TRIDHA
Journal of Clinical Cases & Reports
Volume 2023, Issue S11, 10 pages
https://doi.org/10.46619/joccr.2023.6-S11.1066

CLINICAL RESEARCH

A Pilot Study for at-Home Measurement of Grip Strength via Telemedicine

Zach Griebel[1], Bruce Bolon[1], Jerry Artz[1] and John Alchemy[2*]

[1]*Department of Physics, Hamline University, Saint Paul MN, USA*
[2]*RateFast Corporation, Santa Rosa CA, USA*

Correspondence should be addressed to John Alchemy, RateFast Corporation, Santa Rosa CA, USA

Received: 24 October 2022; Accepted: 4 November 2022; Published: 11 November 2022

ABSTRACT

The COVID-19 pandemic has forced many sectors of society and industry to implement technology at a distance. The success of this implementation, particularly in the medical field, has prompted an increase in demand for online visits. This demand heightened the need for telemedicine to allow medical professionals to serve patients in a wider range of diagnostic settings and to increase the accessibility of medical care to patients. Diagnostic visits, however, often require the use of standardized medical devices, which can limit the value of virtual visits. For example, the objective measurement of patient hand grip strength is particularly difficult to accomplish in virtual visits, as it traditionally requires the use of an expensive calibrated dynamometer. The reliability of this measurement is essential when evaluating upper extremity injuries with regard to impairment and functional loss. The research described herein demonstrates an alternative to the standard clinical procedure and eliminates the need for patient access to a dynamometer. Using readily available household materials, a clinician can guide a patient through the diagnostic evaluation of their maximum grip strength via telemedicine. In this research a protocol is established for remote measurement of quantitative grip strength. This should increase patient accessibility to grip-strength evaluation and serve as a valuable tool in quantitative impairment rating.

KEYWORDS

Telemedicine; Grip strength; Hand impairment; American medical association guides to the evaluation of permanent impairment; Dynamometer

INTRODUCTION

In response to the COVID-19 pandemic and as an overall transformation in accessibility for remote clinical care, telemedicine visits are becoming popular due to the advantages the platform presents to both patients and medical care providers. Eighty-three percent of studies on telemedicine determined virtual medical visits are at least as effective as in-person medical visits, additionally finding high patient acceptance and satisfaction [1,2]. Helping

address the deficit of specialty-care clinicians in America, virtual visits can reduce transportation barriers and expand availability to underserved patient populations [2,3]. This increase in accessibility of care has been very beneficial to patients. The costs associated with setting up the infrastructure for and transitioning to new technological systems can be prohibitive. Regarding telemedicine, such initial investment costs have already been addressed through the global response to COVID-19. As a result, telemedicine has become economically viable for both patients and medical clinics. "Patients are 30% more likely to show up to a virtual visit than an in-person visit" [3]. This improves the efficiency of the medical delivery system and lowers the operational costs, which in turn should make the care more affordable to the patient [1]. With virtual visits becoming standard, telemedicine provides additional economies of scale. An individual study found that a minimum of 151 patients is required for the telemedicine platform to be cost effective [1]. By combating both physical and economic barriers, virtual medical visits improve the healthcare system by expanding access to the care that patients need. While benefits of telemedicine have been highlighted in recent publications, telemedicine visits have been shown to be as effective as in-person visits for more than 20 years [4-16].

The option of providing medical visits through a telemedicine platform improves the availability of medical care for patients. The required use of standardized medical devices for many diagnostic evaluation procedures, however, often limits the suitability of remote clinical care. For example, this requirement is problematic when there is a need to perform the hand motor strength exam, which is an integral component of the upper extremity neuromuscular exam necessary for evaluating injuries with regard to impairment and functional loss. The American Medical Association Guides to the Evaluation of Permanent Impairment, 5th Edition (hereafter, the "AMA Guides") is the basis for workers' compensation systems in thirty-three states in the United States and defines a standard for this evaluation [17]. The procedure to measure grip strength, standardized by the AMA Guides, requires a device called a hand dynamometer (e.g., JAMAR grip dynamometer). This expensive device is not commonly available for at-home use by patients, which is a primary reason the Evaluation of Permanent Impairment for grip strength, cannot typically be performed virtually. Patients who request an evaluation of permanent impairment are often struggling both financially and physically due to work-related injuries. Limitations in both finances and physical mobility can be obstacles in obtaining such an evaluation. The ability to provide an evaluation of permanent impairment via telemedicine minimizes these limitations and increases the likelihood that care would be available to patients who need it.

