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Occupational Telemedicine for Pinch Strength Testing: A Pilot Study of Methods for At-Home Measurement

Grace Alchemy[1], Sarah Alchemy[2], Bruce Bolon[3], Jerry Artz[3], John Alchemy[4*] and Christian C Young[5]

[1]*Stanford University, Palo Alto, CA, USA*

[2]*University of Puget Sound, Tacoma, WA, USA*

[3]*Department of Physics, Hamline University, Saint Paul, USA*

[4]*RateFast Corporation, Santa Rosa, USA*

[5]*Department of Biology, Alverno College, Milwaukee, USA*

Correspondence should be addressed to John Alchemy, j.alchemy@pr4report.com

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ABSTRACT

Neuromuscular hand strength evaluation is challenging under the best clinical circumstances. With the rapidly growing importance of telemedicine and video-assisted medical examination, objective assessment of the hand neuromuscular function persists as a difficult challenge. The COVID-19 pandemic ushered in a rapid transition to online medical visits. The increased volume of virtual patient visits pushed physicians to adapt physical examinations into a suitable format for online evaluation. The hand motor strength exam (pinch and grip) typically relies on expensive standardized medical-office measurement devices, such as a pinch dynamometer. The pinch test is a major element of the hand neuromuscular exam that practitioners rely on for valuing injury impairments and functional loss involving the elbows, wrists, hands, fingers, and thumbs. Outside the clinical setting, telemedicine providers require a reproducible method of standardizing pinch-strength testing. In this research, we hoped to identify common items found in the home that could be used to determine a patient's maximum pinch-strength and would provide results consistent with those obtained in the office, thereby providing an extremely valuable alternative. In this study, we focused on creating an accessible, standardized approach that could be used to determine a minimum pinch-strength threshold for an individual using common household items. An average coefficient of static friction between skin and paper was determined using elementary physics, pinch-strength measurements, and the corresponding maximum weight of bucket and water before slippage occurs. Coefficient of static friction values for skin on paper are not found in standard tables (e.g. Handbook of Chemistry and Physics), nor are the values published in the AMA Guides to the Evaluation of Permanent Impairment. The results of this research serve as the foundation for establishing a baseline protocol for remote examination of quantitative functional pinch-testing.

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KEYWORDS

Pinch ability; Coefficient of static friction; Skin on paper friction; Dermatological comparison; Telemedicine; clinical comparison; Key pinch; Pinch dynamometer; Pinch strength; Pinch impairment rating; American Medical Association Guides to the Evaluation of Permanent Impairment

INTRODUCTION

Understanding impairment is challenging in a clinical setting for even the most experienced practitioner. Providing accurate and substantive diagnostic evaluations generally requires a thorough examination across a range of tasks and the use of careful and reproducible measurements. This combination of expectations often means that impairment ratings are available only to patients with access (logistically and financially) to experienced diagnosticians in specialized facilities. Because impairment can result from work-related injuries, personal injury, and progressive conditions, the incentive for pursuing a diagnosis and seeking treatment varies widely. Efforts to make such examinations more convenient and accessible to more patients, yet still provide reliable results, could lead to dramatically improved care and quality of life across a wide sector of the population.

This study focuses on the pinch strength needed to accomplish activities of daily living (ADLs) and a new means of assessing this important measure remotely, such as in the home. Measurement of pinch strength traditionally requires access to a dynamometer, a specific device used to test neuromuscular capacity. Alternatives that use materials and techniques readily available can overcome the challenge of the remote examination without having this dynamometer. This paper proposes an effective, reliable method for testing the functionality of the hand in such a way that people can participate remotely. The method requires no purchase of medical equipment, nor does a clinic need to mail out any equipment.

