A WEARABLE SENSOR SYSTEM FOR QUANTIFYING ISOMETRIC ELBOW AND KNEE JOINT STRENGTH

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INTRODUCTION

Muscle strength measurement is a critical component of physical therapy and rehabilitation and sport science in general. Rehabilitation outcomes for many diseases, disorders and injuries, ranging from stroke in older populations to athletic injuries in younger populations requires assessment of muscle strength in a clinical environment [1]. Research in rehabilitation and sport science often use muscle strength as a primary outcome, and furthermore requires measurement of "maximal voluntary isometric contraction" to normalize muscle electromyography assessments [2]. There are currently two choices for obtaining quantitative measurement of muscle strength. Isokinetic dynamometry systems can accurately and reliably measure both isokinetic and isometric muscle strength [3], but very few clinical facilities have access to such equipment due to its cost of purchase and maintenance as well as its space requirements. Hand-held dynamometry systems are considerably cheaper and require far less resources to maintain, but testing of major joints (like the knee and below) is difficult to perform, mostly in terms of the tester stabilizing themselves against the patient's ability to generate force [4]. As such it requires considerable training and experience, and is most often used clinically. Currently there is no strength measurement device available to the clinician or researcher that is inexpensive and portable, and that requires no external support from the therapist or other supporting structure.

This paper presents an innovative and novel concept for obtaining measurement of elbow and knee joint strength using a wearable system of sensors and mechanical constraints.

The system is easily donned and doffed from the arm or leg, and can measure isometric (fixed angle) strength of both flexor and extensor muscles of the joint.

DESCRIPTION

The Limb Strength Measurement Device (LSMD) measures the human subject's isometric flexion and extension strength of the elbow and knee joints with the joint at a fixed angle, which in this manifestation of the device is approximately 90 degrees. See Figures 1a and 1b. The arm and leg models are essentially the same device on different scales. Each is adjustable in size.

Figure 1a: LSMD Arm v2 on arm in flexion.

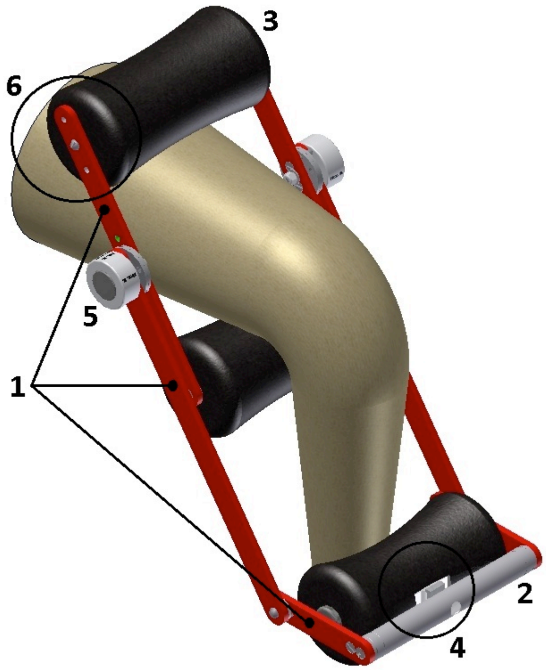

Figure 1b: LSMD Leg v3 on leg in extension.

Components

Each LSMD is composed of the following components (see Figure 1b for numbering):