This study defines a method to accurately measure grip strength without a hand dynamometer and improve access to the Evaluation of Permanent Impairment. Alchemy, et al., have previously defined a reliable method for pinch-strength measurement using readily available items to remotely replicate a standardized medical device [18]. Similar methods are explored in this pilot study to use readily available home resources to measure a subject's maximum grip strength as an alternative to the standard clinical method which uses a hand dynamometer. The results of this study serve as the foundation to establish a baseline protocol for remote quantitative functional grip-strength testing and to expand availability to patients.

METHODS

The at-home protocol introduced in this study, with equipment shown in Figure 1, utilizes a water bottle to evaluate grip strength as an alternative to using a hand dynamometer. A subject squeezes the bottle with maximum

grip exertion to expel water horizontally, and the horizontal distance the water travels is measured. This distance will be used to determine the grip-strength force that was applied to the water bottle, as described below.

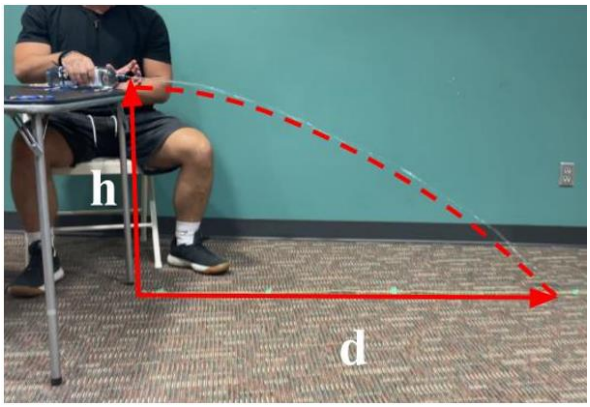

Figure 1: A simulated trial, demonstrating how the at-home experiment is performed, with relevant parameters labeled.

The at-home protocol utilizes items that are inexpensive, readily available, and easy to set up, to ensure that grip-strength evaluation can be conducted by patients at home. Items used in this study include a 700 mL "LIFE WTR" water bottle with a "sport top" aperture (i.e., pop-up cap) as seen in Figure 2, four standard pencils, adhesive tape, a table with foldable legs, a standard folding chair, and a measuring tape (which should be five meters or greater in length) [19]. The at-home protocol presented in this paper can be readily adapted to accommodate different table heights, but the brand and type of water bottle specified is required for the results presented in this study to apply.

Figure 2: LIFE WTR bottle with pop-up cap.

To assemble the apparatus, the measuring tape is fixed on the ground with strips of adhesive tape, aligning the zero marker with the front edge of the table to measure the horizontal distance the water travels (i.e., so that the water exits the bottle directly above this point). Two pencils are fixed on each side of the table with adhesive tape. The pencils are 8 cm and 23 cm from the edge of the table and are used to prop the bottle off the table to allow the hand placement to best replicate the way the dynamometer is grasped, as shown in Figure 3. The water bottle

may distort near the center when squeezed so the presence of the pencils also helps prevent tilting of the bottle. A research team member records the horizontal distance the water travels as the reported variable for the at-home protocol.

Figure 3: The grip strength arm testing position used in the AMA Guides protocol.

To perform a trial of the at-home protocol, a subject sits in the chair and holds the filled bottle vertically, placing the middle finger where the two colors meet on the label. All fingers are close together to replicate the way that the dynamometer is grasped. A finger from the opposite hand is placed over the cap opening to prevent spillage of the water. The bottle is placed horizontally on the pencils and is aligned with the front edge of the table, as shown in Figure 1 - Figure 4. The participant is seated in the chair in a position of comfort that allows them to exert maximum grip strength. When instructed, the subject rapidly removes the finger from the tip of the bottle and simultaneously exerts maximum grip strength to squeeze the bottle. The subject sustains this effort for one or two seconds. The water expelled from the bottle is measured to the farthest point where water initially strikes the ground, as shown in Figure 1. This horizontal distance will be used to calculate the exit velocity of the water from the bottle, which then determines the applied grip strength, as described below.

