CHAPTER 2

HAND ASSESSMENT INSTRUMENTS

When a person experiences a hand injury, an accurate assessment of the type and extent of the injury can indicate the length of time to recovery and any residual impairment and disability. Whilst a person undergoes treatment for their injury, whether that treatment is pharmaceutical, surgical, or conservative therapies, the consumer (the patient) and the service payee (the patient, or insurance company) will want to know if the intervention is effective. This chapter will focus on assessment methods commonly used by clinicians, especially Hand Therapists\(^1\) as baseline assessments and as indicators of changes in hand function as a response to treatment.

1. PEN AND PAPER TESTS

There are many ways to assess an injury and measure the effects of intervention. Typically, clinicians measure such aspects as range of motion, grip strength and sensory function. However, these parameters do not directly measure hand function, or the perception that a patient has of his or her own health. One indirect way to measure function is to ask the patient to self-assess how they are progressing. This approach is often not seen as objective, or accurate, as small improvements from day to day may not be recognised by the patient. Also, this approach may be seen as open to either over or under-exaggeration, either intentionally, or unintentionally. However, the self-reporting of functional abilities has been shown to be reliable and valid when standardised self-report questionnaires are given to patients. Over the last 30 years many such questionnaires have been developed. Some are pathology-specific, others are age, or culture specific. Specific tools are usually more sensitive to change, than generic ones, but only a few have been developed for the upper limb.

\(^1\) Hand Therapists are either Occupational Therapists, or Physiotherapists who have acquired specialist skills in the treatment of pathology to the hand and upper limb.
One commonly used self-report questionnaire that has been developed for the upper limb is the Disability of Arm Shoulder and Hand (DASH). It was developed conjointly by the American Academy of Orthopaedic Surgeons, the Council of Musculoskeletal Specialty Society, and the Institute of Work and Health in Toronto (McConnell, Beaton & Bombardier, 1999). This 30-item questionnaire provides information about how the patient perceives his or her symptoms and functional status for activities of daily living, with four extra questions each specifically for sports/performing arts and work. Although it is not pathology-specific, it has been shown to be valid and reliable for measuring functional changes in various upper limb conditions, and has been promoted as being able to compare functional outcomes across upper limb pathologies (Beaton, Katz, Fossel, Wright, Tarasuk & Bombardier, 2001). Since its introduction in 1997 it has been translated and adapted for many language and cultural groups, one of the most recent being an adaptation into French-Canadian (Durand, Vachon, Hong & Loisel, 2005).

Upper limb joint-specific questionnaires include such examples as the Patient-Rated Wrist Evaluation (PRWE). This is also a short, self-assessment questionnaire. It has been shown to be sensitive to improvements in patients with distal radial fractures over a one-year follow-up period (MacDermid, Richards & Roth, 2001). Clinicians are encouraged to use such assessment tools for comparing the abilities of a patient over time and for comparisons with average scores for other similarly diagnosed patients over the same recovery stages. It is believed that “baseline patient scores are the most influential predictors of final status” (MacDermid et al., 2001).

MacDermid et al. (2001) assessed and followed 250 patients with distal radial fractures for one year post-trauma. They used a number of assessment tools, including active range of motion (ROM), the DASH, the PRWE and grip strength scores. When these indices were plotted over a year, the improvements in all four measures were similar. Thus each of these tools resulted in an assessment with a certain degree of overlap that could be used to validate the other tools.
2. TOOLS TO MEASURE SENSORY NERVES

A hand that cannot feel, or is slow to respond to painful stimuli, is not a hand that is safe and efficient to use for everyday tasks (Brand & Hollister, 1999). Although sensation is a vital function, in comparison to grip strength assessment tools, there are only a few tools available to measure its integrity. The common sensory assessment tools can be divided into two classes, functional and physiological.

Functional tests include all tests which require the patient to give an intentional response, such as tests of vibration threshold, electrical current perception threshold (the Neurometer™ by Neurotron, Baltimore), light touch, pin prick, one and two point discrimination, Tinel’s tapping test, hot or cold perception thresholds and pressure sense. Novak (2001) points out the difficulties with quality control and monitoring of contact time and application of force with one and two point discrimination, light touch tests such as the monofilament tests. With the exceptions of the Neurometer™ and the monofilaments, the patient must be able to remember and compare the stimulus on the normal hand with that presented to the injured hand. Thus most of these tests assume unilateral neuropathology (Novak, 2001).

There are also functional tests that rely on the integration of various aspects of sensory abilities, such as timed pick-up tests that require the patient to pick up and identify small items, with vision occluded. Brand and Hollister (1999) recommend the approach of Omer, whereby the speed and accuracy of one hand is compared to that of the other hand. However, if both hands have been injured, the quality of the performance must be compared with normative data from healthy people.

Common physiological tests for sensory function are tests such as the sensory nerve velocity condition test (sNVCT). The sNVCT is limited to assessing only the large myelinated sensory nerve fibres in a measured section of a peripheral nerve. Conduction velocities can be obtained without cortical input, and so can be taken from unconscious patients and up to six hours after death. They are thus not functional tests assessing the whole finger-tip to cortex integrity of the sensory nerves. Heybeli, Kutluhan, Demirci, Kerman and Mumcu (2002) found no correlation
between improvements in nerve conduction and clinical outcome questionnaire scores of carpal tunnel syndrome at 3 and 6 months post-surgical release, as compared to preoperative values. Thus accurate and clinically useful sensory nerve testing is far more difficult to achieve than that of grip strength unless clinicians wish to invest in sophisticated tools such as the Neurometer™.