1. Frame members made from 1-inch wide by ¼-inch thick aluminum bars. (The LSMD Arm v3 uses 2-inch wide bar for the middle member.)
2. Cross members made from 1-inch outside diameter aluminum tube. These tubes hold the frame together and hold the pads.
3. Pads are vinyl-covered, foam roller pads similar to those used on common fitness equipment. Pads have a 1-inch hollow core and radial foam thickness of 1-inch for the arm and 1.5-inches for the leg. Several thicknesses and firmnesses were tested to find the optimal size and comfort.
4. A load cell which measures the applied load is contained within the distal pad. The load cell currently being used is a stainless steel, tension/compression load cell, with a rated capacity of 300lbs (LC703-300 from Omega Engineering Inc.).
5. A locking mechanism to lock the proximal and middle frame members at fixed angles for flexion, extension, or straight for storage. The mechanism is a spring-loaded pin which fits through mating holes in the proximal and middle frame members. The original locking mechanism, shown in Figures 1a, 3a and 3b, has proven difficult to use. It is an off-the-shelf device which can be difficult to disengage and has broken under load. Figures 1b and 2 show a custom design with a spring-loaded knob which is larger, plastic and contains two pins. The larger size is easier to grasp and pull, and the double-pin means less force and less friction per pin making it easier to disengage.
6. Size adjustment holes. The proximal pad (at the shoulder or thigh) can be attached at three different distances from the middle pad (elbow or knee) to accommodate different size limbs. Although the drawings show screws attaching the proximal pad, threaded knobs are now used so that no tool is needed for the adjustment. Being able to disconnect the pad quickly is also a safety feature to allow removal of the device in the event the user experiences a spasm and the locking mechanism won't disengage.

Figure 2 shows the LSMD Arm v3, a "single-sided" version with bars on only one side and a wider middle bar for more strength.

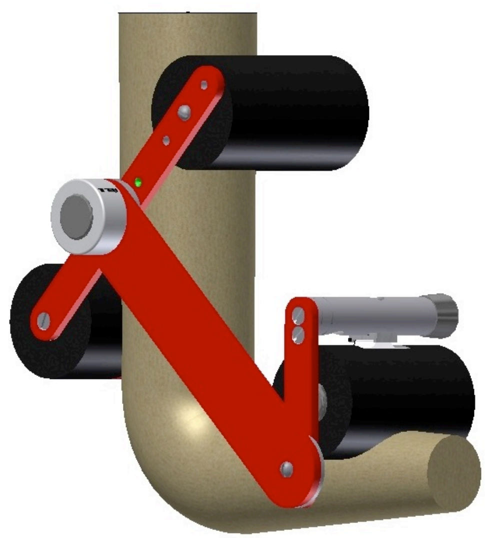

Figure 2: LSMD Arm v3 single-sided on arm in flexion

Function

The LSMD is intended to be included as part of an assessment tool-kit used in a clinic, gym or the home with little instruction. Therefore it was designed to be easy to use and produce repeatable measurements.

Operating the LSMD is very simple whether using the double-sided arm or leg model in flexion or extension. In the case of flexion of the arm, first the shoulder pad is set in the correct sizing holes depending on the size of the subject's limb. To place the device on the limb, the device, locked in its folded straight setting with the wrist pad just above the shoulder pad, is slid over the arm to place the shoulder pad in front of the shoulder and elbow pad behind the elbow. See Figure 3a. (For extension, the shoulder pad is placed behind the shoulder and elbow pad placed in front of the elbow.)

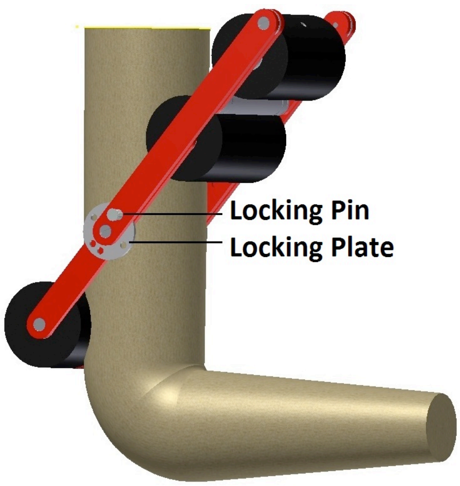

Figure 3a: LSMD Arm v2 locked folded and placed on the arm for flexion.

Next, the device is unlocked, by disengaging the locking pins, and unfolded to place the wrist pad against the forearm near the wrist. See Figure 3b. The locking pins engage into the appropriate "flexion" holes in the locking plates to lock the device in place with the subject's arm at approximately 90 degrees (other set angles are possible by modifying the location of the holes on the locking plates).