Figure 4: The hand placement on bottle used in at-home protocol.

Method for preliminary experiment: Verification that grip-strength measurements do not vary between the two relevant arm positions

The standard protocol to measure grip strength from the AMA Guides specifies the use of a calibrated grip dynamometer [20]. This protocol directs a patient-or in this case, a research subject-to have their shoulder neutral, elbow at 90-degree flexion and wrist at 0-degree pronation/supination, as shown in Figure 3. The at-home test, however, requires a subject to give maximum grip exertion while having their shoulder flexed and abducted to 45

degrees, elbow extended to 45 degrees, and wrist 90-degree pronation as shown in Figure 4. The arm positioning in this study, therefore, varies from that described in the AMA Guides.

There is no consensus in the literature or in the medical community regarding the influence of arm positioning on the validity of a subject's maximum grip-strength measurement [17,21-30]. Therefore, a sub-cohort was established to compare maximum grip strength in each subject's two arm positions using a dynamometer to verify that there exists no significant variation in strength. Subjects in this sub-cohort (3 males and 2 females) exerted maximum grip strength alternating between the AMA Guides protocol positioning and the at-home protocol positioning with 30 seconds of rest in between. Each subject performed five trials in each position with each hand. The results of this experiment, shown in Table 1, verify that no statistically significant difference in maximum grip strength was found when the dynamometer was used in the AMA Guides protocol position vs. the at-home protocol position.

Table 1: Sub-cohort comparison between maximum grip-strength dynamometer measurements in the AMA Guides protocol positioning versus the at-home protocol positioning.

	Average Percent Difference of Maximum Grip Strength Between *AMA Guides* Position and At-home Position	**Average Percent Standard Deviation of Trials**			
		Major Hand		**Minor Hand**	
		***AMA Guides* Position**	**At-home Position**	***AMA Guides* Position**	**At-home Position**
Males	1.05%	5.14%	3.84%	5.00%	3.01%
Females	0.31%	6.11%	3.98%	5.86%	7.42%
All	0.75%	5.53%	3.89%	5.34%	4.77%

Method for main experiment: Data collection for AMA guides protocol and at-home protocol

As described previously, the purpose of this study is to establish an at-home protocol, using common household items, that would allow a patient to measure grip strength without the necessity of using a dynamometer. For this experiment, however, it is necessary to establish a correlation between the at-home measurement of the horizontal distance the water travels and the dynamometer reading. To do this, it is necessary to establish a relationship between the grip strength applied to the bottle and the exit velocity of the water. Then basic physics principles can be used to relate the exit velocity to the horizontal distance that the water travels. As will be shown below, using the relationship found in this experiment between exit velocity and applied force, a patient will be able to perform the at-home protocol and use the horizontal distance the water travels to determine the exit velocity and therefore grip strength.

Subjects participating in this study were classified by gender, age, and hand dominance. No data was included that corresponded to hands that had prior injuries. All subjects were required to sign Hamline University Institutional Review Board-approved consent forms to participate. A total of 38 volunteers (71 uninjured hands), 21 males and 17 females, participated in the study with an age range from 15 years to 79 years old.

The following procedure was used to collect data for each participant in this study. A participant begins a data collection trial by obtaining a grip-strength measurement using the AMA Guides protocol, followed by a water-distance measurement using the at-home protocol, with 30 seconds of rest in between. The rest between measurements was inserted in an attempt to prevent fatigue throughout the experiment. The reason for alternating between protocols was to avoid potential effects of fatigue with one protocol more than the other, though no

significant effects of fatigue were observed. This pair of measurements was performed five times with one hand, then the entire procedure was repeated with the other hand.

This data collection procedure can be compared to the Swanson, Matev, and Groot study that defines the AMA Guides normative values of grip strength [26]. In this 1970 study only three trials were performed for each individual subject, and results were listed by age with an unknown distribution across age ranges. In comparison with the Swanson, Matev, and Groot study, the research presented here provides a telemedicine procedure that can be performed at home, involves more trials with each subject, and presents the percent standard deviation among trials [26].

