The Effect of Simulated Total Distal Interphalangeal Joint Stiffness on Grip Strength

L'effet de la simulation de la raideur de toute l'articulation interphalangienne distale sur la force de préhension

Kitty Wu, MD^{1,2} , Romeet Ahluwalia, MD, FRCSC^{1,2},
 Shrikant J. Chinchalkar, MThO, BScOT, OTR, CHT^{2,3},
 Joshua I. Vincent, MPT, PhD⁴, Robert S. Richards, MD, FRCSC^{1,2},
 and Nina Suh, MD, FRCSC^{2,5}

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Abstract

Purpose: Production of a functional grip pattern requires the concerted action of numerous structures within the hand. This study quantifies the effect of total distal interphalangeal joint (DIPJ) stiffness to grip strength. **Methods:** Fifty (25 men, 25 women, 100 hands) individuals with a mean age of 38 years (range: 17-69 years) were recruited. Exclusion criteria included history of previous upper limb injury, neuropathies, or systemic disease. Custom thermoplastic orthoses were used to splint participants' DIPJ in full extension simulating stiffness. Grip strength before and after splinting was measured using a calibrated Jamar dynamometer. Data were analyzed using paired and independent sample *t* tests and 2×2 repeated-measures analysis of variance with hand dominance and configuration (splinted or unsplinted) as within-subject factors. **Results:** Restriction of DIPJ flexion led to a 20% decrease in grip strength ($P < .001$). There was no significant difference in this decrease between dominant and non-dominant hands. Univariate analysis did not demonstrate any interaction between hand dominance and testing configuration. Post hoc analysis revealed no statistical difference in baseline grip strength between the dominant and non-dominant hands. Furthermore, men had significantly stronger grip strength than women in all configurations ($P < .001$). **Conclusions:** Flexion at the DIPJ contributes significantly to grip strength, and stiffness at this joint greatly limits functional capabilities of the hand. This necessitates the need for targeted rehabilitation in DIPJ injuries to minimize adverse effects on grip strength.

Résumé

Objectif : Pour produire un schéma de préhension fonctionnel, il faut l'action concertée de multiples structures de la main. La présente étude quantifie l'effet de la raideur de toute l'articulation interphalangienne distale (AIPD) sur la force de préhension. **Méthodologie :** Les chercheurs ont recruté 50 personnes (25 hommes, 25 femmes, 100 mains) d'un âge moyen de 38,28 ans (plage de 17 à 69 ans). Les critères d'exclusion incluaient des antécédents de blessure d'un membre supérieur, de neuropathie ou de maladie systémique. Les chercheurs ont utilisé des orthèses thermoplastiques sur mesure pour mettre une attelle sur l'AIPD en pleine extension des participants, afin de simuler la raideur. Ils ont mesuré la force de préhension avant et après la pose de l'attelle à l'aide d'un dynamomètre Jamar calibré. Ils ont évalué les données à l'aide de tests de Student appariés et indépendants et

¹ Department of Plastic and Reconstructive Surgery, Western University, London, Ontario, Canada

² Roth/McFarlane Hand and Upper Limb Centre, St Joseph's Health Care, London, Ontario, Canada

³ Department of Hand Therapy, St Joseph's Health Care, London, Ontario, Canada

⁴ Clinical Outcomes Research Lab, Roth/McFarlane Hand and Upper Limb Centre, St Joseph's Health Care, London, Ontario, Canada

⁵ Department of Orthopedic Surgery, Western University, London, Ontario, Canada

Corresponding Author:

Nina Suh, The Roth/McFarlane Hand and Upper Limb Centre, St Joseph's Health Centre, 268 Grosvenor Street, Suite D0-215, London, Ontario, Canada N6A 4L6.
 Email: nina.suh@sjhc.london.on.ca

de l'analyse de variance à mesures répétées 2×2 et se sont servis de la dominance de la main et de la configuration (avec ou sans attelle) comme facteurs individuels. **Résultats :** La restriction de la flexion de l'AIPD suscitait une diminution de la force de préhension de 20 % ($P < 0,001$). Il n'y avait pas de différence significative entre les mains dominantes et non dominantes. L'analyse univariée n'a pas démontré d'interaction entre la dominance de la main et la configuration des tests. L'analyse *a posteriori* n'a révélé aucune différence statistique de la force de préhension entre les mains dominantes et non dominantes en début d'étude. De plus, les hommes avaient une beaucoup plus grande force de préhension que les femmes dans toutes les configurations ($P < 0,001$). **Conclusions :** La flexion de l'AIPD contribue de manière significative à la force de préhension, et la raideur de l'articulation limite considérablement la capacité fonctionnelle de la main. Ainsi, il faut prévoir une réadaptation ciblée des lésions de l'AIPD pour en réduire le plus possible les effets indésirables sur la force de préhension.