The methods tested and described here allow a telemedicine practitioner to answer questions related to the threshold pinch strength of the patient. Those answers are based on the patient's experience following instructions for manipulating readily available household items. The practitioner, then, can evaluate the patient in relation to thresholds established in the AMA Guides to the Evaluation of Permanent Impairment, 5th Edition (hereafter, the "AMA Guides") [1]. These thresholds require a 4.9-kg minimum pinch strength for female patients and a 7.5-kg minimum pinch strength for male patients. Direct measurement of these forces is possible in the clinic with a classic pinch dynamometer [2]. The dynamometer can be helpful in detecting the specific pinch strength singly or across a series of repetitions of the test. Its usefulness in demonstrating impairment extends to the generation of measurements that fall below the threshold. When a calibrated device is not available, the full range of measurements may be cumbersome to collect. However, for evaluating the strength necessary to achieve the threshold, a dynamometer is not necessary. In the absence of a device, a method for recording pinch strength above or below the threshold may be demonstrated accurately and reliably to AMA Guides specifications.

The adoption of telemedicine raises concerns about the efficacy of clinical practice and introduces new financial pressure on the economic model of health care clinics. A recent study of these concerns and pressures in orthopedic care concluded that under circumstances where the number of patients seeking care meets a certain threshold, clear benefits to the population emerge. These circumstances also depend on the distance that patients need to travel and the kind of care, diagnosis, or treatment being sought. This study included patients who visited a nearby clinic that was remote from the hospital where an orthopedic specialist provided video-assisted consultations [3]. Offering video-assisted consultations without the patient needing to leave home raises even greater concerns about efficacy, but these consultations may reduce reliance on regional clinics that are better provisioned for direct care.

A literature review of telemedicine in orthopedics concluded that a growing number of publications illustrate the effectiveness of telemedicine. Remote follow-up in postoperative cases including fractures as well as fracture diagnosis has consistently yielded good results, both in patient satisfaction and quality of care. Standardizing orthopedic examination is emerging as the next frontier in telemedicine for musculoskeletal conditions [4].

Telemedicine may not be the only application for these techniques, when a fast, reliable determination of strength is needed to complete an evaluation. Even in a clinical setting, a pinch dynamometer may be misplaced or malfunctioning at the time of an examination, leading to incomplete or inaccurate reporting of this measure of strength for ADLs.

In the clinical experience of one of the authors who has expertise in completing evaluations of the hand (Alchemy, J.), pinch strength loss measurements tend to be "higher value" impairment ratings, meaning the Whole Person Impairment (WPI) values may be higher than those of joint range of motion or peripheral nerve loss. Hand functions including pinch strength involve at least 14 ADLs, ranging from non-specialized hand activities and self-care to communication, driving, and sleep across a wide range of actions [1]. Previous research demonstrates that telemedicine opens new opportunities for clinicians to evaluate more patients for strength and range of motion function that can lead to better care and more complete access to compensation for all stakeholders. This includes use of a readily available exercise resistance band to evaluate shoulder strength and motion [5]. Another study described a novel method for evaluating neurosensory loss and monofilament testing using an organic substitute ("angel hair" pasta spaghetti noodles) for nylon 10-gram Semmes Weinstein monofilaments [6].

The aim of this paper is to provide a single threshold measure of whether a patient can achieve the pinch strength recognized to accomplish ADLs, and not to provide incremental quantitative measures of the strength as it varies over time.

Pinch strength in this study is distinguished from the wider range of activities classified with grip strength. In general, unsupported grip includes the capacity and strength of finger, hand, and wrist muscles and the associated physiology [1].

In this study, an intentional vertical orientation of the gripped surfaces eliminated consideration of the variation in coefficient of static friction resulting from angled surfaces [7].

METHODS (CALCULATING μS)

This study tests the do-it-yourself potential of a simple method of determining the presence of the normal pinch strength threshold. The procedure requires no specialized device and no visit to the clinic. Using household materials commonly available, and supervision via telemedicine, a patient can follow the steps of the procedure presented here. Based on data collected in this study, the procedure provides a threshold weight to test the strength of the pinch between thumb (volar pad) and index finger (radial side of the distal phalanx) of the patient. In evaluating hand function, the full battery of tests can complicate measures of particular functions, such as pinch strength. A shorter protocol is recommended in the literature [8].

