Grip Strength Evaluation in Hand Surgery

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An individual's ability to execute tasks and lead a productive life is majorly the function of hands. After hand injury or surgery, the assessment of recovery remains a questionable domain. Range of motion (ROM), sensation and grip strength are integral parameters for assessing the outcomes after hand surgery and trauma.

"Any phenomenon worth treating is worth measuring."[1]

Grip strength assessment provides an accurate, quantifiable tool for establishing realistic treatment goals and outcome data. Handgrip strength reflects the maximum muscle strength exerted by the extrinsic and intrinsic flexor muscles of the hand. Muscle strength is the maximum force/torque that skeletal muscles can exert for a short period through a voluntary contraction. Measuring the grip strength checks both intrinsic as well as extrinsic muscle strength. It is frequently used to determine hand disability ratings.

The utility of Grip strength testing has been described in the following conditions (Table-1)

To assess upper limb impairment[2].
To evaluate the work capacity after hand injuries[3].
To evaluate other disabilities/impairments, e.g. rheumatoid arthritis[4]
To determine the efficacy of treatment for various impairments/disabilities[5].
To assess the overall fitness[6].

Dynamometry is a term referred to as the measurement of mechanical force/torque. In the domain of medicine, the term is associated with the instruments that measure the strength of muscle contraction.

Measuring outcomes in hand surgery: The role of Grip Strength

Subjective vs Objective measurement:

The outcome of an intervention can be assessed using subjective as well as objective means. Patient-reported outcome measures are used to evaluate results from the perspective of patients.

Grip strength and pinch strength are performance-based measures that are used to assess the outcomes objectively. Grip strength measurement is an objective parameter that was a concept pioneered by hand surgeons for determining the functional capacity after trauma or surgery[7]. Objective measures are necessary to avoid biases and confounders from differing patient perspectives and subjective personal experiences and priorities. The measurement of grip strength is an established indicator of the hand's functional status and forearm musculature. Newman et al stated that grip strength has excellent potential to be incorporated into clinical practice as it is easier to measure.[8]

The most commonly used and cited method of measuring grip strength is by using handheld dynamometers. Handheld dynamometry is an accessible, non-invasive, and objective test that can be administered bedside .[9] The reliability, reproducibility, and validity of the currently recommended grip strength measurement methods have been established through several studies over the years.[10-14] A systematic review conducted by Bobos et al. (2020) found excellent reliability and validity measures for handheld dynamometry among normal and clinical populations. Several novel methods of grip strength measurements, including virtual reality and motion sensors, are currently under study.[15] Grip and pinch strength measurements have clinical value and are helpful prognostic and outcome indicators in hand surgery.[14]

Biomechanics of hand relevant to hand grip:

When most simplified, a hand consists of a stable wrist with at least two opposable digits with sufficient power.[16] To be able to grasp, at least one digit must be capable of motion, and the other must act as a stable post against which the first one can exert a force. Most effective use is facilitated when the digits have sensation and are free from pain.

Seven* basic manoeuvres have been described regarding the biomechanical motion of the hand that make up most of its functions (Table-2)

S. no.	Manoeuvre	Mechanism	Example	Remarks
1.	**Precision pinch**	Tips of the Index finger and thumb are brought together by flexion of the interphalangeal (IP) joint of the thumb and the distal IP (DIP) joint of the index finger	Holding a pen with the thumb and index finger	
2.	**Oppositional pinch/sub terminal pinch**	Thumb and index finger's pulp are opposed with their IP and DIP joints in extension. This allows for more force due to the increased leverage that the thumb adductors can exert with the IP joint in extension. This manoeuvre also involves the contraction of the first dorsal interosseous.	Holding a card between the pulps of thumb and index finger	
3.	**Key pinch**	The thumb is adducted to the radial aspect of the middle phalanx The prerequisites are a stable post, adequate length of the finger and a metacarpophalangeal joint (MCP) capable of resisting thumb adduction.	Holding a key between the thumb and index finger	*Pinchometers that test for pinch strength usually use the key pinch manoeuvre*
4.	**Chuck grip /directional grip**	Index finger, middle finger and thumb come together to grip a cylindrical object. Flexion of the IP, DIP, Proximal Interphalangeal (PIP) and MCP joints of the three fingers to varying degrees depending on the object being grasped. The grip is usually used to exert an axial force or a torque on the object.	Holding a screwdriver	
5.	**Hook grip**	Flexion at the PIP and DIP joints with extension at the MCP joints of one or more digits. This grip does not require a functional thumb.	Carrying a suitcase by its handle	
6.	**Power grasp**	Fingers and thumb flex such that forces are generated between the digits and the palm. It is the strongest among the seven basic manoeuvres and involves both the intrinsic flexors and the forearm flexors.	Holding a hammer for forceful blow	*Handheld dynamometers that test for grip strength use the power grasp manoeuvre.*
7.	**Span grasp**	Involves the fingers and thumb's flexion such that forces are generated between the thumb and the remaining digits. Stability of the thumb, MCP and IP joints is a prerequisite.	Grabbing a glass	

Table 2: Seven basic manoeuvres describing the bio-mechanical motion of the hand.