Keywords

DIP joint, grip strength, Quadriga

Introduction

Grip strength is an objective measure of the functional integrity in the hand and upper extremity. Well established as a valid and reliable measure of overall hand function,¹ it is commonly used by physicians and hand therapists to determine baseline values and monitor ongoing progress of therapy. The formation of a prehensile pattern requires the exquisite coordination of the flexor digitorum superficialis, flexor digitorum profundus (FDP), and intrinsic muscles of the hand. Injury or pathology to any of these structures can result in decreased maximal output and functional limitation. Better understanding of how these specific muscle groups individually contribute to grip strength allows for more precise characterization of the impact of injury and focused direction for rehabilitation protocols.

Stiffness of the distal interphalangeal joints (DIPJs) can occur as a result of osteoarthritis, psoriatic arthritis, or post-traumatic injury.^{2,3} This can lead to chronic debilitating pain, severe deformities, and functional impairments. Arthrodesis is effective in relieving the pain of hand osteoarthritis; however, mechanical testing after simulated arthrodesis of the index finger alone demonstrated a significant decrease in grip strength.^{4,5} Further studies have examined the impact of simulated arthrodesis at varying degrees of flexion on grip strength; however, the effect of total DIPJ stiffness has not been previously investigated. The present study aims to examine grip strength with simulated total DIPJ stiffness. The purpose of the study is to quantify the total contribution of the DIPJs to overall grip strength. We hypothesize that restriction of the DIPJs of the second to fifth finger will result in a substantial decrease in overall grip strength. Furthermore, a secondary hypothesis is that this detriment may differ between the dominant and non-dominant hands.

Methods

Participants

Fifty participants, selected using a convenience sample of hospital staff and university students, were studied. The sample included 100 hands from 25 men and 25 women (45 right-hand dominant; 5 left-hand dominant) with ages ranging from 17 to

69 years (mean [standard deviation]: 38 [14]). A small pilot study of 6 participants was completed demonstrating a 25% decrease in grip strength with splinting of the DIPJ. Based on these results, 19 participants were required since each participant acted as their own control in the unsplinted testing condition to achieve 80% power at $\alpha = .05$. We recruited 25 male and 25 female participants to ensure data would reach adequate power even when stratified according to gender. A screening questionnaire was administered to gather demographic information including hand dominance, age, and previous injuries. Exclusion criteria included previous history of upper limb injury, neuropathies, or significant systemic illness that interfered with daily functioning.

Study Design and Procedure

Total DIPJ stiffness was simulated using custom thermoplastic orthoses to splint the DIPJ of the second to fifth digit in full extension (Figure 1). Varying sizes of splints were available to accommodate differences in digit size and to ensure consistent restriction of flexion.

A calibrated Jamar dynamometer (Lafayette Instrument Company, Lafayette, Indiana) with an adjustable handle was used to test all participants. Testing was done with the handle in the second position (1.5-in grip span) as is recommended for clinical and research purposes to produce maximum grip strength.⁶

Participants were tested in accordance with the standardized testing position recommended by the American Society of Hand Therapists⁷ with shoulder adducted, elbow flexed to 90°, and forearm and wrist in neutral position. Maximal grip strength was measured in both hands of all participants at baseline without any restriction to movement and then with the DIPJs of the second to fifth digit splinted (Figure 2). The testing order was randomized for hand dominance and testing configuration for a total of 4 separate testing conditions. A pretest trial run was administered to familiarize participants with the Jamar dynamometer. Each participant was then tested 3 times in each configuration, with 30 seconds of rest in between to avoid fatigue. The mean of the 3 trials was recorded for analysis. Measurements were recorded by a single observer to maximize intra-rater reliability.⁸ The total testing procedure took approximately 20 minutes to complete. All procedures

Figure 1. Custom thermoplastic splints used to restrict distal interphalangeal (DIP) joint motion.

Figure 2. Grip strength testing using Jamar dynamometer in 2 configurations: baseline grip strength with no limitations and with distal interphalangeal (DIP) joint restricted from second to fifth digit.

followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.⁵ Informed consent was obtained from all participants prior to testing and approval from the study was obtained from the institutional ethics review board (HSREB 108426).

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences 11.0 (SPSS Inc, Chicago, Illinois). Independent and paired sample *t* tests were used to determine the effect of total DIPJ stiffness on grip strength and the effect of gender on grip strength. A 2×2 repeated-measures analysis of variance with hand dominance and configuration (control or splinted) as within-subject factors was used to determine whether there were any significant interaction between hand dominance and testing configuration. All univariate analyses were evaluated for lack of sphericity using the Greenhouse-Geisser epsilon

Table 1. Descriptive Statistics.