In this study, pinch strength, as measured by a pinch dynamometer, was used to determine the coefficient of static friction between skin and paper, as is about to be shown. Four participants used identical materials to compare their abilities to lift a known weight by pinching a folded sheet of paper wrapped around the handle of a bucket of water. Other studies have compared static and dynamic performance in tests of pinch strength, which was not the aim here [9].

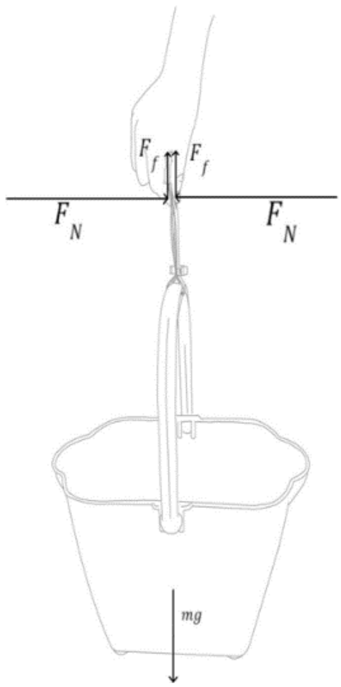

Figure 1: Force diagram for the system consisting of the bucket, clothespin, and paper while a measurement is made.

The coefficient of static friction for skin on other surfaces has not been exhaustively determined. For this study, the particular coefficient for skin on paper is required to be established experimentally.

Calculating the Coefficient of Static Friction from Pinch Experiments

In this part of the experiment, the coefficient of static friction between human skin and paper was to be determined. A diagram showing the forces acting on the bucket of water (technically including the negligible contributions from the paper and clothespin) is shown (Figure 1). All measurements correspond to the case when water has been added to the bucket to the point that a person can just barely prevent the paper from slipping.

The clothespin ensures that the paper surfaces in contact with the thumb and forefinger are parallel. It also ensures that the normal forces, F_N, applied on each side are horizontal, and the static frictional forces, F_f, are vertical. It is important to note that the system is in equilibrium (i.e., not accelerating). Because of this, symmetry requires that the normal forces are equal in magnitude, and therefore, so are the frictional forces. This symmetry is already accounted for by labelling the magnitudes of these forces identically on each side of the force diagram, as shown (Figure 1).

The static frictional force (when slippage is just about to occur) is related to the normal force by the equation $F_f = \mu_S F_N$, found in standard physics textbooks [10], and mg is the weight of the bucket of water. Since the system is not accelerating, the net force in any direction must be zero, by Newton's 2nd Law ($\sum \vec{F} = m\vec{a}$). Using this force diagram and labelling upward the +y-direction yields:

$$\sum F_y = F_f + F_f - mg = ma_y,$$

or,

$$\sum F_y = 2\mu_S F_N - mg = 0,$$

which gives:

$$\mu_S = \frac{mg}{2F_N}.$$

F_N was assumed to be equivalent to the maximum measurement obtained separately utilizing a pinch dynamometer. The coefficient of static friction is proportional to the ratio of the weight of the bucket to the pinch strength. Hence, a lower pinch strength F_N will result in a lower weight of the bucket that can be raised and will still result in the same coefficient of static friction for the individual. The experimental setup used in this study is specifically designed so that the way in which the person pinches the paper closely mimics the way in which a pinch strength dynamometer was used.

Materials for Pinch Experiments

The materials used to assemble the apparatus for this lab analysis included a 2.5-gallon bucket, water, multipurpose copy paper (Amazon Basics, white, 8.5 inches × 11 inches folded three times longitudinally), and a standard spring-and-wood clothespin. The bucket, water, paper, and clothespin were assembled as shown (Figure 1).