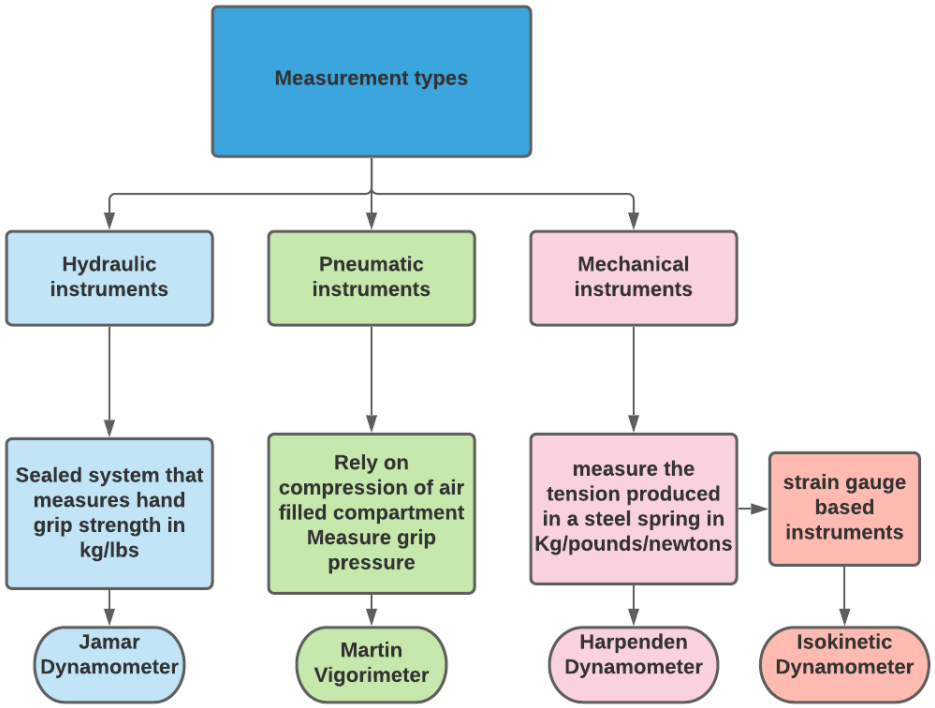
*The ***Eight basic manoeuvre***, as per Lister, is the '**flat hand'**, which is used to push off flat surfaces or use the hand between closely opposed surfaces.

After a clinical event or surgery, the hand's ability to exert appropriate forces in these positions determines the outcome of surgical interventions and recovery from injury or disability.

Methods of measuring grip strength

Handheld dynamometry remains the most feasible and widely used method for the measurement of grip strength[7,17]. In the 1950s, the Sklar, Narranganset, Collins and Geklers dynamometers were developed, however they fell out of use due to unsatisfactory results. Several types of hand dynamometers with distinct operating principles have been developed over the years. Fundamentally, all handheld dynamometers convert the mechanical force exerted by the forearm and hand musculature into a quantifiable form measureable through established methodologies. The instruments' reliability and validity depend on their design, construction, and the limitations inherent to the principle used for measurement.

The three basic principles for all types of measurement devices being used (fig 1):



(Illustration: Shivangi Saha)

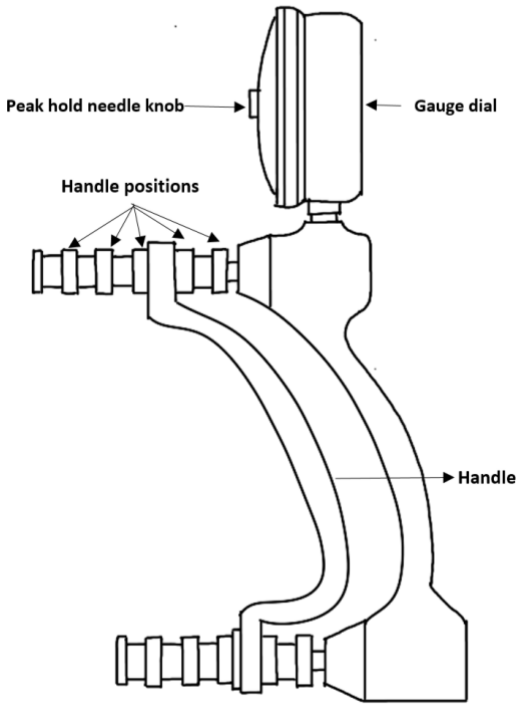
Fig 1. Basic principles and instruments for measuring grip strength.