3. MEDICO-LEGAL IMPLICATIONS OF LOSS OF HAND FUNCTION, AS REFLECTED IN LOSS OF GRIP STRENGTH, ACCORDING TO VARIOUS AUTHORITIES

AMA Guides

The authors of The Guides to the Evaluation of Permanent Impairment (American Medical Association, 2000) consider that grip strength tests are influenced by factors that are difficult to control, such as fatigue, handedness, time of day, age, nutritional state, pain, and the individual’s cooperation. Accordingly, the Guides main weightings are based on “anatomical impairment”. The authors state “increased strength does not necessarily equate with increased function” (p. 507). However, the Guides do allow for an examiner to rate the loss of strength separately if the loss of strength represents an impairing factor that has not been considered adequately by other methods in the Guides. For example, if there is a loss of strength due to a severe muscle tear that has healed leaving a palpable muscle defect, the examiner can rate the loss of strength separately in an arm that has other impairments, such as a joint range of motion limitation. When maximal force cannot be generated due to pain, neuromuscular conditions, or amputations etc., these other factors must be rated in preference to the strength loss.

These Guides are currently used by many legal and insurance companies in Australia as a means of assessing upper limb impairment (Le Leu & Shanahan, 1994; Streeton, 1994). The authors of the Guides consider that “maximal strength is usually not regained for at least a year after an injury or surgical procedure” (p. 508). Thus they recommend taking measurements over a “period of time”. The authors consider that pinch and grip strengths are used to “evaluate power weakness relating to the
structures of the hand, wrist, or forearm. Manual muscle testing of major muscle
groups is used for testing about the elbow and shoulder” (p. 508). However, many
other authorities consider grip strength to be a good general reflection of upper limb
strength (Bohannon, 1991; Innes, 1999) or whole body strength (Kerr, Syddall,
Cooper, Turner, Briggs & Sayer, 2006).

The Guides authors consider that there is insufficient evidence to consider dominance
in the impairment ratings, but at the same time they present grip strength norms for
use with bilateral injuries, including separate averages for the “major” and “minor”
hands, as reproduced from Swanson, Matev and de Groot (1970). In the chapter on
the principles of assessment it is stated that for some people hand dominance can have
a major impact on activities of daily living (p. 435).

Queensland injury settlement groups

In assessing common law claims for general damages in Queensland, Newton (2005)
quoted the Civil Liability Act (2003) section 61 as dictating that the injury scale value
(ISV) system should be used. The ISV is a 100-point scale from 0 to 100 and relates
directly to a dollar value awarded for compensation. Thus an ISV of 35 to 40 equates
to $56,000 to $68,000 and it is capped at $250,000. The ISV is calculated according
to schedule 4 of the Civil Liability Act and is based heavily on the AMA Guides (5th
edition). An ISV of not more than 10 is considered appropriate if there is a ‘whole
person impairment’ of 8% caused by soft tissue injury for which there is no
radiological evidence. This ‘whole person impairment’ is calculated from the Guides.

Veteran Affairs

The Department of Veteran Affairs has its own guides for evaluating permanent
impairment. Their personnel use the Guides to Assessment of Degree of Permanent
Impairment for Comcare, which is taken from the Safety, Rehabilitation and
Compensation Act of the Comcare Act of 1988 (SRC8 of 1988). They may also use
the other Guides.
SUMMARY

As can be seen from the above discussion, measuring grip strength is considered to be an important part of any injury assessment and outcome measure. Grip strength testing tools have advanced to sophisticated isokinetic tools. The next part of this chapter presents the design, advancement and utilisation of these grip strength assessment tools.

4. HISTORY OF GRIP STRENGTH TOOLS

The history of the evolution of strength assessment tools reflects the history of the professions that have developed and used them (Davis, 1978). The chronology of their development also describes the direction and the problems encountered with their adaptations, some of which are still pertinent. There has been variation in the rationale for comparing the strength of a person from time to time, and in the motivations for comparing one person to another. These have ranged from the monitoring of health status (Kellogg, 1893), assessing the impact of an injury (Geckler, 1939), identifying ‘superior human breeding stock’ (Galton, 1907), to assessing the effects of electrotherapy (Cheing & Luk, 2005; Hammond, 1868), and to pure ego (Horne & Talbot, 2002).

William A. Hammond MD, wanted to elevate the status of neurologists above that of general practitioners, partly by the use of “sophisticated tools” such as the handgrip dynamometer and dynamograph (Hammond, 1876). The people who invented the machines were often the people who used them, such as Dr. John Harvey Kellogg, Dr. William Hammond and Sir Francis Galton.

There is scant information about early strength assessment tools. Much of the ancient writings have been lost during wars in which libraries have been destroyed, such as the library in Alexandria, which at its peak around 330 B.C. is said to have possessed over 750,000 papyrus scrolls (Parsons, 1952). Thus, as far as can be determined, the first information pertaining to instruments that measure upper limb strength appeared in 1699 A.D. It was then that the Frenchman De La Hire produced the first scientific
study of muscle strength. Upper limb strength was measured by the ability to lift loads of known weights (Evans, 1981; Hunsicker & Donnelly, 1955). This method was impractical for field researchers as the loads were too heavy to take on data-gathering expeditions. In the early 1700s there was growing anthropological curiosity about strength differences between the genders and between different racial groups, as English and European explorers discovered the occupants of distant lands (Pearn, 1978a, 1978b). Anthropologists (or naturalists) became interested in measuring strength with tools that were portable and accurate.

EARLY DYNAMOMETERS

At the beginning of the 18\textsuperscript{th} century, a Frenchman at Oxford University named John Theophilus Desaguliers had a “great interest in the physics of human muscle action, [thus]… he designed the dynamometer, which bears his name” (Pearn, 1978b, ¶ 8). The device was only a slight modification of one made a few years earlier by George Graham, the clock maker. There are no records of the exact construction of the one made by Graham. The dynamometer Desaguilers produced in 1763 was named the Graham-Desaguliers dynamometer to recognise the contribution of Graham (as cited in Pearn, 1978b).

