ORIGINAL ARTICLE

The Development, Validity, and Reliability of a Manual Muscle Testing Device With Integrated Limb Position Sensors

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ABSTRACT. Li RC, Jasiewicz JM, Middleton J, Condie P, Barriskill A, Hebnes H, Purcell B. The development, validity, and reliability of a manual muscle testing device with integrated limb position sensors. Arch Phys Med Rehabil 2006;87:411-7.

Objective: To report the development and validation of a new hand-held muscle strength-testing device that is integrated with orientation sensors and designed to test the strength of major muscle groups at a given limb or joint position.

Design: Design description and validation study.

Setting: University-based human movement facility.

Participants: Twenty-eight able-bodied, healthy subjects.

Interventions: Not applicable.

Main Outcome Measure: A device was developed based on a hand-held force dynamometer with integrated orientation sensors. The validity and reliability (interrater, intertrial) of 5 maximum isometric contractions of hip flexion, knee extension, and ankle plantarflexion and dorsiflexion were assessed. The results were compared with those from an isokinetic dynamometer (KinCom).

Results: The new manual muscle tester was highly reliable and valid in estimating muscle strength of the lower limbs. The coefficient of variation between trials of all movements was low, with a mean less than 10% (range, 3.7%–8.9%). The only significant difference in muscle strength between the new device and the isokinetic dynamometer was found for hip flexion.

Conclusions: The new hand-held muscle strength tester appears to be a reliable and valid clinical assessment tool that can be used to objectively assess muscle strength at particular limb positions and/or joint angles. This feature appears to represent a technical advance in portable muscle strength devices, providing comparable information to those obtained by isokinetic dynamometers at a fraction of the cost and size. However, the device needs to be validated in clinical populations, such as patients with spinal cord injury and stroke, in order to demonstrate its general clinical utility.

Key Words: Muscles; Rehabilitation; Reliability and validity; Transducers.

MUSCLE STRENGTH TESTING is an essential component of any neurologic[1-4] and orthopedic examination.[5,6] However, it is generally recognized that traditional manual muscle testing, using a 5-point grading scale, has poor validity and reliability.[7,8] Traditional clinical manual muscle testing is inherently subjective and cannot reliably distinguish subtle differences in strength.[7-9] Alternative methodologies are available to objectively assess muscle strength in a clinical setting.[10-15] These include isokinetic dynamometers (KinCom, Biodex, Cybex) and hand-held force dynamometers (MicroFET2, MicroFET3, Nicholas manual muscle tester). Isokinetic machines are considered the criterion standard and provide multiple parameters, such as peak force, endurance, power, and angle of maximal force, occurrence and generate strength curves. These machines enable precise measurement of muscle strength while eliminating potential problems associated with strength disparity between subject and tester (ie, when the subject happens to be stronger than the tester),[16] as is often the case when testing large joints like the hip.[17] However, the disadvantages of isokinetic machines are that they are expensive,[18] bulky, and are not really designed for routine clinical examinations.[12,13] Hand-held dynamometers, on the other hand, are much more convenient to use clinically because they are portable, simple, user friendly, and comparatively inexpensive. The downside of commercial hand-held dynamometers is that they provide only limited information, such as peak force, time-to-peak force, and total test duration. Their limitation vis-à-vis isokinetic machines are that they are not capable of generating strength curve profiles or power output estimates. They also do not provide positional information on the limb or joint at which strength was tested. Hand-held force dynamometers could be improved considerably if information about limb position and joint angle could be measured concurrently.[19,20] Nevertheless, the sensitivity and reliability[7] of newer generation hand-held manual muscle testers have improved considerably, although reliability is still an issue especially when assessing the strength of the lower-extremity musculature.[21]

In this article, we report the design of a new hand-held manual muscle test (MMT) device and demonstrate its validity and reliability. The major distinguishing feature of the new MMT device compared with other hand-held devices is that it integrates orientation (motion) sensors into its design.

METHODS

Instrumentation

Manual muscle tester system. The MMT device, designed by Neopraxis,[a] consists of 3 components: (1) a hand-held force transducer; (2) motion sensor pack(s); and (3) a pocket personal computer (PC).

The hand-held force transducer (fig 1A) has 2 major components: the handgrip and the force pad. The hand grip (made of aluminum) is ergonomically designed, which allows a clinician to grasp and apply a force similar to that applied by the palm of the hand. The force pad is specifically designed to

