Analysis of the application of force measurements of the hand: a comparison of two hand-held dynamometers

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Abstract

Objective. To assess the accuracy of measurement performance of two hand-held dynamometers in the application of force measurements of the intrinsic muscles of the hand.

Design. Repeated measurements with a generic dynamometer (AIKOH) using a pushing technique and with a newly designed instrument, the Rotterdam Intrinsic Hand Myometer (RIHM) using a pulling technique.

Methods. Three force measurements were studied of the right hand of ten healthy persons: little finger abduction, index finger abduction and thumb palmar abduction. The position and angle of application was recorded with a three-dimensional videorecording technique. Three repeated measurements within a session were averaged to determine the systematic differences and variances of the measurements of the two dynamometers

Results. The variance was smaller for all three measurements of the RIHM regarding the positioning of application and the angle of application of the index finger abduction in the frontal plane. Systematic differences between the dynamometers were found only for the angle of application in the frontal plane of index finger and thumb measurements in favour of the RIHM.

Conclusion. Performance of force measurements of the intrinsic muscles of the hand with the RIHM dynamometer had less variances than the AIKOH dynamometer in the positioning of the instruments at the same anatomical reference point of the finger. The difference in angle of application has much smaller influence on the variance of measurements between the two instruments.

Relevance

Instruments for force measurements of the hand are important in evaluating the hand function. A new force measuring instrument, the Rotterdam Intrinsic Hand Myometer (RIHM), has been developed with a pulling technique to improve reliability. Because small inaccuracies in applying a dynamometer may have considerable consequences for measurement error, determining the cause of measurement error will provide information on how to improve measurement instruments.

Keywords: Hand; Finger; Force; Evaluation; Dynamometry; Intrinsic muscle force; Force measurements; three-dimensional videorecording.

1. Introduction

Weakness in muscle force resulting from neurological or musculoskeletal lesions can greatly reduce the patient's hand function and often cause major impairments and disabilities. Measurements of the muscle force of the hand through objective and reliable methods are important in order to follow the recovery rate and effectiveness of treatments after upper extremity nerve injuries (Brandsma, 1993; Lundborg, 2000; Rosen et al., 2000), or changes of muscle force in several hereditary motor and sensory neuropathies.(Florence et al., 1992; Vinci et al., 2003) Different methods for monitoring hand function have been investigated by many researchers who work in the area of hand rehabilitation (ASHT, 1992; Bear-Lehman et al., 1989; Bruyns et al., 2003; Hunter et al., 2002; Light et al., 2002; Sollerman et al., 1978).

Measurement of muscle force is possible by non-instrumental techniques such as manual muscle strength testing (MMST), or instrumental techniques such as grip and pinch force dynamometers (Bohannon, 1995) and electro-physiological methods. Mannerfelt was one of the first to measure the intrinsic muscle force of the hand with a dynamometer (Mannerfelt, 1997). Later, others have designed devices for e.g. force measurements of the index finger (Li et al., 2003; Li et al., 2000; Zijdewind et al., 1994) and intrinsic thenar muscles of the thumb (Boatright et al., 1997; Liu et al., 2000; Trumble et al., 1995).

In a previous study we assessed the reliability of force measurements of the intrinsic muscles of the hand with a generic industrially designed hand-held dynamometer using the pushing technique (AIKOH) in 24 patients with ulnar and/or median nerve injury (Schreuders et al., 2000). The Standard Error of Measurements (SEM) for the little finger, index finger and thumb abduction were 10, 11 and 12 N, respectively (Schreuders, et al., 2000). We concluded that only relatively large changes in intrinsic muscle force could be confidently detected. With a specifically designed dynamometer (RIHM), using a pulling technique (Figure 1), similar muscle strength measurements in 27 patients with ulnar and/or median nerve injuries showed much lower SEMs of 2.2, 2.3, 5.8 N, respectively (Schreuders et al., 2004).