Desaguliers was the first to establish a standard position for muscle testing, which in turn made quantitative dynamometry possible. He established that there was variability in the strength of individual muscles from person to person even though their physical appearance was comparable.

In 1798 Régnier (a Parisian mechanical engineer) described a dynamometer invented by Leroy, circa 1790. This dynamometer was able to test the strength of individual fingers or a hand as described in Horne & Talbot (2002, ¶ 2):

It consisted of a metal tube, ten to twelve inches long, which stood on a base. Inside the tube was a spring and surmounting this, a rod with a scale, which was graded for difficulty. At the top of this rod was a small globe/plunger,
which could be pressed with resistance by a finger or hand, and the strength was indicated by the level that could be read on the scale.

In 1798 Régnier wrote that the French anthropologists Buffon and Gueneau of Montbelliard wanted to compare the strength of men across a number of muscle groups. They thought that the dynamometer made by Graham was “too large and too heavy to be carried” and that which was made by Leroy was considered to be too specific (as cited in Pearn, 1978b, ¶13). They thus commissioned Régnier to invent a multi-purpose dynamometer, but before it was completed they died in the French revolution. The physician Coulomb, who encouraged Régnier to continue work on his design, wanted the instrument to measure a large range of forces, from human strength to the pulling strength of bridled animals (see Figures 2.1, 2.2 and 2.3). The mechanics of the dynamometer were described as “Distortion of a sprung steel bar, which operated a pointer, the movement being magnified through a lever system” (¶13). Various attachments were also designed (see Figure 2.4). Régnier was the first person to give a medical reference to the use of dynamometers as being for measuring “relative strength at the different stages of life, and in different states of health” (¶13).

Figure 2.1. The dynamometer invented by Edme Régnier in 1798 and used by Péron in his Australian experiments. From the original engraving accompanying Régnier’s work Description et usage du dynamomètre. S: position to test the muscular strength of the thighs; R: the handgrip position to test the force of the grasp (from Pearn, 1978a).

![Image of the dynamometer invented by Edme Régnier in 1798 and used by Péron in his Australian experiments.](image-url)
Figure 2.2. Diagrammatic sketch of Régnier’s dynamometer (from Hunsicker & Donnely, 1955).

Figure 2.3. Régnier’s dynamometer (from Pearn, 1978).

Figure 2.4. Régnier’s dynamometer with attachments as it stands in the Musée de L’Armée, Paris (from Horne & Talbot, 2002).
In 1798 Régnier gave an eloquent description of the dynamometer in his book *Mémoires Explicatifs du Dynamomètre et autres machines inventées par le C:*

The dynamometer is also impressive to observe: an elliptical spring, which serves as the frame of the apparatus, covered with leather (so as to prevent the hand from injury) and forged of tempered steel. Surmounting this is an engraved brass double scale shaped almost like an open fan. One scale shows results in myriagrams (one of which equals just over 20 lbs.), which rises by 10 lbs per mark, was used for any experiment that required the dynamometer to be elongated, such as testing the strength of the lower back: in fact, any movement that caused the two ‘elbows’ of the ellipse to be pulled apart. The second scale was intended to be used when both ends of the ellipse were being squeezed together, such as when testing the strength of the hands. … The entire object is 12 inches long. With it was supplied an iron stand, …[with attachments] to test the strength of the back. Along with this is an iron hook …[along with other attachments which were employed] in order to ascertain the strength of a horse pulling against the machine. (as cited in Horne & Talbot, 2002, ¶5)

Note the use of leather to cover the area gripped by the hands to “prevent the hand from injury”. The complaints of the ‘hardness’ of the handles hurting the fingers as they grasp the device is a recurring theme throughout the development of grip strength assessment tools, and is still recorded as a complaint today (Massey-Westropp, Rankin, Ahern, Krishnan & Hearn, 2004).

**Isometric, “isotonic” and isokinetic grip strength measuring tools**

At this point, three terms concerning muscle contractions need to be distinguished, as noted by Soderberg (1986), for through the historical development of measurement tools different aspects of muscle contraction were being determined. Firstly, an isometric muscle contraction occurs when the two ends of a muscle are fixed, the muscle develops tension, but does not change length. Isometric dynamometers measure the effort, or the force generated by the muscle when there is no change in length. The force exerted on the tool is typically reported in pounds of force,
kilogrammes of force, or more correctly Newtons. This force is also called ‘static strength’.

Secondly, there are two types of isotonic contractions. Concentric isotonic contractions occur when the muscle contracts, develops tension and then when this tension exceeds the load (or the external counterforce) the muscle is able to shorten and move the load, thereby performing work. Eccentric isotonic contractions occur when the muscle is activated to contract, but then because the external load is greater than the internal tension developed, the muscle lengthens whilst maintaining tension. Because the muscle is shortening, or lengthening as it contracts, this type of strength development is called ‘dynamic strength’.

Some tools have been developed that can measure the maximum load that a muscle can move, or lift (using dynamic strength), for example, the Ergograph by Mosso (Hunsicker & Donnelly, 1955). Other devices such as pneumatic (air-filled) and hydraulic (liquid-filled) manometers, and spring-loaded resistive devices, have all allowed the hand to contract around a yielding handpiece and have the muscles shorten with effort against the measurement tool. The outcome measurements produced from these devices are in essence a final maximum isometric force, or effort, at a new final muscle length, peculiar to that device. These devices have often incorrectly been labelled as isotonic measurement tools. There are no true isotonic tools, because an isotonic contraction should be measured by muscle shortening, or lengthening, not force. But the tools that are typically employed to measure weak grip, are these soft, yielding, bulb-like devices that allow the hand to contract and the flexors to shorten as much as pain and strength allow. There are components of static and dynamic muscle activity in these measurements and changes in muscle length to be considered, when appraising the nature of these measurement devices.

