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Development of a Portable Upper Limb Muscle Dynamometer for Assessment of Neuromuscular Injury Patients

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1 Introduction

Neurmuscular injuries (e.g. spinal cord injuries, brain trauma, etc.) leading to upper limb dysfunction can severely affect a patient's quality of life. Treatment advances (e.g. nerve transfer), show promise in restoring function (Mackinnon, J Neurosurg, 2012). Current manual methods to evaluate patient recovery (e.g. the MMT-8 scoring method that uses task observation and physical assessment) offer limited reliability, are time consuming, and require extensive training (Bohannon, Clin Rehabil, 2005). To capture incremental changes in upper limb functionality and to obtain consistent measurements between clinicians, a standardized testing system is required (Garcia, J Sport Rehabil, 2016). Existing muscle dynamometers, which measure patient strength objectively, are expensive and impractically large, making them inaccessible to most clinics and patients with disabilities. The value of isotonic contraction data and its notable difference from its isokinetic counterpart has become clear (Yamada, Int J Sport Heal Sci, 2018). Our goal was to develop a table-top upper limb muscle dynamometer that provides standard positioning, ease of use, and portability while giving clinicians consistent and reliable quantitative data on a patient's isotonic and isometric muscle power and strength, respectively. This device would address the need for an objective tool to quickly measure upper limb muscle strength at multiple joints, with little expertise and in any clinical setting.

2 Materials & Methods

Design Considerations: The dynamometer was designed to address many of the usability challenges in existing strength evaluation devices. By focusing on the upper limb, the dynamometer has a footprint orders of magnitude less than existing systems (e.g. a Biodex), allowing the dynamometer to travel between clinics. Critically, the dynamometer prioritizes patient accessibility; dynamometry's importance to rehabilitation of patients with severe neuromuscular dysfunction means the device needs to be usable for patients with any functional limitations. Due to their similarity to functional movement, measuring isotonic contractions was a priority because it is impossible to measure with existing handheld load sensors, which also have considerable reliability issues[5].

Device Development: The interfacing portion of the device is a lever arm affixed to a brushless DC motor (SM34165DT, Moog Animatics, USA). A precision load cell (CTD-100, Load Cell Central, USA) embedded in the distal end at a fixed distance from the center of rotation measures all the tangential loading through an ergonomic interfacing cuff, thereby quantifying torque. The motor allows the lever arm to be moved to various positions for testing various joint motions and will enable more complex functionality, such as isotonic measurement, in the near future. The load cell signal is conditioned and output as an analog signal via BNC ports on the back of the device allowing clinicians to use their data acquisition systems of choice to view and record patient data.