The following additional materials were used: a pinch dynamometer (Baseline 12-0026 pinch gauge), a 10 kg scale (ACCUTECK series W-8250), and liquid hand soap. The pinch dynamometer and scale were factory calibrated. The pinch dynamometer, paper, and scale were purchased from online retailer Amazon.

Data Collection for Pinch Experiments

Through a series of tests, each consisting of multiple trials, the participants in the study determined their individual pinch strength using the dynamometer. This pinch strength measurement was then used along with the maximum weight of bucket and water that could be supported to determine the coefficient of static friction.

The following steps refer to the method of data collection hereafter referred to as the "Pinch-Bucket Method."

Step one: Determine the individual's baseline pinch strength

A series of measurements of the pinch strength for each hand, dominant and non-dominant, was recorded using classic key pinch on a dynamometer. The key pinch involves the volar pad of the thumb on the dial side of the dynamometer and the radial side of the distal phalanx on the underside as shown (Figure 2).

It is noteworthy that only the thumb and the index finger participate in the generation of the force excluding the remaining fingers from participation. It is critical to isolate the pinch mechanics to the thumb and index finger action, removing any confounding contribution of the other digits.

Figure 2: Classic key pinch on dynamometer.

The pinch dynamometer is marked in 0.5 kg increments, as shown (Figure 2), and a dynamometer reading was taken each time before the bucket was lifted. This reading, together with the mass of the bucket and water constitute a single data point, as shown in Table 1, which is then used to calculate a corresponding coefficient of static friction.

Name/ Dominant Hand	RIGHT HAND			LEFT HAND		
Date	Dynamometer Classic Pinch F_N (kg)	Bucket Mass (kg)	µ	Dynamometer Classic Pinch F_N (kg)	Bucket Mass (kg)	µ

Table 1: Data table for dynamometer value, terminal bucket weight, and coefficient of static friction calculation (μ_s).

Step two: Determine the terminal weight of the bucket apparatus

The hand skin surfaces were cleaned using a drop of liquid hand soap approximately five millimeters in diameter and washed for 15 seconds to reduce surface skin contaminants. The hands were allowed to air dry prior to each series of tests. Rewashing between each trial made hands too slippery, and it was determined that efforts to keep hands clean and dry throughout the testing provided the most consistent results. One participant noticed hands becoming sweaty after three trials. Before collecting the fourth data point, the participant repeated the hand wash and dry procedure.

Figure 3: Apparatus including 2.5 gallon bucket, water, clothespin, and copy paper.

Figure 4: Recording the threshold weight of the bucket of water - i.e., the maximum weight before slippage occurs.

A volume of approximately three kilograms of water was placed in a bucket as a starting mass. A preliminary test gripping the apparatus and lifting the bucket provided assurance that the starting weight was reasonable. A single sheet of copy paper was folded longitudinally three times to form an eight-ply strip which was looped through the handle of a bucket containing water (Figure 3 and Figure 4).

Each participant lifted the bucket from the ground with the arm approximately vertical (with the elbow at full extension) while reproducing the hand position used in the key pinch (Figure 2). For each weight, the participant gripped an unused surface of the paper and lifted the apparatus in a manner consistent across all trials, without jerking upward or changing the position of the arm or hand. If no slippage occurred, the bucket was returned to the floor, more water added, and an attempt at lifting repeated.

In this study, the threshold weight is defined as the minimum weight to result in slippage of the paper between the individual's fingers while the maximum pinch strength is maintained. Water was added to the bucket in measured increments (approximately 0.05 kg, slightly less than a quarter cup), and the total mass of the apparatus was measured for each amount. If slippage occurred, the participant would take a one-minute break and repeat the trial with the same mass to minimize the effect of hand-pinch fatigue.

To further confirm the threshold weight (when slippage occurred), the mass of the apparatus was decreased by approximately 0.05 kg, and another trial was performed. Once the threshold was reached, the combined mass of the bucket, clothespin, water, and copy paper was determined using the scale as seen in Figure 4. Each participant rested for at least five minutes between trials to reduce the effects of fatigue.