Configurations	n	Minimum	Maximum	Mean $\pm$ 95% CI
Dominant control	50	14.21	66.06	35.33 $\pm$ 3.62
Dominant DIPJ splinted	50	11.19	56.99	28.36 $\pm$ 3.17
Non-dominant control	50	15.87	68.78	34.33 $\pm$ 3.57
Non-dominant DIPJ splinted	50	12.09	56.39	27.38 $\pm$ 3.07

Abbreviations: CI, confidence interval; DIPJ, distal interphalangeal joint.

Figure 3. Comparison of mean grip strengths at baseline and following distal interphalangeal (DIP) joint restriction for the dominant and non-dominant hand. * $P < .001$. Mean and 95% confidence interval (CI) are shown.

correction. Post hoc evaluations of significant main effects were conducted using Bonferroni-adjusted pairwise comparisons. Significance was set at $P < .05$.

Results

The range and mean $\pm$ 95% confidence interval (CI) for grip strength (kg) for the 2 testing configurations is presented in Table 1 for the dominant and non-dominant hand. Total simulated DIPJ stiffness resulted in a 20% decrease in overall grip strength in both the dominant and non-dominant hand ($P < .001$). There was a 6.97 kg (95% CI: 5.48-8.47) decrease with DIPJ splinting of the dominant hand and comparably a 6.94 kg (95% CI: 5.56-8.33) decrease in the non-dominant hand (Figure 3). The effect of DIPJ restriction on grip strength was not statistically different between the 2 hands; both hands were as equally adversely affected. Independent *t* tests showed that men had significantly stronger grip strength than women in all testing configurations ($P < .001$).

Univariate analysis did not demonstrate any interaction between hand dominance and testing configuration that was predictive of grip strength ($F_{1, 0.009} = 0.002$; $P = .968$). Significant main effects were seen for testing configuration ($F_{1, 2422.71} = 2422.71$; $P < .001$), but not for hand dominance ($F_{1, 49} = 3.356$; $P = .073$). Post hoc evaluation of the main

effect of testing configuration revealed a statistically significant decrease in grip strength with DIPJ restriction in both hands. However, post hoc analysis of the difference in grip strength at baseline between the dominant and non-dominant hand was not statistically significant ($P = .107$).

Discussion

The present study investigated the effect of total simulated DIPJ stiffness of the second to fifth digit on grip strength and demonstrated a significant decrease of 20%. This decrease was observed in both the dominant and non-dominant hands equally. Although only contributing 15% of the total digital active range of motion,⁹ the DIPJs are demonstrated here to be important in generating a power grip. The loss of total DIPJ flexion causes a great detriment to overall hand strength and functional capability.

Previous studies have examined the impact of simulated DIPJ arthrodesis of the index and middle fingers both in isolation and together.^{4,5} Morgan et al described a 20% decrease in grip strength with fusion of the index and middle fingers alone and a 25% decrease in grip strength with the simultaneous fusion of both digits. This appears incongruent with our findings of a 20% decrease with simultaneous blocking of all 4 DIPJs of the index, middle, ring, and small fingers. A possible explanation is the decrease in strength attributed to the Quadriga effect. The flexor profundus tendons of the ulnar 3 digits share a common muscle belly originating more proximally in the forearm.^{10,11} Restricted flexion of any 1 of the 3 ulnar digits prevents full excursion and muscle contraction of the other 2, resulting in decreased strength in excess of that expected with mechanical loss of a single digit. Although classically the Quadriga phenomenon is referenced for the middle, ring, and small digits, Quadriga-like connections have also been described for the index finger with an oblique tendon connecting the profundus tendon of the index finger with the musculotendinous unit of the ulnar 3 digits.¹⁰ Thus, the effects of physically blocking all 4 DIPJs may be comparable with the cumulative mechanical and Quadriga effect of blocking solely the index and middle fingers.

Horton et al quantified the Quadriga effect by sequentially simulating isolated stiffness of the index, middle, ring, and small fingers and measuring the strength of the each of the remaining digits during power grip.¹⁰ Simulated stiffness of the index finger resulted in a 52% and 47% decrease in strength in the ring and small digit, and similarly stiffness of the middle finger resulted in a 48% and 38% decrease in strength of the ring and small digit. Simulated arthrodesis with the index finger in 20 degrees of flexion improved grip strength compared with positioning in full extension.⁵ Flexed posturing reduces tension on the FDP tendon and thus decreases the Quadriga effect exerted on adjacent digits. This subsequently translates into a lessened effect on grip strength. Further study is required to further elucidate the individual and combinatorial effects of DIPJ stiffness of each digit to grip strength.