Because the early dynamometers measured the distortions to elliptical steel rods through a lever system to magnify the distortion on a display dial, there would have been some small isotonic component to the applied forces, but the force was considered to be isometric. These ‘near isometric’ dynamometers, were used for many years before true isometric (and later isokinetic) tools were invented.
Thirdly, there are isokinetic contractions, which literally mean “constant, or same speed”. Thus an isokinetic device allows a muscle to perform at a constant velocity whilst it is lengthening or shortening. Isokinetic muscle force is sometimes called “dynamic muscle strength” (Dvir, 1997). It is “commonly measured using isokinetic dynamometry and it refers to the torque-generation capacity of muscles during their concentric (muscle shortening) or eccentric (muscle lengthening) contractions” (Dvir, 1999, ¶4). Isokinetic handgrip dynamometers measure effort against a two-piece handle moving either together or apart from each other at a set speed. The hand strength measurement tools measure concentric, or eccentric strength, of the finger flexor muscles anywhere along the movement continuum of full finger flexion to full finger extension. Their force units of measurement are usually displayed as Newtons, or Newton/meters. These tools were not available until the late 20th century.

**The first recorded comparative grip strength study**

The first recorded comparative grip strength study between a number of racial groups was conducted by the Frenchmen François Péron and Louis de Freycinet. In Australia in the year 1800, they used the Régnier dynamometer to compare the strength of five racial groups (Pearn, 1978a).

One hundred years later, the Régnier dynamometer was still in use for recording the progress of strength training in athletes. In 1902 Professor Edmond Desbonnet, the famous French physical culturist, trainer of strongmen and wrestlers, asked “Apollon” (Louis Uni) to try the Régnier dynamometer. Apollon recorded a force of 153 Kg. He refused to perform more than one trial; he complained that it hurt his hands (as cited in Horne & Talbot, 2002).

Other dynamometers followed the design of that of Régnier. Amongst these were the George Tiemann dynamometer (see Figure 2.5) from the 1800s and the Marine Compass Company’s apparatus from circa 1910 (Horne & Talbot, 2002).
Sir Francis Galton

Sir Francis Galton was called the “Great Man of Measurement” because he wished to measure all human parameters, including anthropometrics and intelligence (Forrest, 1974, p.183). He invented many “mechanical, optical and other contrivances” (Forrest, 1974, p.289). Woo and Pearson (1927) cite a tool Galton used to test the “grip in lbs. of right and left hands” (p. 165) of 7,000 British men during the 1880s (Jensen, 2002; Woo & Pearson, 1927). Hunsicker and Donnelly (1955) described this dynamometer as a spring scale dynamometer that had a clock-like face that was used to measure push and pull forces of the upper arms.

William Alexander Hammond

Dynamometers came into general use by North American neurologists in the late 19th century (Lanska, 2000). The Collin and Mathieu dynamometers (see Figures 2.6 and 2.7), both modifications of that by Régnier, were popular in France at that time (Hunsicker & Donnelly, 1955). One of the first neurologists in the United States of America was William Alexander Hammond. He was initially interested in promoting the Mathieu dynamometer and the Mathieu dynamograph, used to graphically record measurements made over time with a dynamometer (see Figure 2.8). He used the dynamometer to assess the grip strength of his patients before and after the application of “galvanism” (Hammond, 1868, p. 142).
Hammond was at one stage convinced that the dynamograph had many applications. In his journal article of 1868, Hammond stated that he had not yet found a way to use the information from the dynamograph to assist in diagnosis or assessing progress,
stating “but I have no doubt that further observation will enable me to do so” (Hammond, 1868, p. 144). This reservation did not stop him from using the dynamograph in medicolegal investigations, including a controversial murder case in 1870 in which he interpreted a fluctuating dynamograph tracing as indicative of the defendant’s inability to control his will. “On the basis of this and other pseudo-objective evidence of the temporary insanity, the defendant was acquitted” (Lanska, 2000, ¶ 33). However, further experience did not assist him, so after having appeared in the first 8 editions of his textbook, it was deleted in the 9th edition in 1891 (as cited in Lanska, 2000). It would appear that its cost to import from Paris and its lack of proven clinical utility meant that it did not become a tool that the North American neurologists wished to pursue (Lanska, 2000).

Thus by the late 1800s there were several types of strength measuring devices in circulation, some having undergone revisions that made them more versatile. By 1885, Hammond became critical of the Mathieu dynamometer because the force dial was covered by the hand of the patient when it was being squeezed, although the indicator arm remained at the peak force, when the force was released (as cited in Lanska, 2000). He re-designed the dynamometer of Mathieu by placing the dial outside the spring steel at one extreme, see Figure 2.9.

Figure 2.9. Hammond dynamometer of 1891 (from Lanska, 2000)

The dynamometers of Hammond, Mathieu and Collin were similar in overall design to that of Régnier, devised in 1798. A major flaw in their manufacturing remained undetected until in 1956 when Kirkpatrick pointed out that the steel springs of the Collin dynamometer were “not made with uniform or calibrated resistance and
consequently a wide variation in comparative figures can be obtained with different instruments, no two being alike insofar as resistance is concerned” (Kirkpatrick, 1956, p. 285). Another design flaw he saw was that “the edge of the spring gouges into the soft tissue of the hand to the extent that it causes pain even in an uninjured hand” which can “keep the patient from gripping his best. Some investigators have padded the spring with sponge rubber” (p.285) to help with this, but padding alters the nature of the tool and again invalidates comparisons with other Collin dynamometers. When Solgaard, Kristiansen and Jensen (1984) tested a Collin dynamometer they found that its precision was “inferior” to the My-Gripper, a steel helical (curled) spring dynamometer that could be compressed 1-2 cm and the Martin Vigorimeter. They concluded their report with the comment “the steel spring can hardly be recommended” (Solgaard et al., 1984, p. 572). Manufacturing quality control was still a major problem for grip strength measuring tools even in the late 1980s. Thus the need to carefully calibrate and continually monitor the calibration of these tools came to the attention of clinicians and researchers at this point in time (Fess, 1987; Floodjoy & Mathiowetz et al., 1987).