The above steps were repeated for both the dominant and non-dominant hand for a total of 10 trials (five right and five left). The trials alternated between right and left hands to mitigate fatigue that might otherwise impact the data.

RESULTS

Four volunteers participated in this study. Each was determined to be free of dermatological disease that might affect skin friction in the area under examination. For reporting purposes, each volunteer is identified by letter: A, B, C, or D. Volunteer A is a right-hand dominant, 19-years old female. Volunteer B is a right-hand dominant, 19-years old male. Volunteer C is a right-hand dominant, 20-years old female. Volunteer D is a left hand-dominant, 52-years old male.

The pinch-bucket method described above was used by all volunteers for data collection. A total of 100 data points was collected for each volunteer (a data point in this experiment consisted of a threshold bucket mass measurement and corresponding pinch dynamometer measurement). Of these, 50 data points were collected for the right hand and 50 for the left hand. A summary of the experimental data is reported in the following tables (Table 2 and Table 3). The average coefficient of static friction of human skin on copy paper was determined in this study to be 0.29 in Table 2. The average of individual dynamometer pinch strengths for both female and male subjects are listed in Table 3.

SUMMARY OF μ DATA						
	Dominant			Non-Dominant		
Subject	∝	**STDEV**	**%**	∝	STDEV	%
A	**0.32**	**0.03**	**11%**	0.30	0.03	11%
B	**0.27**	**0.03**	**9%**	0.29	0.02	8%
C	**0.32**	**0.04**	**12%**	0.31	0.03	11%
D	**0.26**	**0.04**	**14%**	0.27	0.04	14%
AVERAGE	**0.294**			0.293		
STDEV	**0.032**			0.016		
%	**11%**			6%		

Table 2: Summary of coefficient of static friction (μ) values for subjects A-D. Note that there are no units for μ because this property of matter a ratio of two forces and therefore is dimensionless.

	SUMMARY OF AVERAGE PINCH EQUIVALENT FORCE (KG) DATA					
	5 KG PINCH IS NORMAL FOR FEMALES					
	Dominant			Non-Dominant		
Subject	Pinch (kg)	STDEV (kg)	%	Pinch (kg)	STDEV (kg)	%
A	5.55	0.42	8%	5.69	0.45	8%
C	6.82	0.58	8%	7.69	1.20	16%
Average:	6.18			6.69		
STDEV	0.90			1.41		
%	15%			21%		

	SUMMARY OF AVERAGE PINCH EQUIVALENT FORCE (KG) DATA					
	7 KG PINCH IS NORMAL FOR MALES					
	Dominant			Non-Dominant		
Subject	Pinch (kg)	STDEV (kg)	%	Pinch (kg)	STDEV (kg)	%
B	7.00	0.54	8%	6.49	0.55	9%
D	7.50	0.60	8%	8.35	0.72	9%
Average:	7.25			7.42		
STDEV	0.35			1.31		
%	5%			18%		

Table 3: Summary of individual dynamometer pinch strengths for subjects A-D.

DISCUSSION

The results of this study include the determination of a value for the coefficient of static friction, μ_s, for skin on standard copy paper. Although the small sample size in this pilot study provides a less than ideal statistical confirmation of the calculated coefficient of static friction, this work involved undergraduate college student research conducted against the backdrop of the COVID-19 global pandemic. This research and value for μ_s is an introductory value that requires revisiting when large numbers of participants can be recruited and coordinated in a COVID-safe and supervised academic research setting.