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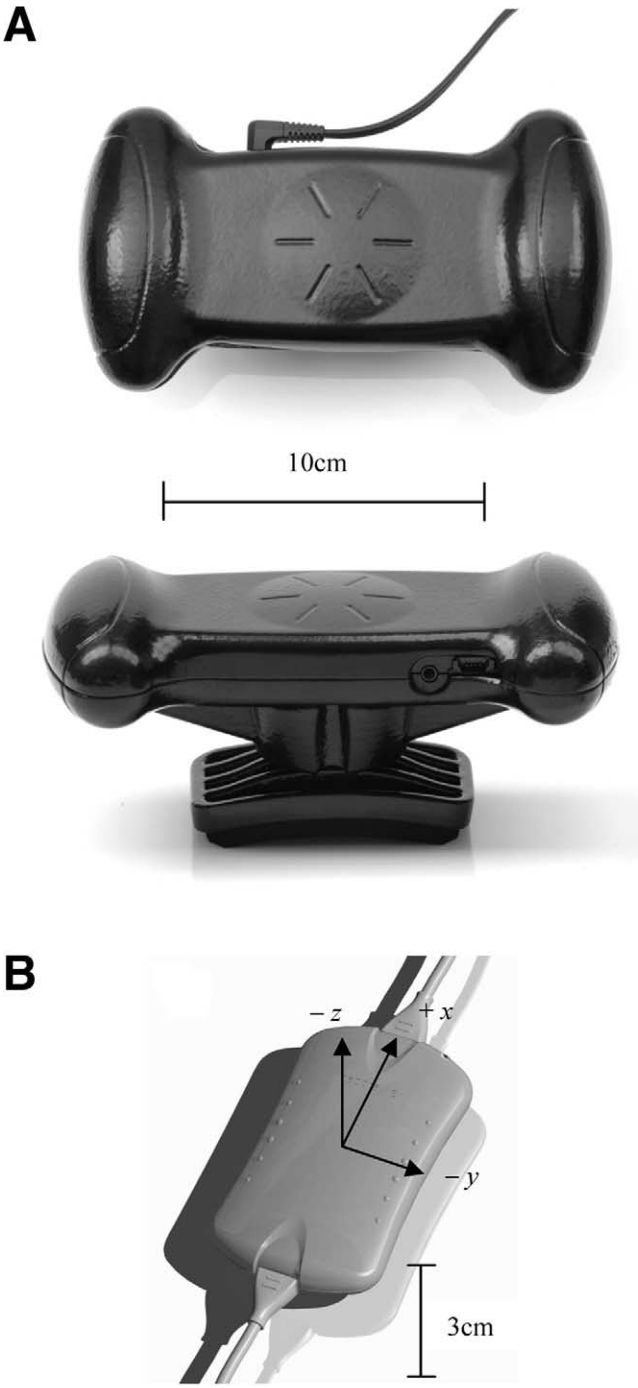

Fig 1. (A) Top and side views of the force transducer. (B) The sensors pack, with the sensor referenced axes of rotations indicated.

direct all force toward the transducer while minimizing shear forces, via a high tensile steel plunger. The force pad has a soft pad that is contoured to provide a best fit for the foot, thigh, and shank of the subject. The measurement accuracy of the force transducer is ±2N (±1%) with a typical measurement resolution of .15N. Table 1 summarizes the relevant technical specifications of the force transducer. The transducer was factory calibrated and calibration data were stored on the pocket PC.

The motion sensor pack (fig 1B) contains 1 angular velocity transducer,[b] two 2-dimensional accelerometers,[c] a programmable 10-bit processing chip,[d] and 3 analog inputs. Table 1 summarizes the essential characteristics of the sensor pack. The dynamic accuracy of the sensor system has recently been reported by Simcox et al.[22] The angular velocity transducer (AVT), also called a rate gyroscope, measures angular rotations about the *y* axis (see fig 1B) through the Coriolis force. The accelerometers (each rated at ±2G) aligned along 3 orthogonal axes provide an absolute reference system (with respect to gravity) and are used to correct integration drift from the AVT. The procedure is similar to that proposed by Luinge et al.[23] To measure the segment's motion in the sagittal plane the sensor's *y* axis (see fig 1B) must be aligned with the sagittal rotation plane of the segment using identifiable anatomic landmarks. Subtracting the absolute angles of 2 adjoining segments (assuming that each segment has a sensor attached) will yield the relative joint angle in the sagittal plane. In addition, the sensors will also provide information on segmental and joint motions, such as angular velocities and angular accelerations. Up to 7 sensors can be connected in series but with a reduced sampling rate.

The pocket PC is a Casio Cassiopeia EG-800[e] with 32MB of memory. The primary interface between the force transducer, sensor packs, and the pocket PC is via a proprietary compact flash card that fits into the pocket PC's internal type II compact flash slot. The force transducer connects to the compact flash card via a 3.5mm audio jack and the sensors through special 10-pin cables. The pocket PC is the primary interactive user interface and supplies power to both the motion sensors and force transducer. The pocket PC collects motion sensor and force transducer data, analyzes the outputs, and stores the results in memory, which can be downloaded onto a personal computer.

Experimental Protocol

Participants. We tested 28 able-bodied, healthy subjects (7 men, 21 women) between 18 and 73 years of age (mean ± standard deviation [SD], 30.5±12y). Subjects who had any lower-limb pain were excluded from the study. The study received ethics approval from the Queensland University of Technology Human Subjects Committee. All subjects provided informed consent before testing. Subjects were asked to wear loose fitting shorts and remove their shoes.

Table 1: Force Transducer and Sensor Pack Specifications

Device	Specification
Force Transducer	
Measurement resolution, N (RT)	.15
Measurement accuracy, N (RT)	1.97 (±1%)
Maximum force, N	590
Transducer mass (kg)	1
Operating temperature (°C)	5–40
Sensor Pack	
Measurement resolution, °C (RT)	.05
Measurement accuracy, °C (RT)	.5
Maximum angular rate (deg/s)	±350
Maximum acceleration (G)	±2
Sensor mass (g)	22
Sensor dimension (mm)	64×34×2
Sampling frequency, Hz (1 sensor – multiplexed)	200

Abbreviation: RT, room temperature.