A. Jamar Dynamometer:

The Jamar dynamometer (Fig 2) uses a hydraulic system, and the reading is measured on a gauge dial. Considered the *gold standard* among handheld dynamometers, it is a portable and economical device widely cited in the literature and has the most extensive normative data available[9,17].

It measures isometric grip force over a range of 0-90 kilograms (200 lb.), the needle retains the highest reading until the device is reset.

The width of the handle can be adjusted from a minimum of 35 mm to a maximum of 87 mm in 13 mm increments (resulting in five levels). Grip strength at the closest handle position measures intrinsic muscles' strength in isolation, while at the widest handle position, the extrinsic muscle's strength is measured in isolation. The grip strength in midspacing is the highest as both the intrinsic and the extrinsic muscles are acting. When plotted on a graph, this gives rise to a bell-shaped curve (Figure 3), i.e. less grip strength at either ends and highest in the middle.



(Illustration: Shivangi Saha)

Fig 2. Jamar Dynamometer

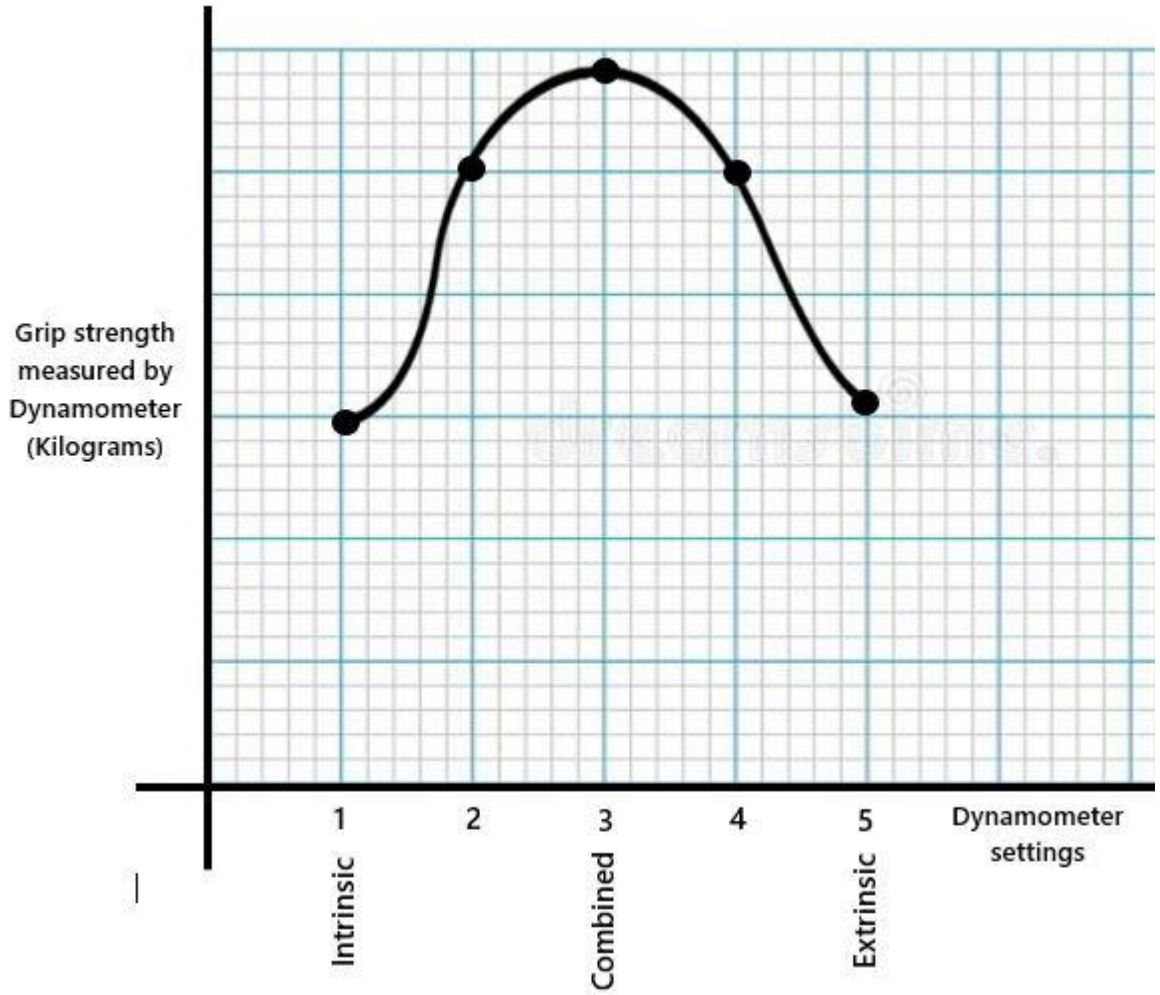


Figure 3- The 'Bell Shaped' Curve noted on tabulating the grips strengths measurements observed on the five handle settings of the Jamar Dynamometer.

This device's limitation is that it is prone to developing leaks and hysteresis over time and can cause stress on the wrist and joints of the hand[17].

B. Martin Vigorimeter:

The Martin Vigorimeter measures grip pressure by compressing an air-filled balloon connected to a manometer. Three sizes of balloons are available to be used depending on hand size[18]. The device is gentler on weak or painful joints, allowing for easier use on post-trauma patients. It is also a commonly used device in assessment of pediatric population.

Due to its principle being the measurement of pressure, its observations are more prone to variability with hand sizes because of the change in the surface area across which the force is applied. There is also the possibility of error due to air leakage[17].

C. Harpenden Dynamometer

The Harpenden Dynamometer measures handgrip strength based on the amount of tension produced in a spring. The dynamometer has limited reproducibility due to difficulties in calibrating and replicating grip position. Its spring system is prone to mechanical hysteresis and fatigue.

D. Isokinetic Dynamometer:

Isokinetic Dynamometers are computerized systems that utilize a strain gauge to measure the force applied. A strain gauge is a sensor in which the electrical resistance changes according to the strain applied to it. It can provide a broad spectrum of data relating to muscle strength, and can also ascertain the peak force, angle of maximal force, endurance, power, etc. Using these parameters, it can also generate muscle strength curves[19]. They are particularly helpful in frail patients (e.g. Duchene's, Spinal muscle atrophy)