**STANDARD MUSCLE TESTING POSITIONS**

It is necessary at this point to discuss the parallel developments in standardising the position of the testee during grip strength measurements. Many of the inventors recognised the need to use their instruments in standardised ways, so that valid comparisons could be made over time, or between people. That testees often wanted to give their best effort using non-standardised positions was highlighted in 1881 by the Neurologist Edward Constant Seguin in the journal *Medical Records*. He stated that “…It [the dynamometer] should be grasped fairly and squarely … without giving the arm a swing at the moment of compression, as some patients will do” (as cited in Lanska, 2000, ¶ 17).

In 1941 at the New York Chapter of the American Physiotherapy Association, Schmier presented an adapted spring scale dynamometer measuring system, which incorporated a plinth, on which the patient could be positioned and stabilised (Schmier, 1945). He pointed out that muscles at different lengths of excursion work
differently, thus the need for standardised testing positions. Techniques for measuring the strength of pronation and supination were described, but not that for grip strength.

Despite these calls for uniformity, in 1954 Charles McCloy was encouraging his subjects to find their own body position of maximal power. He gave directions for the positioning of the dynamometer in the hand and for the hand and fingers to “not rest against the body or against any object” (McCloy & Young, 1954, p.149). He utilised parallel helical springs with parallel handles above and below the springs.

The principle of standardising both body and arm position during grip strength testing was not formalised for hand grip dynamometers until the guide titled *Clinical Assessment Recommendations* of the American Hand Therapy Association (AHTA) was first published in 1981 (as cited in Fess, 1992). A recommended position of sitting upright with the arm adducted by the side, elbow flexed and the forearm in neutral rotation was described. Mathiowetz, Weber, Volland and Kashman (1984) proposed the addition of standardised verbal instructions and wrist extension of between zero and 30 degrees. The following year Mathiowetz, Rennells and Donahoe (1985) recommended that the patient actively maintain his or her elbow specifically at 90 degrees of flexion during grip strength testing. These recommendations were accepted by and incorporated into the second edition of the *Clinical Assessment Recommendations* (American Society of Hand Therapists, 1992).

**DYNAMOMETERS OF THE LATE 19TH CENTURY AND AFTER**

The Ergograph

The previous dynamometers generally measured isometric strength, or ‘near to’ pure isometric strength, due to some small degree of movement of the tools when compressive grip forces were applied to sprung steel bars, or elliptical bands of steel such as used in the Régnier and Collin dynamometers respectively. Then in 1904 the Italian Professor Angelo Mosso, who was “an Alpinist of some reputation, as well as a noted physiologist” (JAMA 100 years ago, 1899/1999, p. 1502L) and his
colleagues, published an article describing their new invention, the ergograph. It recorded loss of power over time, which Mosso defined as fatigue (as cited in Simon, 2001). The ergograph was a weighted, resisted, dynamometer. Fatigue was measured by how often a person could lift a known weight, a certain distance, in a certain timed sequence (see Figure 2.10).

**Figure 2.10. The ergograph of Mosso (from Hunsicker & Donnelly, 1955).**

In 1948 Hellenbrandt & Kelso made an improvement to the ergograph (as cited in Hunsicker & Donnelly, 1955) by re-designing it with no overhanging parts, incorporating an electromagnetic signal for recording the number of repetitions, and ensuring there was minimal friction of the load being moved. There was also a distance meter that automatically recorded the height of each repetition (this could only be done manually with the model of Mosso), and thus fatigue could be quickly calculated by the decreasing height of the load being lifted. This type of endurance strength then became distinguished from the strength readings achieved with a single maximal lift, push, or isometric squeeze of a dynamometer. Thus researchers and clinicians could start to view muscular strength as “dynamic strength” or “static strength” depending on how it was measured (Hunsicker & Donnelly, 1955).

**The Kellogg dynamometer**

In 1893 Dr. John Harvey Kellogg MD wished to measure strength to see if improvement was a reflection of his “health intervention”. He invented a mercury, water and oil-filled dynamometer that could “be adapted to [measure strengths of] the
principal muscular groups of the body” (Kellogg, 1893, p. 270). With this dynamometer he established a normative database with 400 healthy men and women (Kellogg, 1895). He used the dynamometer to assess and evaluate thousands of people in the Battle Creek Infirmary in Michigan. His 1893 article listed the 28 muscle groups he was able to test.

From the description of the dynamometer by Kellogg (1893) its modus operandi is unclear. Hunsicker and Donnelly (1955) described a “dial reading”, but Kellogg described a one metre long tube with graduated readings. The drawing from the 1893 article and the photo from the Hunsicker and Donnelly article are presented in Figures 2.11 and 2.12. The photo in Figure 2.12 is probably a later version, but the only reference given for the dynamometer is from the 1893 article by Kellogg who described the dynamometer as a steel cylinder and piston connected to a metal tube “which was made to slide up and down a vertical rod” (p. 270). The cistern was filled with mercury and a loose-fitting cylindric float was positioned on top of it. The mercury was separated from the oil by a layer of water. Kellogg decided that the “movements of the piston … must necessarily be as sensitive and delicate as possible” (p. 270). It is still not clear from this description whether it was a dynamic or isometric test.

