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A Quantitative Shoulder Strength Testing Method for in-Person and Telemedicine Examinations

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ABSTRACT

INTRODUCTION

In workers' compensation cases, personal injury claims, and other injuries, a physician must sometimes test the muscle strength of an injured body part to determine a patient's whole-person impairment. Injuries to the shoulder are a common workplace injury that frequently requires muscle strength testing. There are several problems related to the testing of shoulder strength: Lack of standardized testing methods, difficulty of performing testing remotely via telemedicine, and inability to determine impairment in the case of bilateral shoulder injuries. This study tested a new quantitative strength testing method involving a patient stretching an elastic band with full strength, and determining the force used by the patient based on the maximum arm angle achievable by the patient while gripping the band. If effective, a band-stretching strength testing method can be used to determine an impairment rating for a patient's shoulder in telemedicine and in cases involving bilateral injuries. A quantitative strength testing method that can be performed remotely via telemedicine and can be applied to bilateral injuries may improve efficiency and accuracy in workers' compensation claims, personal injury claims, and other cases involving impairment ratings.

METHODS

A TheraBand, an elastic band typically used in physical therapy clinics for injury rehabilitation, was stretched by 53 volunteers in various planes relevant to strength testing. The maximum angle each volunteer stretched the band was measured, and the individual's arm length was recorded to calculate the length of the stretched band. The kg-equivalent force as a function of the stretched length of the band was determined to correspond the angle of an individual's arm with a kg-force, thus producing a quantitative measurement of the individual's shoulder strength on the basis of the length of the stretched band. Angles were measured using a goniometer application in person and also on a computer screen to test the viability of a telemedicine approach.

RESULTS

The majority of the data was found to be within the 10% acceptable error range outlined in the AMA Guide to the Evaluation of Permanent Impairment, 5th Edition, which means this strength testing method may be valid in clinical practice. A force lookup table and corresponding graph were generated so that measuring the angle formed between a patient's arm and a TheraBand can be

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used to determine the force the patient is exerting, thus producing a strength testing result that can be used in both in-person and telemedical impairment rating examinations.

KEYWORDS

Telemedicine; Impairment; Muscular strength; Dynamometer; Goniometer, Shoulder range of motion; Bilateral and unilateral injury

INTRODUCTION

The strength of an injured body part is commonly measured in a clinical setting. Evaluating the muscle strength of injured shoulders is necessary for determining an impairment rating in workers' compensation claims and other injuries requiring a settlement value, according to the *AMA Guides to the Evaluation of Permanent Impairment, 5th Edition* (hereafter, the "*AMA Guides*") which is a text that provides guidelines for impairment rating in many states [1]. In this context, muscle strength refers to "the capacity for active development of tension by a muscle irrespective of the mode of testing (isometric, isotonic, isokinetic), the muscular contractile velocity (slow *vs.* fast), or the type of muscle contraction (isometric, concentric, eccentric)" [2].

In current clinical practice, there are several problems related to the testing of shoulder muscle strength, including lack of standardized strength testing methods, difficulty of performing testing remotely via telemedicine, and inability to determine impairment in the case of bilateral shoulder injuries.

To understand the current practices and requirements for testing, we turn to the *AMA Guides*, where muscle strength is graded on a 6-points scale, grades 0 through 5. For a patient that has a unilateral injury, where only one shoulder has been injured, the strength of the injured shoulder is compared with that of the uninjured shoulder [3]. In Table 16-11 on page 484 of the *AMA Guides*, a grade assignment is given according to the following criteria:

- Grade 5: Active movement against gravity with full resistance.
- Grade 4: Active movement against gravity with some resistance.
- Grade 3: Active movement against gravity only, without resistance.
- Grade 2: Active movement with gravity eliminated.
- Grade 1: Slight contraction and no movement.
- Grade 0: no visible contraction of the muscle [1].

As the *AMA Guides* states, muscle testing "remains somewhat subjective until precise methods of measuring muscle contractions become generally available." Although the *AMA Guides* provides a clear 0 to 5 scale for describing a patient's muscle function, it does not instruct physicians or other examiners to measure a patient's upper extremity strength using a specific procedure beyond stating that the "examiner must use clinical judgment to estimate the appropriate percentage of motor deficits and loss of power within the range of values shown for each severity grade." As a result, each physician currently classifies the grades of their patients' muscle strength according to their individual "Clinical judgment."

While there may be as many methods of estimating muscle function as there are medical examiners, it is desirable to quantitatively measure rather than estimate a patient's upper extremity muscle strength using a consistent well-defined procedure that can produce similar results when replicated by different examiners. Ideally, such a quantitative strength testing method could be used in both in-person and telemedicine settings and for both unilateral and bilateral shoulder injuries. Such a method - hereafter referred to as "quantitative strength testing" - is the subject of the current study.