Presently, isokinetic dynamometry is the reference standard used to compare other instruments[20]. They are not prone to leaks which can compromise accuracy[17]. However, they require a specialized set-up and technical expertise to operate. They are typically 40 to 50 times more expensive than a handheld dynamometer (which costs about $1000)[20]. Due to the high cost and the lack of portability, it's use remains limited; thus, handheld dynamometers have gained far more widespread clinical use[9].

Procedure for using Jamar dynamometry:

One of the major limitations of using the handheld dynamometry as standard tool for measuring grip strength is the lack of consensus on measurement protocols[7].

The summary of the procedure of testing for the Jamar Handheld dynamometer as recommended by the National Institute of Health Research (NIHR) South Hampton; American Society of Hand Therapists and from the manufacturer for the Jamar Dynamometer is summarized below:

i. Document the serial number of the dynamometer being used.
ii. Ensure the device is clean before use.
iii. Instruct participants to remove shoes, accessories, jewelry and articles of clothing over the hand and forearm.
iv. Record the participant's hand dominance; the right and left hands are tested alternately.
v. Demonstrate how the Jamar dynamometer is to be held and the test conducted by performing it on yourself.
vi. Posture and position: The American Society of Hand Therapists recommend that grip strength be assessed with the participant in sitting position with their shoulders adducted, elbows at 90° of flexion and wrists in neutral. This method was associated with high intra-test and inter-test reliability[11]. (Fig 4)
    a. Use a chair with low back support. It is ideal to use the same style of chair for every measurement.
    b. Instruct the participant to rest their feet flat on the floor. Ensure that the participant's feet remain flat when squeezing the dynamometer.
    c. Hips to be at 90° of flexion with the spine in neutral.
vii. The Jamar dynamometer is to be held by its handle in the power grasp position. One side of the handle is held against the thenar and hypothenar surfaces with the thumb flexed around it. The other side is the be held against the palmar surfaces of the remaining digits in flexion. The handle width must be adjusted according to the hand size to ensure this position. The separation of the fingernails from the palm can be used as a guide.
viii. Confirm that the instrument feels comfortable in the hand of the participant. The measurer should support the dynamometer's weight while the subject holds it without restricting the device's movement.
ix. Start with the right hand and then repeat the measurement with the left.

