		87.1 ± 6.9	82.4 ± 7.5	83 ± 8	78.9 ± 9.3
Grip strength	Supination	26.1 ± 3.6	28.5 ± 3.8	46.6 ± 7.5	51.7 ± 8.7
(kg ± SD)	Neutral	27.4 ± 4.3	29.1 ± 4	51.4 ± 9.3	56.1 ± 8.9
	Pronation	22.3 ± 3.7	24.1 ± 3.3	40.1 ± 7.9	42.9 ± 7.5
Wrist flexion	Supination	74.4 ± 6.5	74.9 ± 9.5	63.1 ± 15	62.4 ± 12.6
(degrees ± SD)	Neutral	79.9 ± 5.8	79.7 ± 6.5	72.6 ± 9.4	70.2 ± 11.2
	Pronation	78.1 ± 5.8	77.6 ± 7.1	73.3 ± 8.6	70.3 ± 8.9
Wrist extension	Supination	73.5 ± 6.8	70.5 ± 7.3	64.6 ± 10.5	60.2
(degrees ± SD)	Neutral	75.9 ± 7.9	74.4 ± 7.6	70.3 ± 8.8	65.6 ± 10.1
	Pronation	75 ± 7	73.3 ± 7.2	69.5 ± 8.5	62.7 ± 8.9
Ulnar deviation	Supination	44.6 ± 8.2	37.5 ± 11.9	38.2 ± 10.4	35.6 ± 13.6
(degrees ± SD)	Neutral	36.8 ± 13.3	37.9 ± 14	33 ± 12.6	37.2 ± 10.2
	Pronation	33.2 ± 10.7	32.8 ± 10.2	28 ± 8.2	30.6 ± 9
Radial deviation	Supination	14.7 ± 8.1	17.4 ± 7.3	16.3 ± 7.4	15.4 ± 7.4
(degrees ± SD)	Neutral	23.1 ± 11.1	26 ± 14.9	23.6 ± 8.2	23.2 ± 11.6
	Pronation	21.7 ± 9.4	21.1 ± 10.6	24.6 ± 8.1	23.9 ± 6.8

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Wrist extension was similar in all three forearm positions in females on both sides. In males, wrist extension was significantly greater in pronation (69.5°± 8.5) than in supination (64.6°± 10.5) on the nondominant side (p = 0.02). Wrist extension was similar between nondominant and dominant sides in both sexes. The results are shown graphically in ►**Fig. 3**.

Ulnar and Radial Deviation

The mean results of ulnar and radial deviation measurements are summarized in ►**Table 1**. Ulnar deviation in females was significantly greater in supination (44.6°± 8.2) as compared with pronation (33.2°± 10.7) on the nondominant side (p = 0.011). It was also higher in the nondominant hand as compared with the dominant side (37.5°± 11.9) in supination (p < 0.001). There were no differences in ulnar deviation in all three forearm positions and between sides in males. This is shown graphically in ►**Fig. 4**.

Radial deviation in females was significantly greater on the nondominant side (14.7°± 8.1) than on the dominant side (17.4°± 7.3) in supination (p < 0.001). Additionally, ROM was similar within each side. In males, however, radial deviation of the wrist was greater in supination (nondominant: 16.3°± 7.4, dominant: 15.4°± 7.4) than pronation

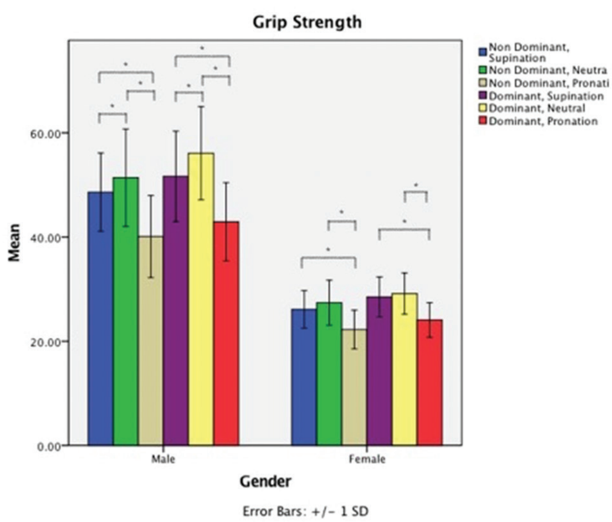

Fig. 1 Variation of grip strength in nondominant and dominant hands with forearm rotation in males and females. Error bars indicate SEM. Statistically significant differences are indicated with an asterisk. SD, standard deviation.