An accurately determined μ_s value is necessary for evaluating pinch strength to establish impairment ratings for assessment of impact on ADLs. While the pinch dynamometer remains the standard for measurement, alternate tools have been evaluated with increasing confidence for varied populations where a common condition (Rheumatoid arthritis) is indicated [11]. It is noteworthy that pinch (and grip) strength are known to vary in relation to a wide range of conditions [12,13]. Notably, occupational demand on the hand may strengthen and improve pinch strength, even as injury or disease may impair it. There appears to be little differentiation in strength between dominant and non-dominant handgrip, although pinch strength significantly favored the dominant hand [14]. Other factors that vary by individual include body size, especially as measured by overall height, forearm length, and forearm circumference. These typically correlate in a secondary fashion with categories of sex, race, and age [15,16]. It is notable that in the literature, these latter categories are often problematically offered as primary correlating features, even though within those categories the behavioral, occupational, and lifestyle factors along with physiological features in the first list are directly relevant to the measure of pinch strength.

Age, for example, has been shown in numerous studies to be a significant factor affecting hand strength across a range of activities. Accurately measuring hand strength, therefore, can offer a correlation to estimated hand strength, but age alone would not be an appropriate guide to determining hand strength [17,18].

Sex, race, and age fail as categories to provide meaningful guides to pinch strength. All of this points to the need to record individual measures of strength by consistent and independently verifiable means, whether in the clinical setting or via telemedicine, following steps under the guidance of a skilled practitioner.

For simplicity, this study used a folded sheet of copy paper to provide sufficient strength to support the range of weight of the water-filled bucket. The thickness of the folded paper for this pinch strength apparatus was near 0.2 cm. The calibrated dynamometer used in our studies has a thickness of 2.2 cm. Other studies have found that the optimum distance between fingers to test pinch strength is closer to 5 cm [19]. The accepted thickness for measuring pinch strength is that of the standard dynamometer. The difference in measurements that may result due to varying thickness of the pinch dynamometer as compared with the folded paper in this work may need clarification in future research.

While skin conditions can result in varying values for friction, studies of these variations tend to focus on differences in body part, temperature, hydration, and the material in contact with the skin [20-23]. These differences were eliminated from consideration by maintaining the controls in this experimental approach.

From this pilot study, a value for the coefficient of static friction, μ_s, provides an essential starting point in expanding the potential for remote evaluation of pinch strength. This study determined the coefficient of static friction for skin on copy paper to be 0.29. While the range of values may grow with further testing, it seems likely that the factors affecting individual values can be determined readily and categorized effectively. Most importantly, those factors are less likely to also correlate to injury or disease that may affect pinch strength, allowing use of this technique to remain valid across changing conditions.

The pinch-bucket method proved reliable in testing pinch strength across a range of weights in order to determine the coefficient of static friction between skin and copy paper. However, the use of a specified constant weight for testing pinch strength would be sufficient to determine if an individual suffering from a work-related injury meets or exceeds Maximum Medical Improvement (MMI) criteria and is therefore eligible for medical insurance benefits. The authors recommend that a practical application of this study would be to use a standard sheet of copy paper folded as previously described and wrapped through the handle of a gallon of dairy milk. This would serve to test a pinch strength of approximately 6.7 kg using the pinch-bucket method used in this study. The AMA Guides specify average thresholds of 4.9 kg for women and 7.5 kg for men [1]. Hence a gallon of milk could be used to screen an adequate pinch strength threshold for women but is not considered an adequate threshold for men. Alternatively, a 12-packs of cans of water (or soda) for women or an 18-packs for men would meet the AMA Guide threshold [24,25].

AUTHOR INFORMATION

The principal researchers in this study were undergraduate researchers Grace Alchemy, Stanford University in Palo Alto, CA; and Sarah Alchemy, University of Puget Sound in Tacoma, WA; along with John Alchemy, MD, of Santa Rosa, CA. Research direction and review of all aspects of the experimentation and computation provided by Bruce Bolon, PhD, and Jerry Artz, PhD, professors of physics, Hamline University in St. Paul, MN; additional review and writing by Chris Young, PhD, professor of biology, Alverno College in Milwaukee, WI. Funding for this study was provided by John Alchemy, MD Medical Corporation, Santa Rosa, CA.

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