x. Ensure zero position of the needle and instruct the patient to squeeze.

xi. For the best result, encourage squeezing for as long and as tightly as possible until the needle stops rising. It is recommended to use a standard squeeze phrase, *"Squeeze……harder, harder…and stop squeezing".*

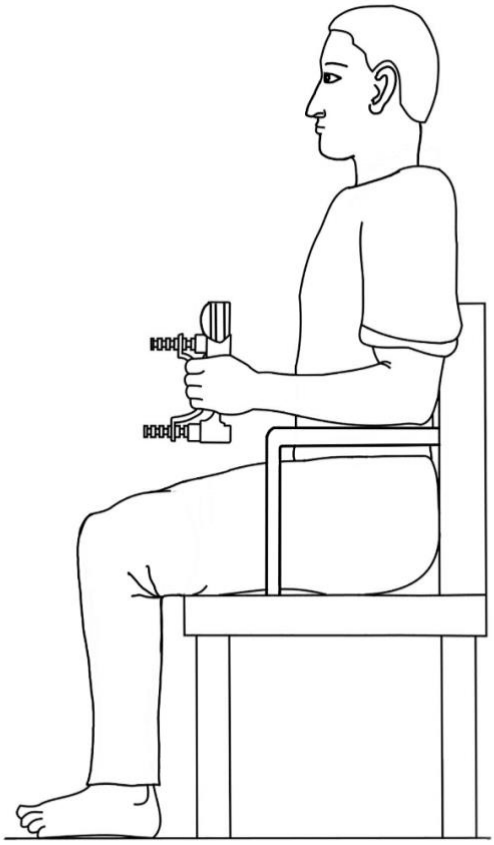
xii. When the needle stops rising, read the measurement from the dial.

xiii. Disregard or repeat the test if the participant's arm rises above the armrest or if they lift their feet off the floor during measurement.

xiv. Record three measurements at each handle position for each hand alternating between sides with adequate resting time in between measurements.

xv. Comparison index = Trial mean/ Pretrial mean X 100

or Trial mean/established normal (for age, gender, dominance, occupation etc.) X 100.



(Illustration: Shivangi Saha)

Fig 4: Sketch diagram depicting correct position for assessing Grip Strength.

Sources of Error and other considerations:

The reliability of dynamometry depends on the type of device being used and the patient's clinical profile. If the patient is too weak even to move limbs or too strong to overpower the

tester, the dynamometer's reliability becomes questionable[21,22]. A handheld dynamometer's reliability also depends on age, gender, weight, palm-size, hand dominance, time of the day, usual occupation, and motivation level. Thus it is essential to document these factors[23].

Maximum reading values are recorded at the first or second attempt and usually at the second or third handle position. While it is best to obtain readings at all the five handle positions, the American Society for the surgery of hand recommends the ***second handle*** position while evaluating the strength. Mc Mohan suggested placing the dynamometer farther from the joint to improve its reliability[24]. Regarding its reproducibility, Lindstrom-Hazel et al[25] stated that occupational therapists could be trained for reliable testing with a dynamometer.

It is critical to ensure consistency in measurement as posture, arm side and handle position of the dynamometer can affect maximum grip strength[11,26,27]. In cases where the participant is unable to be seated, the measurements can be made using a comfortable posture for the participant in a consistent manner, i.e. the same posture should be used for all measurements[26,27]. If in the sitting pose, the forearms should be resting on the armrests, and feet should be flat on the floor throughout the measurement. The participant must take care to focus their effort on squeezing and keep other muscle groups relaxed.

Fess has proposed a solution to waive away fatigue in protocols by giving a 5-minute rest after each handle setting during three trial systems for five consecutive handle readings [28].
It is also essential to periodically recalibrate the dynamometer being used to maintain accuracy in measurements.

Reference Values and Factors that Influence grip strength.

The factors which exert an influence over muscle mass and strength would affect grip strength as well. As discussed earlier, grip strength varies with age, sex, nutritional status, and occupation. Hence, dynamometry is more suited for establishing a baseline and measuring outcomes at the individual level. A person's grip strength in the dominant hand is 10% greater than a non-dominant hand[29].