We hypothesised that this reduction of measurement error was mainly due to better standardisation of these measurements due to an improved consistency of application of the dynamometer at the right position and the right angle during testing. The dynamometer is usually placed at a joint crease because it is easy to identify. Positioning of the dynamometer needs to be done consistently at precisely the same position (Figure 2); e.g. when the muscles around the meta-carpophalangeal (MCP) joint can deliver a net moment of 25 Nm, the force that is measured at a position (arm) of 5 cm to the joint (**X** in Figure 1), will be 5 N (force = moment/arm). However, when the dynamometer is positioned 0.05 m (**Z**) more proximally from that point, making the arm 0.045 m from the MCP joint, the force will be 2.5/0.045 = 5.5 N, i.e. about 10% higher than in case of accurate placement.

Regarding the angle of application, an accurate measurement is performed when the dynamometer is positioned perpendicular to the finger and thumb in two directions; in the frontal plane of the hand (dividing the hand into an anterior and posterior portion) and the transverse plane (dividing the hand into a distal and proximal halve). A change in the angle between the device and the finger may cause large differences in outcome force. For example, applying the dynamometer at an angle of 25° will cause an underestimation of the measured force of almost 10% (cosinus 25° = 0.91).

Thus, relatively small changes in the position and angle when applying the dynamometer may have considerable consequences for measurement error. The aim of this study was to compare the accuracy of the older industrial dynamometer (AIKOH) with a newly designed instrument, the Rotterdam Intrinsic Hand Myometer (RIHM) (Schreuders et al.), in positioning the instruments at exactly the same point of the finger and applying it at the correct angle to the digit in the two planes.

Both the angle and position of application were determined with a three-dimensional (3D) videorecording technique (Coert et al., 2003; Spoor, 1983; van den Bosch et al., 2003). Measurements with the two instruments were compared with respect to the consistency and variance of positioning and angle of force application during testing.

2. Material and Methods

2.1 Test Protocol

The right hand of 10 healthy persons was tested. These were 5 males and 5 females with a mean age of 31.5 (SD 7,1) years. Three force measurements were analysed: little finger abduction, index finger abduction and thumb palmar abduction (Figure 2). The first two movements are produced by ulnar nerve innervated muscles and the latter is a movement produced by the thenar muscles of the thumb, which is mainly a median nerve innervated function. For little finger abduction the resistance force was applied at the ulnar side of the proximal interphalangeal (PIP) joint crease of the little finger. For the index finger abduction, the anatomical reference point was chosen at the radial side of the PIP joint and for the thumb movement this was the radial side of the MCP joint crease. Hand position, fixation and anatomical reference point for the application of resistance force were comparable to the MMST technique (Brandsma et al., 1995).

The volunteer and examiner were seated at a table opposite each other. Participants were instructed how to hold the finger/thumb in the maximally abducted position and were told to maintain the finger in that position, while the examiner pushed or pulled the finger in the opposite direction with the dynamometer. An experienced tester familiar with both instruments (TARS) completed all the measurements.

This study employed two hand-held instruments: the generic AIKOH dynamometer (Aikoh Model 9520A.B. Aikoh Engineering Co., Ltd. Tokyo, Japan) using a push technique, and the specifically designed RIHM dynamometer (Experimental Medical Instruments department of the Erasmus MC, Rotterdam, the Netherlands) with a pull technique. Three measurements, comprising one session, were performed, then the dynamometer was removed and the person asked to move the hand out of the testing position. The dynamometer was positioned again at the same anatomical reference point and another session of three measurements was carried out. This was repeated one more time, providing three sessions of three measurements per movement. Both the order of the measurements (i.e. testing the little finger, index finger and thumb) and the order of the testing with the two instruments were randomised.

In order to obtain 3D position measurements, two videocameras were used to record the signals from reflective markers on the hand and dynamometers. These markers reflected the infrared light sent from a light source attached to the camera. Three pairs of infrared light reflecting markers were used (Figure 3). For the AIKOH one pair (no.1 and 2) was on the dynamometer and for the RIHM the markers were on the pull string. A small bar with two markers (no. 3 and 4) was taped on the skin above the metacarpal bone such that these two markers were parallel to the plane of the hand. The third pair (no. 5 and 6) was located on a small splint which was attached with two Velcro straps to the distal phalanx of the finger.