RESULTS

The results for both the AMA Guides protocol (using the dynamometer) and the at-home protocol (using the water bottle) were within the 20% grip - and pinch-strength reproducibility standard set by the AMA Guides. Among the 38 subjects, a total of 71 hands (i.e., with no history of injury) were analyzed to relate the results of the AMA Guides protocol to those of the at-home protocol. With the at-home protocol, the horizontal distance the water traveled, d, was measured, which was then used to calculate the corresponding exit velocity, v_o, using the following fundamental physics equations of motion [31].

$$d = v_o t \qquad h = \frac{1}{2} g t^2$$

Therefore,

$$v_o = \frac{d}{t} = \sqrt{\frac{g}{2h}}\, d$$

Where:
d = Horizontal distance water traveled
v_o = (Horizontal) exit velocity of water
t = Time water is in the air before first striking the ground
h = Height of bottle tip above ground
g = 9.80m/s^2

It should be noted that the above equations allow for any height, h, to be entered, allowing someone at home to use whatever table they have available. For the research presented here, the height from the ground to the tip of the bottle was 0.740 m. This provides the following direct relation between exit velocity and horizontal distance traveled by the water.

$$v_0 = \sqrt{\frac{g}{2h}}\, d = \sqrt{\frac{9.80 m/s^2}{2(0.740 m)}}\, d = 2.58 d$$

For each participant, it is assumed that the average grip-strength measurement from the AMA Guides protocol is the same as the grip strength applied in the at-home protocol. As previously mentioned, the horizontal water distance measured in the at-home protocol relates directly to the exit velocity of the water leaving the bottle.

Therefore, each data point consists of the average grip strength and corresponding average exit velocity for a given participant (Table 2). This data was used to create the calibration curve shown in Figure 5, which demonstrates the relation between exit velocity and applied force (grip strength). The expected increase in exit velocity with increased applied force is observed.

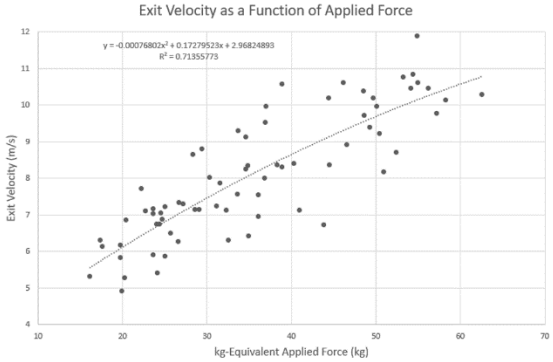

Figure 5: Exit velocity of water leaving the bottle as a function of applied force.

Table 2: Average percent standard deviation of the ama guides protocol compared to the at-home protocol for various cohorts.

	Average Percent Standard Deviation by Cohort					
	Major Hand		**Minor Hand**		**Both Hands**	
	***AMA Guides* Protocol**	**At-home Protocol**	***AMA Guides* Protocol**	**At-home Protocol**	***AMA Guides* Protocol**	**At-home Protocol**
Males	6.72%	4.64%	5.99%	4.81%	6.35%	4.72%
Females	9.23%	6.84%	6.21%	6.06%	7.67%	6.44%
All	7.79%	5.59%	6.09%	5.34%	6.92%	5.46%

The results from the AMA guides protocol and the at-home protocol are all within the 20% grip - and pinch-strength reproducibility standard set by the AMA guides. The equation describing the relationship between exit velocity and applied force is given by the quadratic curve fit shown in Figure 5. The standard residual error of this curve is a statistical estimate of the average amount that the data points deviate from the curve fit [32]. The standard residual error divided by the spread of the response variable, i.e., the exit velocity, estimates the percent deviation of the data points to the curve to be 12.9%. This deviation fits within the AMA guides grip - and pinch-strength reproducibility standard, therefore the curve fit can be classified as reliable [33].

DISCUSSION

This pilot study demonstrates that the at-home protocol is practical and produces results consistent with the AMA guides. The AMA Guides reproducibility standard for grip- and pinch-strength testing states that "tests repeated at intervals during an examination are considered to be reliable if there is less than 20% variation in the readings" [17]. The average percent standard deviation from all groups in Table 2 are within the AMA Guides reproducibility standard which verifies that the at-home protocol is reliably consistent with the AMA Guides protocol. The curve fit shown in Figure 5 can be used by a patient performing the at-home protocol described herein to measure the water distance traveled and use this distance to determine the exit velocity and corresponding grip strength. Additionally, the Residual Standard Error of the curve fit is within the AMA Guides grip- and pinch-strength reproducibility standard. Therefore, the curve fit relating grip strength to exit velocity can be considered reliable.