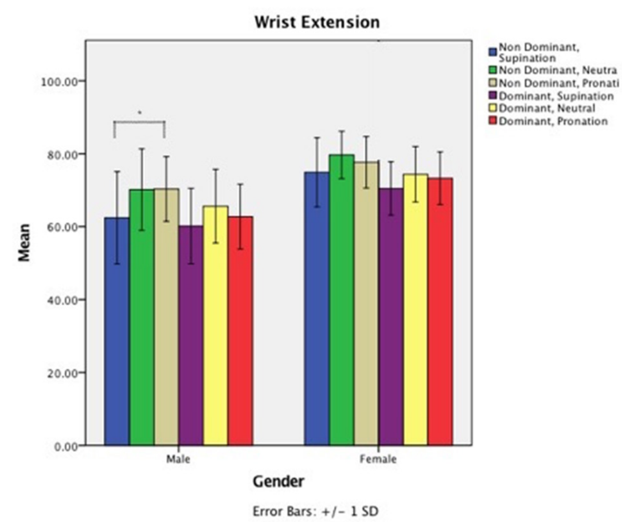

Fig. 3 Variation of wrist extension in nondominant and dominant sides with forearm rotation in males and females. Error bars indicate SEM. Statistically significant differences are indicated with an asterisk. SD, standard deviation.

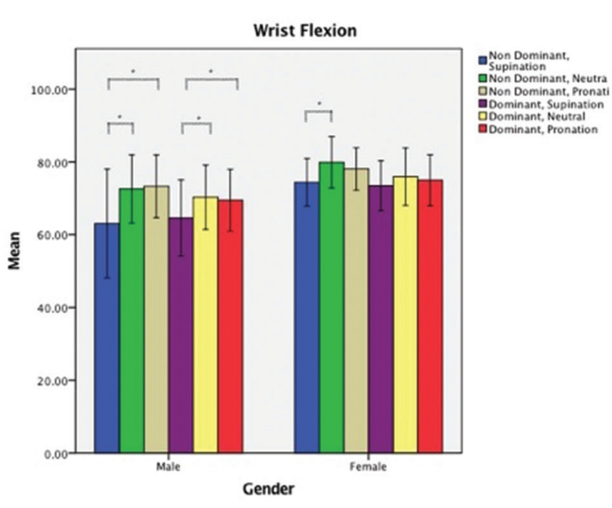

Fig. 2 Variation of wrist flexion in nondominant and dominant sides with forearm rotation in males and females. Error bars indicate SEM. Statistically significant differences are indicated with an asterisk. SD, standard deviation.

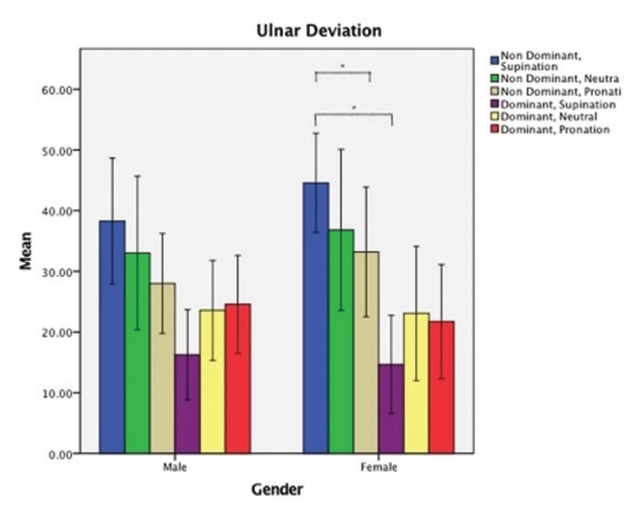

Fig. 4 Variation of wrist ulnar deviation in nondominant and dominant hands with forearm rotation in males and females. Error bars indicate SEM. Statistically significant differences are indicated with an asterisk. SD, standard deviation.

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(nondominant: 24.6°± 8.1, dominant: 23.9°± 6.8) on both sides (nondominant p = 0.031, dominant p = 0.001). Radial deviation was similar between sides in each position. This is shown graphically in ►**Fig. 5**.

Discussion

The results show that many parameters (grip strength, wrist flexion, wrist extension in males, ulnar deviation in females, and radial deviation) were significantly different with respect to position of forearm rotation. Grip strength was significantly different in all combinations of forearm rotation in males (supination versus neutral, neutral versus pronation, supination versus pronation) and was significantly reduced in females with the wrist in pronation on both sides. These differences may be attributable to the change in length of the extrinsic finger flexors with forearm rotation. Due to the length-tension relationship of muscle fibers, a variation in grip strength with forearm rotation is consequently expected.[9]