The markers were illuminated by an infrared light source mounted on the cameras. The image co-ordinates from the two cameras were combined to 3D spatial co-ordinates using Direct Linear Transformation (Spoor, 1983). The video signal was digitised using a Vision Dynamics[1] VCS 512 videoprocessing board to calculate the marker co-ordinates. From previous tests, the resolution of the system proved to be about 0.1 mm (van den Bosch, et al., 2003).

2.2 Data processing

To record the point of application of the dynamometer, the position was determined by measuring the distance between one marker on the small splint at the fingertip (no. 5) and a virtual line through the two markers on the dynamometer (no. 1 and 2), which provided the position in millimetres (mm). Systematic difference was not relevant because the position of markers 3 and 4 was chosen at a point which gave the least movement; proximal of the MCP joint. The exact moment arm between the MCP joint and the position of application at the IP joint could therefore not be established. Regarding the angle of application of the dynamometer, a perfect measurement would provide two 90° angles, recorded as a zero degree difference in angle in both the frontal and transverse plane of the hand. Systematic differences could be calculated for angle measurements.

For the nine measurements, mean and SD were calculated. Mean differences in position (mm) and angles (degrees) of application between both instruments were calculated. To test whether differences exist between both instruments regarding the variance of position and angle of force applications between sessions, a repeated measurements analysis was carried out using Proc Mixed of the Statistical Analysis System (SAS version 8.2 of the SAS Institute Inc., Cary, NC, USA). Three repeated measurements within a session were averaged, and the analysis was done on the three session averages. In the statistical models, 'person' was a random factor and 'instrument' was a fixed factor. For each outcome, two models were fitted. The first model assumed that the between sessions variance was equal for both instruments, the second model allowed that the variances were different. The likelihood ratio test comparing these models was used to test the null hypothesis that the between sessions variance of the two instruments was identical.

3. Results

In Table 1 presents data (mean, SD) on the position (mm) at which the two dynamometers (AIKOH and RIHM) were placed for measurement of the little finger, index finger and thumb abduction. There was a significant difference between the two instruments for the thumb abduction and little finger abduction measurements. The variance between three sessions of positioning the dynamometer was smaller ($p < 0.0001$) for all three finger measurements with the RIHM as compared to the AIKOH measurements.

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Table 1 also presents data (mean, SD) on the angles, i.e. deviations from 0°, recorded in two planes (frontal and transverse) with both dynamometers. In the frontal plane the mean of the angle measurements of the RIHM dynamometer was smaller (closer to 0°) for the index finger and thumb measurements as compared to the mean of the angles measured with the AIKOH dynamometer.
The variances of the angles between three sessions with the AIKOH and RIHM dynamometers are also presented. In the frontal plane the variances of the RIHM measurements were smaller only for measurement of the index finger. In the transverse plane, no differences in variance of the angles between sessions with the AIKOH and RIHM measurements were found, although we did find a trend that the variance of the little finger measurements was smaller for measurements with the RIHM ($p = 0.11$).

4. Discussion

In many muscle force measurements with dynamometers, the instrument is pushed against the body while the patient tries to resist the movement, e.g. the microFET (van Meeteren et al., 2002), Citec (Geertzen et al., 1998), Nicholas CANDHY (Roebroeck et al., 1998) and Kin-Com (Stratford et al., 1994). In our previous study on force measurements of the intrinsic muscles of the hand with the AIKOH, a similar pushing method was used. In an attempt to decrease the measurement error, we questioned whether the reliability could be improved by using a pulling technique, which may allow for a better visual standardisation of measurement performance.

In our previous studies on the intraobserver reliability of the forces measured with the AIKOH and the RIHM dynamometers, in a comparable group of patients with injuries to the ulnar and median nerve the Standard Error of Measurements (SEM) were much lower for the RIHM measurements (Schreuders, et al., 2004). We hypothesised that this reduction in measurement error might be due to better standardisation of these measurements with the RIHM dynamometer due to the improved consistency of the application of the dynamometer at the right position and the right angle during testing.

The present study analysed the control of the point and angle of application of the older (pushing technique) and the new dynamometer with the pulling technique. Differences between the two instruments were found, especially in the position of application. We found that the pulling technique with the RIHM showed systematic differences for two measurements, while the variances between three sessions was smaller for all three measurements of the RIHM dynamometer. Apparently the point at which the dynamometer is placed is an important source of measurements error. Standardisation of this aspect might be even further improved by e.g. drawing of a small line on the finger/thumb.