In 1970 Schwarz wrote that the Kellogg dynamometer was adopted by the Military Academy at West Point and by Yale University in their physical education programmes (as cited in Jackson, Dudrick & Sumpio, 2004). The Naval Academy tested every new cadet for 25 years from 1907 with the device. When and Hunsicker and Donnelly wrote their review on dynamometers, they stated that the Kellogg design had “not been widely utilized, partly because of the relatively high cost for the machine and also because of its cumbersome size” (Hunsicker & Donnelly, 1955, p. 419). Although it was versatile and had normative databases, researchers and clinicians were still seeking other qualities in a dynamometer, such as portability and low cost.
A dynamometer with adjustable handle size

In 1900 Fred Smedley, a North American anthropologist, developed the first isometric parallel handle dynamometer to have an adjustable grip span handle to accommodate small hands. The handle size was adjusted by turning a screw to adjust the inner bar of the handle in and out towards the outer stationary handle, depending on the size of the hand being measured. As it was manufactured by Stoelting, it was sometimes called the Stoelting and sometimes the Smedley dynamometer (Hunsicker & Donnelly, 1955), see Figure 2.13.
Figure 2.13. Smedley/Stoelting dynamometer (from Hunsicker & Donnelly, 1955).

Due to the adjustable handle size of the Smedley/Stoelting dynamometer, it has been used over the years in some large database studies. In 1947 it was used in a study of 552 male industrial workers (Fisher & Birren, 1947). Fisher and Birren found that men increased their grip strength until the mid twenties “with a continuous decline thereafter”. In 1977 the dynamometer was used in a grip strength study of more than 6,000 males and females, aged 10 to 69 years (Montoye & Lamphiear, 1977). It has been used in other large population studies with adults ($n = 9,543$) to examine the effects of body position on grip strength (Teraoka, 1979) and is still being used in studies with children (Toh, Hitoshi, Kouchi, Masahiro, Masayuki & Kenji, 2003) and adults (Markel et al., 2003).

The cost of dynamometers

It is interesting to note that as early as 1868 doctors such as Hammond were encouraging colleagues to measure grip strength with dynamometers rather than cruder methods such as squeezing the hand of the physician. “The plan of causing the patient to grasp the hand of the physician, gives very rough indications, and does not allow the progress towards cure or further paralysis to be clearly estimated” (Hammond, 1868, p.140). Cost has been repeatedly cited as a noteworthy factor in the decision-making for the rejection or redesigning of dynamometers (Hunsicker & Donnelly, 1955; MacDermid & Lee, 2004; McCloy, 1954; Solgaard, et al., 1984).
Testing weakened people

In 1875 a North American Physician, Allan McLane Hamilton MD was interested in measuring the weak muscles of his patients, so he invented the first pneumatic dynamometer, see Figure 2.14. It consisted of an air-filled “glass tube which dips into the rubber bulb … the interior of the bulb is filled with coloured water” (Hamilton, 1875, p. 256). To test the grip, the patient squeezed the bulb, causing the water to rise and compress the air in the glass tube. A graduated scale marked in pounds on one side and “on the other by marks separated by regular intervals for the purpose of making comparative estimates” (p. 256). Hamilton promoted his pneumatic dynamometer as being “accurate” and “reliable” due to the shape of the bulb. He thought that this shape (as opposed to the ellipse of the Mathieu dynamometer) allowed “all the flexors of the hand” to be measured and thus “accurate comparative tests may be made from day to day.” Other attributes of the rubber bulb were stated as being “a convenient shape [for] … either small or large hands.” Further its cost was “much less than any dynamometer made” (p.256). He gave no considered rationale for the claim of the dynamometer shape to utilise all of the flexor muscles as compared to other dynamometers.

Figure 2.14. Water-filled dynamometer (from Hamilton, 1875).

From the simple beginnings of a tube of coloured water in 1875, Geckler (1939) published a brief report about his slightly more sophisticated pneumatic (air-filled) device. It consisted of a rubber bulb connected by means of a short tube to an air compressor gauge. The amount of force created as the bulb was squeezed was transmitted to the air gauge and the reading was taken directly from the dial. These two dynamometers were the forerunners of the now popular Martin Vigorimeter (Bohannon, 1991; Desrosiers, Hébert, Bravo, & Dutil, 1995), that has continued to be used in research since the 1970s even though the Geckler dynamometer was criticised by Kirkpatrick (1956) and considered not acceptable for measuring grip strength as it only measured grip pressure, not isometric grip force.
The Martin Vigorimeter first appeared in its current form in a normative study published by Thorngren and Werner in 1979. By 1983 Fraser and Benten declared the Martin Vigorimeter to be “the most common type of instrument available in British occupational therapy departments…” (p.296). The Martin Vigorimeter has continued to be compared to other grip strength measuring tools (Desrosiers, Hébert et al., 1995) and is still in use (Sheldon, 2003). Over the decades other alternative hand strength measuring tools, such as the rolled sphygmanometer cuff, have been promoted, but they do not measure the same parameter with the same units of measurement and thus comparisons between these instruments have not been possible (Desrosiers, Hébert et al., 1995; Solgaard et al., 1984).

**Tensiometers**

Tensiometers measure the tension in a cable or wire when a force is applied to the cable or wire. In 1948 Harrison Clarke was the first to use a tensiometer to measure strength, claiming that tensiometers were more precise than strain gauges, spring scales and dynamometers (as cited in Hunsicker & Donnelly, 1955). The Pacific Scientific Company of Los Angeles, in co-operation with Bechtol of San Francisco, added an attachment to the tensiometer model T5, also manufactured by the Pacific Scientific Company, which enabled it to be used for grip strength testing (Cousins, 1955). Cousins used this adapted tensiometer (see Figure 2.15) to measure grip strength in college students. Two further articles in 1969 (Cotten & Bonnell, 1969) and 1970 (Cotten & Johnson, 1970) used this type of adjustable handle size tensiometer because it was considered to be “frequently in use” (Cotton & Bonnell, 1969, p. 848).