Reference values of handgrip strength using the Jamar dynamometer have been established through multiple studies in normal individuals and many patient sub-groups amongst several

population groups. Most of these studies have been conducted on the western population. Given the multitude of genetic, environmental, and lifestyle distinctions between the Indian and Western people, western studies may not apply to the Indian population regarding reference ranges. The reference values for handgrip strength in the Indian population are as follows (Table-3)

Hand	**n**	**Mean**	**S.D**	**S.E**	**t**
Dominant (Rt.)	50	30.1480	10.0743	1.4247	8.601 p=.001***
Non-Dominant (Lt.)	50	27.2440	10.4572	1.3095	
Dominant (Lt.)	50	29.4320	9.5507	1.3507	4.211 p=.005**
Non-Dominant (Rt.)	50	28.5280	9.6110	1.3592	

Table 3 - The reference values for handgrip strength in Indian population[30].

Pathologies affecting handgrip strength:

Among patients, grip strength can be further affected by disease and injury. In a systematic review, Mafi P et al[31] described the dynamometer uses for multiple different medical applications other than hand trauma. A list of some pathologies known to reduce muscle strength have been enlisted below (Table 4)

Cerebral palsy	Duchene Muscular Dystrophy (DMD)	Stroke	Coronary artery bypass grafting
MB leprosy	Cystic fibrosis	Coronary artery disease	Liver transplant
Huntington's Disease	COPD	Tetraplegia	Rheumatoid arthritis
Charcot-Marie-Tooth (CMT) disease	Ulnar and median nerve injuries	Osteoarthritis	ESRD (end stage renal disease)
ICU-acquired paresis	Capsulitis	Hemiparesis	Chronic PD patients
Malnutrition	Pneumonia	Oral and maxillofacial cancer	Cirrhosis
Patients with disability	Acute rehabilitation	Gastrointestinal cancer	Hip fracture
Spinal cord injury	Haematological cancer	Spina bifida	Spinal muscular atrophy (SMA)

Table 4 - List of pathologies affecting grip strength[31]

Interesting Clinical Applications of Grip Strength Measurement!

Apart from being one of the most widely used objective assessment in hand surgery, grip strength evaluation can be used to objectively assess ***malingering (insincere effort) in the following ways:***

a. On repeat testing, a patient who applies less than maximal effort will not reproduce the exact grip strength of the previous attempt, and the discrepancy will be > 20%.

b. The characteristic bell-shaped curve would be replaced by a flat curve (Figure 5). Most of the clinical conditions reducing grip strength would still result in a bell-shaped curve when the grip strength of the five handles is plotted and a flat curve strongly indicates insincere effort or malingering. The patients with an intrinsic minus hand are the exception to this rule. Their grip will increase from level I to level V because the extrinsic flexors have a greater mechanical advantage at the wider handle spacing.

c. Sincerity of Effort (SOF) can also be assessed by checking the grip strength in three wrist positions- flexion, neutral and dorsiflexion.[32]

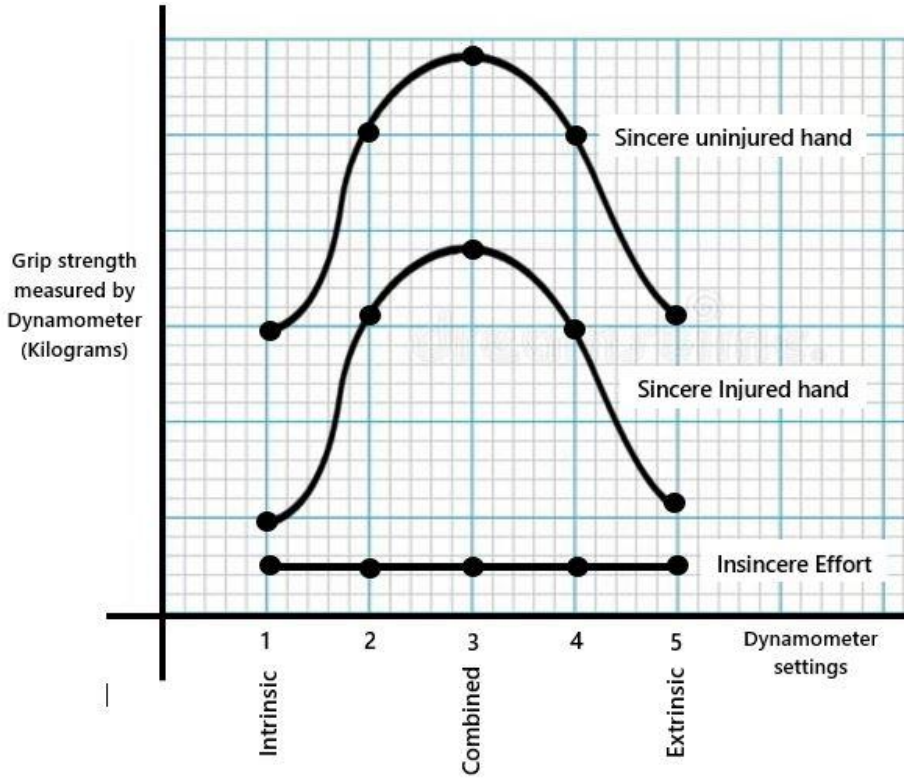


Figure 5: The curve obtained by tabulating the grip strengths measured on the five handles in an injured or normal hand would be a bell-curve. However, an insincere effort would demonstrate a flat curve.