A study by Massy-Westropp et al[10] has shown that males have stronger grip strength than females at all ages, which is demonstrated in our data; however, statistical analysis was not completed comparing sexes. Sex differences may be due to skeletal muscle fiber composition or levels of exercise and strength training.[11,12] Other studies have shown that females aged 18 to 29 years have increased extension-flexion and ulnar-radial deviation in comparison to males of the same age group.[2] Several studies have found that motion was significantly greater on the nondominant side.[1,13,14] Our results are consistent with this in females for ulnar and radial deviation with the forearm supinated. Our results for grip strength are similar to a study by Klum et al,[2] which has shown that in the same age group, mean grip strength in females was 26.7 kg on the right and 27.1 kg on the left; in males, grip strength on the right was 42.9 kg, and on the left, it was 43.8 kg. Additionally, mean wrist flexion in males measured 71.6° on the right and 69.2° on the left; in females it measured 72.9° on the right and 74.2° on the left. Mean wrist extension was mildly reduced as compared with wrist flexion. Our measurements were slightly higher for wrist flexion and extension, possibly secondary to our smaller sample size, particular cohort of volunteers and/or measurements with goniometry.

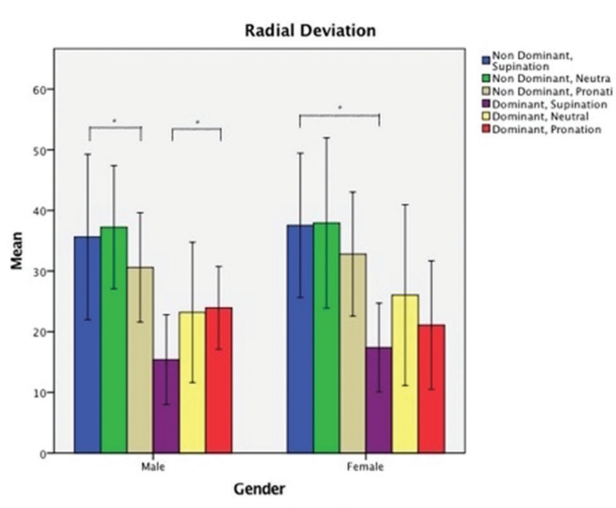

Fig. 5 Variation of wrist radial deviation in nondominant and dominant hands with forearm rotation in males and females. Error bars indicate SEM. Statistically significant differences are indicated with an asterisk. SD, standard deviation.

Wrist flexion in males was similar with the forearm in neutral position and pronation, and both actions were significantly reduced in supination. In other words, forearm supination limited wrist flexion compared with other positions of forearm rotation. In females, this difference was only seen on the nondominant side and between neutral and supinated positions. However, males demonstrated reduced wrist extension in supination on the nondominant side compared with pronation. The limitation in wrist extension in the supinated position could be explained by increased activation of the forearm flexors in supination that would provide an opposing force to extension.[15] Wrist extension was similar in females in all three positions and between sides.

Putting these results in the context of "normal" functional wrist ROM is difficult, because each individual must perform a unique set of recreational and work-related activities to which their hand and wrist must adapt. In terms of performing ADLs without difficulty, there is evidence suggesting that only a minimal ROM is required.[5,16] However, activities such as sports, playing musical instruments, or performing work-related activities require much more range and complex motion. For example, playing a violin requires a combination of extreme flexion and radial deviation in the nondominant hand with the forearm supinated.[6] In throwing a basketball, the dominant shooting wrist exhibits a large range of flexion. Additionally, a large range of ulnar deviation (up to 30°) is required when typing on a keyboard with bilateral wrists in pronation.[6] Certainly for patients in the skilled trades (e.g., machinists, carpenters) who perform a large variety of complex tasks with their hands daily, the required ROM would be quite variable and more difficult to predict.

There are clinical implications of acknowledging the variation in grip strength and wrist ROM with forearm position. To date these measurements are routinely taken with the forearm in neutral position. This may be for ease of comparison with other studies and between therapists. However, depending on an individual's job or career, they may be doing most of their work with their forearm in a non-neutral position. We would suggest that the rehabilitation process for these individuals may benefit from having their progress evaluated in the positions they more typically utilize. Presently, rehabilitation programs also include a functional score as part of outcome measures, including the DASH (Disabilities of the Arm, Shoulder and Hand) score.[17]

A significant limitation of our study is our small sample size (n = 30) that was determined by convenience sampling of patients who volunteered to partake in our study. Additionally, the restriction of participants aged 18 to 30 years was selected as wrist ROM has been shown to be highest in this age group and to minimize confounding variables