**THE JAMAR™ DYNAMOMETER**

Sylphons are cylindrical metallic bellows that buckle under force (Scaife, Lyons, Vij & Ruttle, 1977), which were invented by Weston Fulton in 1902. They have many applications, shown on line at Tennessee Online (n.d.). Charles Bechtol (1954) described an isometric handgrip dynamometer that used sylphons immersed in oil, to measure force applied to two parallel handles. This was the first Jamar™
dynamometer (Bechtol, 1954). In his article Bechtol described how a cable
tensiometer with a hand grip adaptation and an hydraulic dynamometer with sylphons,
were both designed to meet three different design criteria, namely: adjustable spacings
from one to three inches, handles were to be large and smooth, and handles were to
move less than one eighth of an inch when force was applied to them, see Figures
2.15 and 2.16. It appears that the main reason for the presence of the sylphons was to
allow for the fractional movement of the handles. The results of grip strength testing
of 441 male and female patients were presented as histograms. It appears that these
were compiled with both types of dynamometers. The article did not promote one
over the other. This new dynamometer shape with the adjustable handles has been the
prototype for the shape and size of all hydraulic Jamar™ dynamometers since that
time.

Figure 2.15. Adapted cable tensiometer (from Bechtol, 1954).

Figure 2.16. The Jamar™ dynamometer (from Bechtol, 1954).
In 1956 a committee of the Californian Medical Association, the Subcommittee for the Study of Grasping Power, represented by Dr. Kirkpatrick, stated that they had tested and then fully “recommended the new Jamar\textsuperscript{TM} dynamometer as the most acceptable instrument manufactured at this time”. They also added that “with progress in engineering some better method or instrument may be developed to more accurately study comparative grasping power” (Kirkpatrick, 1956, p.320). No details were given about what the dynamometers were tested against; it may have been that the dynamometers were compared to the Geckler pneumatic and Collin dynamometers.

H. C. Sanderson (of the Committee of Industrial Health and Rehabilitation of the California Medical Association), was quoted as supporting force-measuring dynamometers above the dynamometers with the soft, yielding handles by saying that “devices which measure grip pressure by squeezing a bulb filled with fluid, liquid or air, or one of the common spring dynamometers, can only measure the pressure of grip” (Kirkpatrick, 1956, p. 315). Sanderson ascertained that grip strength was a force, not a pressure, therefore grip strength could only be measured by instruments such as isometric hand force dynamometers, like the Jamar\textsuperscript{TM}, as opposed to manometers. Kirkpatrick also claimed that there were “only three types of instruments available to determine comparative loss of grasping power” (p. 314). The present discussion shows this statement to be incorrect as there were many types of cable-tensiometers, manometers, electrical strain gauges and dynamometers. Despite these inaccuracies, this influential article possibly explains why by 1985 the Jamar\textsuperscript{TM} dynamometer had become popular. Smith and Benge (1985) sent a survey to 510 occupational therapy clinics and 115 occupational therapy schools in the USA asking them about the type of grip strength tool they used. Out of the 195 valid responses 79% used a Jamar\textsuperscript{TM} in their setting, with 40% using more than one type of tool for measuring grip strength.

Despite many advances in instrumentation since the mid 1950s, the Jamar\textsuperscript{TM} handgrip dynamometer is today quoted as being “recognised as the gold standard for grip strength measurement” (Shechtman, Davenport, Malcolm & Nabavi, 2003). The development of small microprocessors and specific electronic sensors that form the basis of load cells (pressor sensors), and progress in analogue to digital technology
have enabled the production of computer-linked versions. These have been accessible to researchers and clinicians since the 1990s. The National Isometric Muscle Strength Database Consortium used a digital electronic version of the Jamar™ in 1996, to measure the grip strength of 493 people (National Isometric Muscle Strength Database Consortium, 1996). With this data they developed regression equations for strength predictions that incorporated age, gender and BMI. Use of the computer-linked, Jamar™-like dynamometers has been promoted to reduce interpretation and recording errors (Brand & Hollister, 1999).

Manufacturers have added Jamar™-like adjustable handles to their strength assessment tools, such as the BTE-Work Simulator. This device added the BTE-Primus in 1994, which was a grip attachment resembling the shape of the Jamar™, with its 5 handle positions. It was not until 2003 that occupational therapists studied the reliability of the values taken with this tool in relation to the original analogue Jamar™ (Shechtman et al., 2003). They found that there were no significant differences in the grip strength scores generated by using either of these two tools. Other computer-linked, Jamar™-like tools, such as the GripTrack™, by JTech Medical (Utah) have been tested in laboratories and deemed acceptable to be used with databases compiled with the analogue Jamar™ devices (Mathiowetz, personal correspondence to JTech Medical, December 12, 1996). However a recent study reported that data collected with one GripTrack™ dynamometer were not transferable to the norms created on the Jamar™ dynamometers (Svens & Lee, 2005).

**Accuracy of the Jamar™**

Kirkpatrick (1956) stated that the Jamar™ could be calibrated and recalibrated if necessary, because they do lose calibration and do develop errors, as other researchers can testify (Floodjoy & Mathiowetz, 1987; King & Finet, 2003). Thus although the Jamar™ and its various versions are still considered to be the “gold standard” by the American Society of Hand Therapists, and others (Desrosiers, Hébert et al., 1995; Shechtman et al., 2003), they are not without their deficiencies (Svens & Lee, 2005).
Electrical strain gauges

In 1979 Pearn and Bullock supported the idea of isometric strength testing for patients, even though by this time there was a large body of literature advocating the use of the pneumatic manometers, such as the Vigorimeter. However, they were assumedly not content with the Jamar™ due to its design flaws. They stated that the dynamic (which they called isotonic) strength measuring tools had “relatively narrow ranges” and that “the interpretation of serial isotonic measurements [was] very difficult, simply because of changing mechanical advantages as the instrument hand-grip moves” (Pearn & Bullock, 1979, p. 107). They considered that “cable-tensiometers tend[ed] to be cumbersome” (p. 107). They were likely referring to tensiometers such as that in Figure 2.15. Thus Pearn and Bullock designed an electronic strain gauge that was “sensitive yet robust … [with a] wide force-application range, … rapid and simple to operate” (p.107). It had a linear load-response curve, suitable for a wide range of loads. It was a portable isometric test that could therefore by used in the clinic and for fieldwork. Because of its wide force range (from 0.5 to 1,500 Newtons) it was possible to use it “in neonates (e.g. analysis of the grasp reflex), or in adult sportsmen” (p. 107). Despite these attributes it appears to have been used for only one other study. That study was in Brisbane, where the tool was developed (Newman et al., 1984). The tool has not reappeared in the grip strength testing literature.