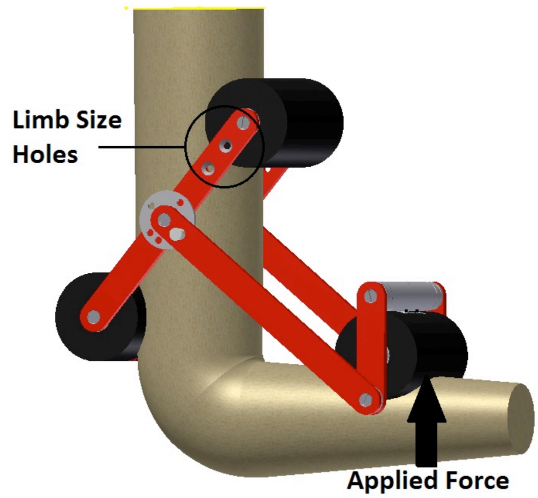

Figure 3b: LSMD Arm v2 unfolded and locked for flexion.

Once locked, the LSMD uses the same principle as a three-point orthotic brace to prevent the joint from flexing. The subject simply applies a force against the wrist pad with his/her forearm. The load cell located in the wrist pad assembly measures the applied force. See Figure 3b.

The same LSMD can be used to measure both flexion and extension. Changing from one direction to the other is done without the need to remove the device from the limb. Simply unlock the spring-loaded pins, re-lock the device in the folded position, rotate the entire device 180 degrees about the limb (in the case of the arm, the shoulder pad moves from front of the shoulder to the back or vice-versa), and unfold the device to lock in the new position.

Using the single-sided arm device (see Figure 2) is even easier than the double-sided version. The device is locked into position for either flexion or extension. It is then slid, from the side, over the arm which is waiting with the appropriate amount of flexion.

The geometric design of the framework and the selected locations of the padded contact points allow the device to be self-stabilizing and self-aligning with the subject's anatomical features when the subject is exerting force on the device. For example, as shown in Figure 3b, when the person tries to flex the arm by pressing the forearm against the wrist pad, the elbow pad presses into the back of the elbow and the shoulder pad presses into the front of the shoulder. This self-contained measuring provides all the restraining force that opposes the subject's developed force and so requires no physical coupling, connection or restraining between the subject and the outside world through a floor, wall, chair or any other immovable objects.

Field Testing

At the time of writing this paper we have partially completed a pilot study at the Stan Cassidy Centre for Rehabilitation (SCCR, Fredericton, NB), which involves the use of the arm and leg LSMDs to measure maximum voluntary contraction for elbow flexion, elbow extension and knee extension. 32 patients have been recruited from the SCCR. Included were adult patients with acquired brain injury (including strokes), cerebral palsy, multiple sclerosis and spinal cord injury. The device has been used by several different OTs and PTs in the study. The LSMD has performed well with this variety of users. The feedback from the therapists and patients has contributed to the improvements made in the design.

Some patients (such as those with contractures at the wrist and hand) required more care in donning and doffing the double-sided arm device. This partially motivated the development of the single-sided arm model. Also current size devices can be tight on larger people especially if stiffness in their joints makes it difficult to reach 90 degrees of flexion. Therefore, it will likely be necessary to provide extra large devices for larger or obese users.

DISCUSSION

Most typical devices that objectively quantify limb flexion and extension strength are large apparatuses attached to the wall or floor which are not easily portable [5]. Other devices such as hand-held dynamometers, require a trained user to hold the device steady while the subject, who must also remain steady, applies a force [4]. The advantage of the LSMD is that it is both portable and stable. It is compact and light-weight for easy carrying. Because of its novel design, it is self stabilizing against the user's own limb. As opposed to the hand-held dynamometers which rely on the experience of the one holding the device to maintain consistency, the LSMD can be easily placed on the limb in a repeatable fashion so that results are consistent and comparable.

The LSMD is intended to be commercialized as part of a suite of tools being developed at the Institute of Biomedical Engineering at UNB in a project entitled "BioTone – Clinician tools for neuromuscular evaluation". The authors have applied for a United States patent for the LSMD [6].

ACKNOWLEDGMENTS

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