Another interesting finding from post hoc analyses is the lack of a significant difference in baseline grip strength between the dominant and non-dominant hands. Earlier papers had cited up to a 33% difference between the 2 hands.^{1,12} In a large sample of 1023 participants, Werle et al established normative grip strength values within the Swiss population and found a significant mean difference of 1.15 kg between the 2 hands.¹² This is very similar to the mean difference found within our study of 1.00 kg; however, the lack of statistical significance may be attributed to our relatively small sample size of 50 participants. Furthermore, the same study stratified grip strength by age, and the difference in grip strength between dominant and non-dominant hands was inversely correlated with age: a difference of 2.9 kg in the 18- to 19-year-old age-group diminished to only 0.8 kg in the over 85 age-group. Unequal sampling of a specific age group can potentially confound comparisons. Individual studies also differ in their definition of handedness. Few studies use the established Edinburgh Inventory for Handedness developed by Oldfield¹³ and many instead rely on participants' self-identification. Depending on the definition, the dominant hand can be classified as the most preferred for unimanual tasks, the most dextrous and skillful, or the strongest.¹⁴⁻¹⁷ A recent 2011 study compiling revised normative values for grip strength found no significant difference between the 2 hands in a population of 720 individuals and attributed the dichotomy in the literature to be a result of varying statistical methodology.¹⁸

A limitation of the study is the static nature of grip strength testing, which may be less representative than dynamic grip strength testing. Dynamic testing conditions cause decreased stabilization and submaximal grip strength.¹⁹ This more realistically represents functional power grip activities of the hand.

Declaration of Conflicting Interests

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ORCID iD

Kitty Wu, MD <http://orcid.org/0000-0002-9389-1740>

References

1. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. *J Hand Surg Am.* 1984;9(2):222-226.
2. Dahaghin S, Bierma-Zeinstra SM, Reijman M, Pols HA, Hazes JM, Koes BW. Prevalence and determinants of one month hand pain and hand related disability in the elderly (Rotterdam study). *Ann Rheum Dis.* 2005;64(1):99-104.
3. Stern PJ, Fulton DB. Distal interphalangeal joint arthrodesis: an analysis of complications. *J Hand Surg Am.* 1992;17(6):1139-1145.

4. Morgan WJ, Schulz LA, Chang JL. The impact of simulated distal interphalangeal joint fusion on grip strength. *Orthopedics*. 2000; 23(3):239-241.
5. Melamed E, Polatsch DB, Beldner S, Melone CP Jr. Simulated distal interphalangeal joint fusion of the index and middle fingers in 0° and 20° of flexion: a comparison of grip strength and dexterity. *J Hand Surg Am*. 2014;39(10):1986-1991. doi:10.1016/j.jhsa.2014.06.021.
6. Firrell JC, Crain GM. Which setting of the dynamometer provides maximal grip strength? *J Hand Surg Am*. 1996;21(3):397-401.
7. Fess E. The effects of Jamar dynamometer handle position and test protocol on normal grip strength. *J Hand Surg Am*. 1982;7(3): 308-310.
8. Boone DC, Azen SP, Lin CM, Spence C, Baron C, Lee L. Reliability of goniometric measurements. *Phys Ther*. 1978;58(11):1355-1360.
9. Lister G. Intraosseous wiring of the digital skeleton. *J Hand Surg Am*. 1978;3(5):427-435.
10. Horton TC, Sauerland S, Davis TR. The effect of flexor digitorum profundus quadriga on grip strength. *J Hand Surg Eur Vol*. 2007; 32(2):130-134.
11. Schreuders TA. The quadriga phenomenon: a review and clinical relevance. *J Hand Surg Eur Vol*. 2012;37(6):513-522.
12. Werle S, Goldhahn J, Drerup S, Simmen BR, Sprott H, Herren DB. Age- and gender-specific normative data of grip and pinch strength in a healthy adult Swiss population. *J Hand Surg Euro Vol*. 2009;34(1):76-84.
13. Oldfield RC. Assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*. 1978;9:97-113.
14. Peters M. Description and validation of a flexible and broadly usable handedness questionnaire. *Laterality*. 1998;3(1):77-96.
15. Annett M. A classification of hand preference by association analysis. *Br J Psychol*. 1970;61(3):303-321.
16. Bowman OJ, Katz B. Hand strength and prone extension in right-dominant, 6 to 9 year olds. *Am J Occup Ther*. 1984;38(6): 367-376.
17. Chau N, Petry D, Bourgkard E, Huguenin P, Remy E, André JM. Comparison between estimates of hand volume and hand strengths with sex and age with and without anthropometric data in healthy working people. *Eur J Epidemiol*. 1997;13(3): 309-316.
18. Peters MJ, van Nes SI, Vanhoutte EK et al. Revised normative values for grip strength with the Jamar dynamometer. *J Peripher Nerv Syst*. 2011;16(1):47-50.
19. LaStayo P, Hartzel J. Dynamic versus static grip strength: how grip strength changes when the wrist is moved, why dynamic grip strength may be more functional movement. *J Hand Ther*. 1999; 12(3):212-218.