THE PRESENT AND THE FUTURE

Thus researchers have continued to develop other hand strength measuring tools (An, Chao & Askew, 1980; Bassey, Dudley & Harris, 1986; Dawson, Felle & O’Donovan, 1998; Pronk & Niesing, 1981). These four studies have all developed their own version of strain gauges with digital read-outs. Such tools have been developed to avoid the main flaw in the hydraulic-based, Jamar™-like tools; namely that they can develop “slow leaks [of the oil] and hysteresis” (Pronk & Niesing, 1981, p. 127). Hysteresis is the development of a slowed response when forces are applied to a force-reading tool.
Throughout the years, researchers have compared the Jamar™ with newer isometric (King & Berryhill, 1988; MacDermid, Alyafi, Richards & Roth, 2001; Shechtman, et al., 2005), dynamic (moving under the person’s own efforts) (Desrosiers Hébert et al., 1995) and isokinetic tools, which move at a set speed (Dvir, 1997). Although not interchangeable, these five research groups found the Jamar™ to have a high correlation between its grip strength readings and that of the other tools. Shechtman et al. found that the average measurement error for suspended known weights with three Jamar™ dynamometers was 7.74% as compared to an average measurement error of 1.63% with three of the new electronic DynEx dynamometers.

Dvir (1999), an Israeli Physiotherapist, argued that the Jamar™ lacks the ability to discriminate feigned maximal grip effort, so when a patient is to be assessed for compensation purposes they should be tested with an isokinetic dynamometer. He stated that isokinetic dynamometers monitor eccentric and concentric force components that are unable to be consciously altered by a patient without obvious signs of feigned effort.

The ability to link computers to force sensors has assisted in the development of more complex tools and more sophisticated analyses of hand strength for activities. Some of these tools measure the isometric force generated by each individual finger phalanx (An et al., 1980; Radhakrishan & Nagaravindra, 1993), some also measure the tangential shear forces imposed by each phalangeal segment of each finger during grasping of cylinders (Amis, 1987) (see Figure 2.17).

**Figure 2.17.** Isometric tool to measure tangential and grasp forces when gripping a cylinder (from Amis, 1987).
A practical application of this technology can be seen in a study of oil-rig workers. Imrahan and Farahmand (1999) used a torque transducer interfaced with an analogue/digital converter linked to a computer to examine the grip force required to turn various handles with clean or grease-smeared gloves. This level of force analysis equipment is not often seen in the hand therapy literature, but is more common in the ergonomics literature, as shown in the reference list of the article by Imrahan and Farahmand (1999).

Another group of researchers are using computer technology to analyse forces required by the hand to hold a glass bottle in a standardised position. They have used small conductive polymer sensors attached to 20 different points on the volar surface of a hand (Kargov, Pylatiuk, Martin, Schulz & Döderlein, 2004).

In contrast to these detailed studies with numerous sensors, the American Journal of Hand Therapy recently published an article about hand function whilst wearing Lycra burns gloves (Weinstock-Zlotnick, Torres-Gray & Segal, 2004). One way to indirectly measure function is commonly accepted to be via measuring grip strength (Brand & Hollister, 1999). Weinstock-Zlotnick et al. used a Jamar™ dynamometer to measure the maximum grip strength achieved whilst wearing burns gloves with or without suede patches on the palmar surface. It would seem that using a more sophisticated force-analysis tool such as those cited above could have better assisted the authors in future burns gloves modifications to improve function whilst wearing the gloves.

The Jamar™, or a computer-linked or electronic version, are still in common use as demonstrated by the number of recent articles in the American Journal of Hand Therapy that have used it to measure grip strength and confirm its reliability (Bohannon & Schaubert, 2005). A recent Australian study examined the outcomes from compliance to treatment for radius fractures using a Jamar™-equivalent dynamometer to measure grip strength (Lyngcoln, Taylor, Pizzari & Baskus, 2005). It is also being used to assist in the prediction of the length of stay in hospitalised elderly patients (Kerr et al., 2006). Although not stated as a reason for the continued use of the Jamar™-equivalent dynamometers, cost may be a consideration, as these tools are typically the cheapest type of isometric dynamometer available. Also they
have multiple normative databases spanning virtually all ages, which clinicians can readily access.

**SUMMARY**

Grip strength assessment tools have evolved over the last 250 years from ‘nearly isometric’ elliptical steel frames, with no calibration methods or standard test positions, to highly sophisticated force sensors which can record adjustments in force readings in individual finger phalanges. There is now a range of tools that can measure static, or dynamic muscle forces. Along with the development of the tools and testing methodologies, there have been an increasing number of normative databases available for these tools. This has been accompanied by a greater understanding of the factors that influence grip strength between individuals, within disease processes and from day to day.

The data collection for this present thesis was performed with the GripTrack™ (JTech Medical Industries, Utah). This tool has the same size and configuration as the most commonly used tool in Australia, the Jamar™ dynamometer. Thus by using a Jamar™-like dynamometer in the present research, other therapists can apply the current findings to their clinical situation.