Use of Sphygmomanometer for Assessment of Grip Strength:

As mentioned earlier, Handheld dynamometry remains the most feasible and widely used method for the measurement of grip strength. However, in many clinical settings, the dynamometer is not easily available because of its relatively high cost. An alternative method to measure grip strength in an objective manner and at a lower cost is to use the sphygmomanometer. Sphygmomanometer is the device commonly used and easily acquired by health professionals to measure blood pressure. This method can be used to measure grip strength at the bedside more objectively. First, the sphygmomanometer is rolled into a cylinder comfortable for the patient to grip at rest. The cuff is then inflated to 20 mmHg, and the patient applies maximal grip force to the cuff. The gauge needle indicates the patient's applied pressure.

Use of sphygmomanometer has often been questioned for its accuracy, reliability, and reproducibility. One of the drawbacks with this method is, it may not detect subtle changes in the grip strength. Furthermore, in sphygmomanometer the grip strength is measured in terms of mmHg whereas Jamar dynamometer measures grip strength in kilograms or pounds (lb) making the comparisons impossible. Interestingly, a formula for conversion of the sphygmomanometer scores into Jamar units has been proposed by Hamilton GF et al., to enhance reporting of sphygmomanometer scores utilizing the Jamar standard.[33]

Jamar = .54 x Sphygmomanometer - 45.12

The above formula gives Jamar values in PSI (Pounds for square inch). This study also showed that the sphygmomanometer and Jamar dynamometer exhibit good within-instrument reliability.

Conclusion:

Handgrip strength reflects the maximum muscle strength exerted by the extrinsic and intrinsic flexor muscles of the hand. Grip strength measurement is an objective parameter pioneered by hand surgeons for determining the functional capacity after trauma or surgery and aiding prognostication. The most commonly used and cited method of measuring grip strength is by using handheld dynamometers. Handheld dynamometry is an accessible, non-invasive, and objective test that can be administered bedside.

Jamar dynamometer is the most used dynamometer worldwide. The gold standard among handheld dynamometers, it is a portable and economical device and has the most extensive normative data. Its reliability depends on physiological parameters such as age, gender, weight, palm-size, hand dominance, occupation, nutrition and pathological conditions.

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References:

1. Hunter JM, Mackin EJ, Callahan AD. Rehabilitation of The hand:Surgery and Therapy. 4th ed. Mosby Incorporated; 1995.
2. Blair, S. J., McCormik, E., Bear-Lehman, J., Fess, E.E., and Rader, E. evaluation of impairment of the upper extremity. Clinical Orthopeadics and related Research.1987: 221: 42-58.
3. Berryhill, B.H Returning the worker with an upper extremity injury to industry. A model for the physician and therapist. Journal of Hand Therapy. 1990: 3: 56- 63.
4. Blankenship, K.L. The Blankenship system functional capacity evaluation: the procedure manual: 2nd ed. Macon: the Blankenship corporation.
5. Sheehan, N. J., Sheldon, F., and Marks, D. Grip strength and torquometry in the assessment of the hand function in-patient with RA. British Journal of Rheumatology.1983: 22: 159-164.
6. Balogun, J, A. Assessment of physical fitness of female physical therapy student. Journal of Orthopedic and Sports Physical Therapy.1987: 8: 525-532.
7. Norman K, Stobäus N, Gonzalez MC, Schulzke J-D, Pirlich M. Hand grip strength: outcome predictor and marker of nutritional status. Clin Nutr Edinb Scotl. 2011 Apr;30(2):135–42.
8. Newman AB, Kupelian V, Visser M, et al. strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci 2006; 61(1): 72-7.
9. Bohannon RW. Muscle strength: clinical and prognostic value of handgrip dynamometry. Curr Opin Clin Nutr Metab Care. 2015 Sep;18(5):465–70.
10. Hamilton GF, McDonald C, Chenier TC. Measurement of grip strength: validity and reliability of the sphygmomanometer and jamar grip dynamometer. J Orthop Sports Phys Ther. 1992;16(5):215–9.
11. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg. 1984 Mar;9(2):222–6.
12. Bohannon RW. Hand-grip dynamometry provides a valid indication of upper extremity strength impairment in home care patients. J Hand Ther Off J Am Soc Hand Ther. 1998 Dec;11(4):258–60.