In the angle of application the main differences were found between the AIKOH and RIHM in the frontal plane measurements. This might be due to the fact that the finger will move in this plane during testing. This knowledge is useful in training examiners in a standardised performance of the measurements and thus might improve the reliability and standardisation of measurement protocols.

Besides the method of application of resistance force by pulling (RIHM) or by pushing (AIKOH), there are other factors which could affect the measurement error. For example, differences in the size and shape of the grip between both dynamometers and the position of the arm of tester might also influence the measurement error. Since the RIHM could be held closer to the body of the tester, less strength was needed to control the dynamometer.

The described video technique provided a method to accurately quantify how the application of the two dynamometers compared while applying a force to the hand. Application of the splint with the two markers was straightforward, but placement of the small bar with the markers 3 and 4 was more difficult and some minor movements where inevitable due to movements caused by the muscles and tendons just beneath the skin were the marker was placed. However, the same marker placement was used for measurements of both instruments, therefore any error would have had the same systematic inaccuracy for both dynamometers.

One limitation of this study is that the same experienced tester performed all measurements. The difference in variances between the two instruments might have been less obvious when performed by a person without experience. The results of this study may help an inexperienced tester to quicker learn how to perform adequate and reliable tests.

In conclusion, we found less variation between sessions in positioning of the dynamometer in measuring muscle force and a smaller systematic error in the frontal plane. Performances of several force measurements of the intrinsic muscles of the hand with the newly designed RIHM dynamometer were more accurate and less variable than the AIKOH dynamometer especially in the positioning of the instruments at the same point of the finger. The difference in angle of application has much smaller influence on the variances of measurements between the two instruments.

References

ASHT (ed.) (1992). "Clinical Assessment Recommendations." American Society of Hand Therapists, Garner, NC.

Bear-Lehman, J., and Abreu, B. C. 1989.Evaluating the hand: issues in reliability and validity. Phys Ther 69, 1025-33.

Boatright, J. R., Kiebzak, G. M., O'Neil, D. M., and Peindl, R. D. 1997.Measurement of thumb abduction strength: normative data and a comparison with grip and pinch strength J Hand Surg [Am] 22, 843-8.

Bohannon, R. W. 1995.Measurement, nature, and implications of skeletal muscle strength in patients with neurological disorders Clin Biomech 10, 283-292.

Brandsma, J. W. (1993), pp. 183. University of Utrecht, Utrecht.

Brandsma, J. W., Schreuders, T. A., Birke, J. A., Piefer, A., and Oostendorp, R. 1995.Manual muscle strength testing: intraobserver and interobserver reliabilities for the intrinsic muscles of the hand J Hand Ther 8, 185-90.

Bruyns, C. N., Jaquet, J. B., Schreuders, T. A., Kalmijn, S., Kuypers, P. D., and Hovius, S. E. 2003.Predictors for return to work in patients with median and ulnar nerve injuries J Hand Surg [Am] 28, 28-34.

Coert, J. H., van Dijke, H. G., Hovius, S. E., Snijders, C. J., and Meek, M. F. 2003.Quantifying thumb rotation during circumduction utilizing a video technique J Orthop Res 21, 1151-5.

Florence, J. M., Pandya, S., King, W. M., Robison, J. D., Baty, J., Miller, J. P., Schierbecker, J., and Signore, L. C. 1992.Intrarater reliability of manual muscle test (Medical Research Council scale) grades in Duchenne's muscular dystrophy Phys Ther 72, 115-22; discussion 122-6.

Geertzen, J. H., Dijkstra, P. U., Stewart, R. E., Groothoff, J. W., ten Duis, H. J., and Eisma, W. H. 1998.Variation in measurements of grip strength. A study in reflex sympathetic dystrophy patients Acta Orthop Scand Suppl 279, 4-11.

Hunter, J., Schneider, L. H., and Mackin, E. J. (2002). "Rehabilitation of the Hand and Upper Extremity." Mosby co.