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such as degenerative forces.[2] This limitation in our target population may limit the generalizability of this study to the clinical population. Additionally, this study does not account for other factors that may influence grip strength and ROM, including ethnicity and level of physical activity. Further, although goniometry is the most popular method of measuring ROM, there are practical factors affecting its reliability. For example, in measuring ulnar and radial deviation, it is difficult to precisely define a reference point in each individual (each participant was asked to place their wrist in neutral position before measurement began). We asked participants to position themselves according to the American Society of Hand Therapists' recommendations and adjusted them as necessary.[7] This may have contributed to the relatively large standard deviation in these measurements compared with other parameters measured in this study. A study conducted by Carter et al has shown that there is high intra-rater reliability with goniometry, and that accuracy of measurements is usually within 7°.[18] Measurements for each participant, which may contribute to measurement bias. We attempted to demonstrate that wrist ROM varies in a healthy young population depending on the degree of wrist rotation. A larger study should be completed to generate normative data, which can then be analyzed for differences in age, sex, ethnicity, and body mass index, among other factors.

Conclusion

Quantitative measurements of grip strength and wrist ROM are frequently used to clinically assess progress of hand and wrist rehabilitation. By acknowledging the normal variations in these parameters with respect to forearm rotation, surgeons and hand therapists may assess clinical improvement in a way that is relevant to the lifestyle of the individual patient being assessed. This study suggests that there are likely significant variations in grip strength and wrist ROM related to forearm rotation in young healthy populations. This is not routinely accounted for in the regularly utilized "normative data" in the literature. Further research is required to generate a normative dataset for wrist ROM in varying degrees of rotation. Relating the trends observed in this study to the specific activities most frequently performed by each patient may aid in achieving rehabilitative goals that are functionally relevant.

Ethical Approval

All procedures performed involving human participants were in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments. All participants in this study gave informed consent before their participation.

Conflict of Interest

None declared.

References

1 Gûnal I, Köse N, Erdogan O, Göktürk E, Seber S. Normal range of motion of the joints of the upper extremity in male subjects, with special reference to side. J Bone Joint Surg Am 1996;78(9):1401–1404

2 Klum M, Wolf MB, Hahn P, Leclère FM, Bruckner T, Unglaub F. Normative data on wrist function. J Hand Surg Am 2012;37(10):2050–2060

3 Neese RM, Konz S, Reams M. Ranges of motion in the human wrist. Paper presented at: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 1989

4 Marshall MM, Mozrall JR, Shealy JE. The effects of complex wrist and forearm posture on wrist range of motion. Hum Factors 1999;41(2):205–213

5 Nelson DL, Mitchell MA, Groszewski PG, Pennick SL, Manske PR. Wrist range of motion in activities of daily living. In: Advances in the Biomechanics of the Hand and Wrist. New York, NY: Springer; 1994: 329–334

6 Ryu JY, Cooney WP III, Askew LJ, An KN, Chao EY. Functional ranges of motion of the wrist joint. J Hand Surg Am 1991;16(3):409–419

7 MacDermid J, Solomon G, Valdes KE. Grip Strength: Clinical Assessment Recommendations. 3rd ed. Mount Laurel, NJ: American Society of Hand Therapists; 2015

8 Firrell JC, Crain GM. Which setting of the dynamometer provides maximal grip strength? J Hand Surg Am 1996;21(3):397–401

9 Gordon AM, Huxley AF, Julian FJ. The variation in isometric tension with sarcomere length in vertebrate muscle fibres. J Physiol 1966;184(1):170–192

10 Massy-Westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. Hand grip strength: age and gender stratified normative data in a population-based study. BMC Res Notes 2011;4:127

11 Wilmore JH. The application of science to sport: physiological profiles of male and female athletes. Can J Appl Sport Sci 1979;4(2):103–115

12 Simoneau JA, Lortie G, Boulay MR, Marcotte M, Thibault MC, Bouchard C. Human skeletal muscle fiber type alteration with high-intensity intermittent training. Eur J Appl Physiol Occup Physiol 1985;54(3):250–253

13 Nemethi CE. Normal wrist motions. Ind Med Surg 1953;22(5):230

14 Allander E, Björnsson OJ, Olafsson O, Sigfússon N, Thorsteinsson J. Normal range of joint movements in shoulder, hip, wrist and thumb with special reference to side: a comparison between two populations. Int J Epidemiol 1974;3(3):253–261

15 Mogk JP, Keir PJ. The effects of posture on forearm muscle loading during gripping. Ergonomics 2003;46(9):956–975

16 Watson HK, Weinzweig J. The Wrist. Philadelphia, PA: Lippincott Williams & Wilkins; 2001

17 Case-Smith J. Outcomes in hand rehabilitation using occupational therapy services. Am J Occup Ther 2003;57(5):499–506

18 Carter TI, Pansy B, Wolff AL, et al. Accuracy and reliability of three different techniques for manual goniometry for wrist motion: a cadaveric study. J Hand Surg Am 2009;34(8):1422–1428

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