Medical evaluations inherently present sources of error which may be minimized by following an appropriate protocol. With the at-home protocol presented herein, there is potential error associated with measuring the horizontal distance the water travels. This was addressed by having multiple research team members observe each trial. Reliability of measurement could be improved upon in a further study by video recording the trials. The data collection in this study was performed outside in the summer. To minimize effects due to wind, the experiment was performed at sheltered locations. The temperature ranged from 18 degrees to 29 degrees celsius. Throughout the study, the dynamometer gauge had a resting baseline reading greater than zero due to natural expansion of the internal fluid within the dynamometer. The instruction manual acknowledges that, for an initial reading, the needle may be out of the "zero range" and states that the reading should be adjusted. The adjustment in this study involved subtracting the initial baseline reading from the final reading [20].

The results of the experiment presented herein were quite promising, as they satisfied the 20% grip - and pinch-strength reproducibility standard presented in the AMA Guides, but additional steps should be taken to adapt the at-home method for clinical assessment. The AMA Guides defines normative values with a cohort of 50 male and 50 female subjects, with results separated by gender [26]. To confirm the results collected in this pilot study, the data collection procedure should be repeated with a cohort composition comparable to the study from the AMA Guides. A larger cohort size such as this should improve reliability and allow the data to be stratified by age. A video camera could be used to both help locate where the water initially hits the ground and verify that the water bottle remains horizontal throughout each trial.

CONCLUSION

This pilot study tests the practicality of the at-home protocol to measure grip strength without needing a dynamometer, the standard medical device typically required. It establishes that the results of performing the at-home protocol reliably match the results of the accepted AMA Guides protocol. This experiment showed that the at-home protocol is a valid substitute for the AMA Guides protocol. However, performing the data collection procedure with an increased number of subjects across a wide range of age groups would also allow stratification by age. The potential to provide this evaluation through telemedicine expands availability for patients with limited access to a clinic to get the care they need.

ACKNOWLEDGEMENT

We thank Chris Young PhD (Alverno College) for assistance in revising the paper. We thank the 38 volunteers that assisted us in this study. This research was funded by the Hamline University Kent H. Bracewell Scholarship Fund. We thank the retired Hon. Steve Siemers who reviewed this paper for compliance with workers' compensation applications. We thank Sarah Alchemy of University of Puget Sound for assistance in the data collection and organization of volunteers.

REFERENCES

1. Bashshur R, Doarn CR, Frenk JM et al. (2020) Telemedicine and the COVID-19 pandemic, lessons for the future. Telemedicine and e-Health 26(5): 571-573.
2. Buvik A, Bergmo TS, Bugge E et al. (2019) Cost-effectiveness of telemedicine in remote orthopedic consultations: Randomized controlled trial. Journal of Medical Internet Research 21(2): e11330.