Li, Z. M., Pfaeffle, H. J., Sotereanos, D. G., Goitz, R. J., and Woo, S. L. 2003.Multi-directional strength and force envelope of the index finger Clin Biomech (Bristol, Avon) 18, 908-15.

Li, Z. M., Zatsiorsky, V. M., and Latash, M. L. 2000.Contribution of the extrinsic and intrinsic hand muscles to the moments in finger joints Clin Biomech (Bristol, Avon) 15, 203-11.

Light, C. M., Chappell, P. H., and Kyberd, P. J. 2002.Establishing a standardized clinical assessment tool of pathologic and prosthetic hand function: normative data, reliability, and validity Arch Phys Med Rehabil 83, 776-83.

Liu, F., Carlson, L., and Watson, H. K. 2000.Quantitative abductor pollicis brevis strength testing: reliability and normative values J Hand Surg [Am] 25, 752-9.

Lundborg, G. 2000.A 25-year perspective of peripheral nerve surgery: evolving neuroscientific concepts and clinical significance J Hand Surg [Am] 25, 391-414.

Mannerfelt, L. G. 1997.Studies on ulnar nerve compression neuropathies with a new computerised instrument--the intrins-o-meter Scand J Plast Reconstr Surg Hand Surg 31, 251-60.

Roebroeck, M. E., Harlaar, J., and Lankhorst, G. J. 1998.Reliability assessment of isometric knee extension measurements with a computer-assisted hand-held dynamometer Arch Phys Med Rehabil 79, 442-8.

Rosen, B., Dahlin, L. B., and Lundborg, G. 2000.Assessment of functional outcome after nerve repair in a longitudinal cohort Scand J Plast Reconstr Surg Hand Surg 34, 71-8.

Schreuders, T. A. R., Eijskoot, F., den Ouden, A. H., and Stam, H. J. The Rotterdam Intrinsic Hand Myometer(RIHM); A technical note. in press.

Schreuders, T. A. R., Roebroeck, M., van de Kar, H. J., Soeters, J. N., Hovius, S. E., and Stam, H. J. 2000.Strength of the intrinsic muscles of the hand measured with a hand-held dynamometer: reliability in patients with ulnar and median nerve paralysis J Hand Surg [Br] 25, 560-5.

Schreuders, T. A. R., Roebroeck, M. E., Jaquet, J.-B., Hovius, S. E. R., and Stam, H. J. 2004.Measuring the Strength of the Intrinsic Muscles of the Hand in Patients with Ulnar and Median Nerve Injury; Reliability of the Rotterdam Intrinsic Hand Myometer (RIHM) J Hand Surg (Am) 29A, 318-324.

Sollerman, C., and Sperling, L. 1978.Evaluation of ADL-function--especially hand function Scand J Rehabil Med Suppl 6, 139-43.

Spoor, C. W. 1983.Balancing a force on the fingertip of a two-dimensional finger model without intrinsic muscles J Biomech 16, 497-504.

Stratford, P. W., and Balsor, B. E. 1994.A comparison of make and break tests using a hand-held dynamometer and the Kin-Com J Orthop Sports Phys Ther 19, 28-32.

Trumble, T. E., Kahn, U., Vanderhooft, E., and Bach, A. W. 1995.A technique to quantitate motor recovery following nerve grafting J Hand Surg [Am] 20, 367-72.

van den Bosch, E. W., van Zwienen, C. M., Hoek van Dijke, G. A., Snijders, C. J., and van Vugt, A. B. 2003.Sacroiliac screw fixation for tile B fractures J Trauma 55, 962-5.

van Meeteren, J., Roebroek, M. E., and Stam, H. J. 2002.Test-retest reliability in isokinetic muscle strength measurements of the shoulder J Rehabil Med 34, 91-95.

Vinci, P., Esposito, C., Perelli, S. L., Antenor, J. A. V., and Thomas, F. P. 2003.Overwork weakness in Charcot-Marie-Tooth disease Arch Phys Med Rehabil 84, 825-827.

Zijdewind, I., and Kernell, D. 1994.Index finger position and force of the human first dorsal interosseus and its ulnar nerve antagonist J Appl Physiol 77, 987-97.