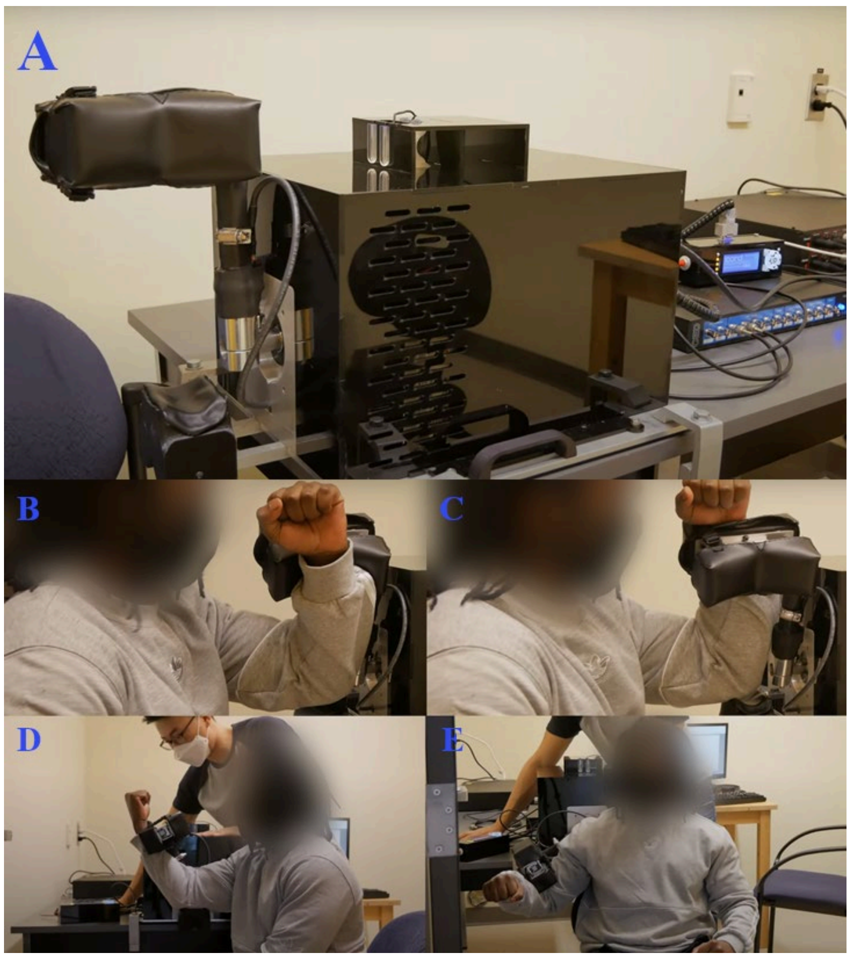

Figure 1: A) The dynamometer in a muscle physiology lab. A subject performing a maximum voluntary contraction in B) shoulder external rotation, C) shoulder internal rotation, D) elbow flexion, and E) shoulder abduction.

To ensure patient safety, the dynamometer has many systems to prevent uncontrolled motion. In addition to software position and velocity limits, and hardware position limit switches, an operator actuated e-stop cuts power to the motor and brakes the lever arm.

Validation: In order to assess the relative repeatability of the dynamometer compared to the MMT-8 method, which is subjective and manual, we collected contraction data for 18 healthy controls. For this validation, the dynamometer was used to collect maximal voluntary contractions (MVCs) in elbow flexion and elbow extension. Three repeated trials were recorded in one session for each participant in each motion with breaks between each exertion to avoid fatigue effects.

3 Results

For the 18 participants, the repeatability across three trials for elbow flexion was 2.70±2.27 Nm (95^{th} percentile: 6.74 Nm) and for elbow extension was 2.83±2.13 Nm (95^{th} percentile: 5.65 Nm). The MVC across participants for the two motions was 48.6±14.2 Nm and 36.3±15.2 Nm, respectively.

4 Discussion

Subjectively graded manual muscle testing, like the MRC and MMT-8 scales, have long been the standard for patient evaluation. However, their lack of detail and inability to track incremental changes make them minimally useful to modern rehabilitation. Dynamometry can overcome this by objectively evaluating a patient's strength; however, it is inaccessible to clinicians due to cost and size constraints and to patients with mobility limitations. Existing dynamometers focus on athletes and thus do not feature a patient-centered design. Attempts to counter this problem with handheld load sensors fall short due to their poor inter-rater reliability and the inability to measure isotonic contractions (Pfister, PLoS One, 2018).

The solution presented combines the portability and accessibility of handheld devices with the reliability and richness of data expected from research-grade dynamometers. Its portability enables it to be moved to patients and clinicians and meet their needs. The results obtained demonstrate a high level of repeatability (±2.8 Nm), which corresponds to ~6-9% of the MVC of healthy participants in this study. Furthermore, in comparing this repeatability to the standard MMT-8 manual method, the dynamometer's repeatability is markedly better. This is borne out by comparing the obtained results to previously published data (Pfister, PLoS One, 2018) that studied the range of force produced by subjects categorized as being an MMT-8 Level 10 (i.e., recovered to a normal strength), where the repeatability across three testing sessions for 33 participants was 5.48±4.23 Nm (95^{th} percentile: 12.29 Nm). Thus the MMT-8 classification method categorizes people of widely ranging strength into the same group while the dynamometer device can identify small but important changes in strength.

While isometric muscle strength is critical to objective patient evaluation, the upper limb dynamometer is designed for more rigorous testing in the future. Maximal power, which depends on both torque and velocity, tend to develop where torque is moderate (Edgerton, Human Kinematics, 1986; Stauber, Clin Physiol, 2000). The implementation of a more advanced field-oriented motor control strategy is ongoing. This will allow isotonic testing (which is not possible with a handheld force sensor), where a patient can move their limb at a constant torque resistance - often a sub-maximal percentage of their isometric MVC - while their rotational velocity is measured. This functional measurement gives a picture of a patient's dynamic power in Watts rather than just static strength in Newton-Meters. It is possible that a patient may present as healthy in isometric, isokinetic, and manual tests with significant power deficiencies that can only be clinically observed in isotonic testing (Stauber, Clin Physiol, 2000), making it a critical ongoing area of development for this dynamometer system.

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