3. Marin A (2020) Telemedicine takes center stage in the COVID-19 pandemic.
4. Alchemy J, Artz J, Bolon B et al. (2019) A novel method of monofilament force testing for nerve sensory loss in telemedicine. Occupational Medicine & Health Affairs 7(1): 284.
5. Wootton R (1996) Telemedicine: A cautious welcome. BMJ 313(7069): 1375-1377.
6. Hailey D and Crowe B (2003) A profile of success and failure in telehealth-evidence and opinion from the successes and failures in telehealth conferences. Journal of Telemedicine and Telecare 9(2_suppl): 22-24.
7. Hjelm NM (2005) Benefits and drawbacks of telemedicine. Journal of Telemedicine and Telecare 11(2): 60-70.
8. Haukipuro K, Ohinmaa A, Winblad I et al. (2000) The feasibility of telemedicine for orthopaedic outpatient clinics: A randomized controlled trial. Journal of Telemedicine and Telecare 6(4): 193-198.
9. Galea MD (2019) Telemedicine in rehabilitation. Physical Medicine and Rehabilitation Clinics 30(2): 473-483.
10. Jacobs K, Blanchard B, Baker N (2012) Telehealth and ergonomics: A pilot study. Technology and Health Care 20(5): 445-458.
11. Mair F and Ferguson J (2008) More patients with minor injuries could be seen by telemedicine. Journal of Telemedicine and Telecare 14(3): 132-134.
12. Cottrell MA, O'Leary SP, Swete-Kelly P et al. (2018) Agreement between telehealth and in-person assessment of patients with chronic musculoskeletal conditions presenting to an advanced-practice physiotherapy screening clinic. Musculoskeletal Science and Practice 38: 99-105.
13. Weinstein RS, Lopez AM, Joseph BA et al. (2014) Telemedicine, telehealth, and mobile health applications that work: Opportunities and barriers. The American Journal of Medicine 127(3): 183-187.
14. Langton Z, Johnson M, Reed Z et al. (2020) Verifying the accuracy and precision of the Ratefast goniometer mobile phone application. Journal of Clinical Cases and Reports 3(S3): 31-39.
15. Hailey D, Roine R, Ohinmaa A (2002) Systematic review of evidence for the benefits of telemedicine. Journal of Telemedicine and Telecare 8(1_suppl): 1-7.
16. Johnson M, Langton Z, Reed Z et al. (2021) A quantitative shoulder strength testing method for in-person and telemedicine examinations. Journal of Clinical Cases and Reports 4(S6): 24-33.
17. Andersson GB and Cocchiarella L (2006) AMA guides to the evaluation of permanent impairment 5th (Edn.). Chicago, Illinois: American Medical Association Press.
18. Alchemy G, Alchemy S, Bolon B et al. (2021) Occupational telemedicine for pinch strength testing: A pilot study of methods for at-home measurement. Journal of Clinical Cases and Reports 4(S9): 28-38.
19. Pepsico (2021) "LifeWtr purified water 700 millilter."
20. Prodcuts, Pro Healthcare (2020) Baseline pinch gauge - hydraulic - LiTE (50-lb Capacity).
21. Belcher HJCR (2017) The assessment of grip strength after upper limb injuries in medico-legal practice. Medico-Legal Journal 85(1): 23-32.
22. Espinoza F, Le Blay P, Coulon D et al. (2016) Handgrip strength measured by a dynamometer connected to a smartphone: A new applied health technology solution for the self-assessment of rheumatoid arthritis disease activity. Rheumatology 55(5): 897-901.
23. Farooq M and Ali Khan A (2012) Effect of elbow flexion, forearm rotation and upper arm abduction on MVC grip and grip endurance time. International Journal of Occupational Safety and Ergonomics 18(4): 487-498.

24. Iconaru EI and Ciucurel C (2020) Hand grip strength variability during serial testing as an entropic biomarker of aging: A Poincaré plot analysis. BMC Geriatrics 20(1): 1-12.
25. Roberts HC, Denison HJ, Martin HJ et al. (2011) A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. Age and Ageing 40(4): 423-429.
26. Swanson AB, Matev IB, De Groot G (1970) The strength of the hand. Bulletin of Prosthetics Research 10(14): 145-153.
27. Valero-Cuevas FJ, Smaby N, Venkadesan M et al. (2003) The strength-dexterity test as a measure of dynamic pinch performance. Journal of Biomechanics 36(2): 265-270.
28. Jiang Z, Wang SZ, Liao J et al. (2010) Test of grip and pinch strengths of 111 healthy university students in Fujian Province. Chinese Journal of Tissue Engineering Research 14(50): 9452.
29. Angst F, Drerup S, Werle S et al. (2010) Prediction of grip and key pinch strength in 978 healthy subjects. BMC Musculoskeletal Disorders 11(1): 1-6.
30. Maleki-Ghahfarokhi A, Dianat I, Feizi H et al. (2019) Influences of gender, hand dominance, and anthropometric characteristics on different types of pinch strength: A partial least squares (PLS) approach. Applied Ergonomics 79: 9-16.
31. Sears FW, Zemansky MW, Young HD (1987) University physics 7th (Edn.) reading, Pennsylvania: Addison-Wesley series in physics.
32. James G, Witten D, Hastie T et al. (2021) An introduction to statistical learning. New York: Springer Nature.
33. Incel NA, Ceceli E, Durukan PB et al. (2002) Grip strength: Effect of hand dominance. Singapore Medical Journal 43(5): 234-237.