13. Bohannon RW, Peolsson A, Massy-Westropp N, Desrosiers J, Bear-Lehman J. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiotherapy. 2006 Mar 1;92(1):11–5.
14. Bobos P, Nazari G, Lu Z, MacDermid JC. Measurement Properties of the Hand Grip Strength Assessment: A Systematic Review With Meta-analysis. Arch Phys Med Rehabil. 2020 Mar 1;101(3):553–65.
15. Nica AS, Brailescu CM, Scarlet RG. Virtual reality as a method for evaluation and therapy after traumatic hand surgery. Stud Health Technol Inform. 2013;191:48–52.
16. Duncan SFM, Saracevic CE, Kakinoki R. Biomechanics of the hand. Hand Clin. 2013 Nov;29(4):483–92.
17. Roberts H, Denison H, Martin H, Patel H, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardized approach. Age Ageing. 2011 Jul 1;40:423–9.
18. Solgaard S, Kristiansen B, Jensen JS. Evaluation of instruments for measuring grip strength. Acta Orthop Scand. 1984 Oct;55(5):569–72.
19. Li RC, Jasiewicz JM, Middleton J, Condie P, Barriskill A, Hebnes H, et al. The development, validity, and reliability of a manual muscle testing device with integrated limb position sensors. Arch Phys Med Rehabil. 2006 Mar;87(3):411–7.
20. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held Dynamometry Correlation With the Gold Standard Isokinetic Dynamometry: A Systematic Review. PM&R. 2011 May;3(5):472–9.
21. Mahony K, Hunt A, Daley D, Sims S, Adams R. Inter-tester reliability and precision of manual muscle testing and handheld dynamometry in lower limb muscles of children with spina bifida. Phys Occup Ther Pediatr 2009; 29(1): 44-59.
22. Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. J Sport Rehabil 2008; 17(2): 160-70.
23. Wadsworth C, Nielsen DH, Corcoran DS, Phillips CE, Sannes TL. Interrater reliability of handheld dynamometry: effects of rater gender, body weight, and grip strength. J Orthop Sports Phys Ther 1992; 16(2): 74-81.

24. McMahon LM, Burdett R, Whitney SL. Effects of muscle group and placement site on reliability of handheld dynamometry strength measurements. J Orthop Sports Phys Ther 1992; 15(5): 236-42.
25. Lindstrom-Hazel D, Kratt A, Bix L. Interrater reliability of students using hand and pinch dynamometers. Am J Occup Ther 2009; 63(2): 193-7.
26. Balogun JA, Akomolafe CT, Amusa LO. Grip strength: effects of testing posture and elbow position. Arch Phys Med Rehabil. 1991 Apr;72(5):280–3.
27. Hillman TE, Nunes QM, Hornby ST, Stanga Z, Neal KR, Rowlands BJ, et al. A practical posture for hand grip dynamometry in the clinical setting. Clin Nutr Edinb Scotl. 2005 Apr;24(2):224–8.
28. Fess EE. The effects of Jamar dynamometer handle position and test protocol on normal grip strength. Proceedings of the American Society of Hand Therapist. J Hand Surg (Br) 1982;7: 308–310.
29. Petersen P, Petrick M, Connor H, Conklin D. Grip strength and hand dominance: challenging the 10% rule. Am J Occup Ther. 1989 Jul;43(7):444-7.
30. Bansal N. Indian Journal of Physiotherapy and Occupational Therapy.Hand grip strength: Normative data for young adults; Vol. 2, No. 2 (2008-04 - 2008-06).
31. Mafi P, Mafi R, Hindocha S, Griffin M, Khan W. A systematic review of dynamometry and its role in hand trauma assessment. Open Orthop J. 2012;6:95-102. doi: 10.2174/1874325001206010095. Epub 2012 Feb 23. PMID: 22423305; PMCID: PMC3296111.
32. Bhuanantanondh P, Nanta P, Mekhora K. Determining Sincerity of Effort Based on Grip Strength Test in Three Wrist Positions. Saf Health Work. 2018 Mar;9(1):59-62.
33. Hamilton GF, McDonald C, Chenier TC. Measurement of grip strength: validity and reliability of the sphygmomanometer and jamar grip dynamometer. J Orthop Sports Phys Ther. 1992;16(5):215-9.