The proposed quantitative strength testing involves a patient stretching a TheraBand (an elastic band) with both the uninjured and injured shoulder as far as possible in both flexion and extension in the sagittal plane, and then determining the force used by the patient - the patient's muscle strength - based on the length of the patient's arm and the length of the TheraBand. Measuring the length of the stretched TheraBand directly with a measuring tape may prove difficult in an in-person clinic setting and even more challenging in a telemedicine setting. For simplicity, the length of the TheraBand can be calculated using the length of the patient's arm, the measurement of the angle formed by the patient's arm while pulling the TheraBand, and simple trigonometry. Once the length of the stretched TheraBand is obtained, the examiner can reference a lookup chart that classifies the patient's strength grade on the basis of the patient's arm length, the angle formed by the patient's arm, and the TheraBand. The creation of such a lookup chart is the purpose of the first experiment in this study, which is described in the Methods section. The "grade" of the patient's muscle strength should include the patient's ability to provide maximum voluntary muscle tension and also requires strength measurement in either force or torque [2]. Grade can then be objectively classified as long as the relationship between the length of stretched band and the strength required to produce such a length is known. An accurate lookup chart that documents this relationship provides a reliable basis for the grade of strength.

If proven to be effective, quantitative strength testing can be used to measure strength not only via telemedicine and in-person settings, but also cases involving bilateral shoulder injuries where there is no healthy shoulder for reference. When evaluating strength using the band-stretching method for unilateral injuries, the physician uses the uninjured shoulder measurements as the baseline for grade 5 to compare with the injured shoulder. However, patients with bilateral injuries do not have a baseline of normalcy to rate the impairment of their injured body part. Therefore, this study attempts to define "Grade 5" (full shoulder strength) among healthy adults.

If viable, quantitative strength testing may improve efficiency, accuracy, and ease of access in workers' compensation claims, personal injury claims, and other cases that require the need for impairment ratings or muscle strength testing. If proven to be effective via telemedicine, remote quantitative strength testing can benefit patients who are far-removed from medical facilities or have limited mobility, for whom in-person medical examinations are a hardship. Even prior to the onset of the Covid-19 pandemic and the emphasis on reducing in-person clinic visits, telemedicine has been rapidly growing [4]. Although face-to-face contact between the physician and the patient is imperative for some types of examinations, there are constraints regarding time and resources that make in-clinic visits increasingly expensive and at times impractical [4]. Telemedicine also has the potential to increase efficiency in the diagnostic process [5]. Many publications discuss the benefits of telemedicine and research showing the agreement between in-person visits and telemedicine visits [6-24].

METHODS

This study was divided into two distinct experiments. The first experiment was designed to create a calibration curve documenting the relationship between force applied to an elastic band and the resultant length of a stretched band. Such a dataset is necessary to infer the grade of the patient's shoulder strength on the basis of the stretched TheraBand. The second experiment involved volunteers stretching elastic bands and measuring the shoulder angle, mimicking a clinical setting in which a patient would be performing a shoulder muscle strength test. The results of the second experiment include data showing a proposed definition of a "healthy" shoulder, and data documenting the relationship between arm length, the measured arm angle, the corresponding stretched TheraBand length, and the force equivalent needed to produce that stretched length The methods for each experiment are elaborated upon below.

MATERIALS

The materials used in this experiment included 5-in wide, 6-ft long green resistance TheraBands (model 104-011) purchased on Amazon.com. These elastic bands are commonly used in exercise and rehabilitation regimens involving shoulder muscles [25]. TheraBands are used world-wide and are proven to increase strength and mobility for patient rehabilitation [26] including shoulder injuries resulting from trauma, a chronic condition, or exacerbation of a chronic condition [3]. In this study, we used the green TheraBand, which has the fourth highest (near the center) resistance rating out of eight levels.

Additional materials include an 18 pound (8.2 kg force equivalent) spring scale dynamometer in 0.5 pound (0.23 kg force equivalent) increments used for initial rough measurements over a large range, a 2 kg spring-scale dynamometer in 40 g increments, a measuring tape, two tripods, and the RateFast Goniometer mobile phone application for measuring the angle formed by a subject's arm and the TheraBand. This study was performed in the Hamline University Department of Physics in St. Paul, Minnesota, by three undergraduate research students under the supervision of Dr. Jerry Artz, Dr. Bruce Bolon, and John Alchemy, M.D. Volunteers included students, faculty, and staff of Hamline University. Ethical approval was obtained by the Hamline Institutional Review Board (IRB). The IRB approval number for this research is 2019-06-42ET.

Experiment 1 Methods

In the first experiment, eleven green TheraBands were tested to determine the kg-equivalent force *vs.* stretched length calibration curve for each band. The purpose of this segment of the study was to document the relationship between the force applied to a TheraBand and the length of the stretched TheraBand, as generating data of the relationship between force and TheraBand length is necessary for the production of a reference chart that would allow clinicians utilizing the quantitative strength testing method to determine the force a patient is exerting on a TheraBand based on the TheraBand's length.

All TheraBands were tested using the following procedure: a single knot was tied at each end of the band with a 2-inch tail, and the 18 pound (8.2 kg force equivalent) dynamometer was attached to the band at one end with a clamp. The fixed end was secured at the bottom of a door frame. The band then rested on the ground perpendicular to the door without slack or tension, corresponding to the starting point of zero on the dynamometer scale.

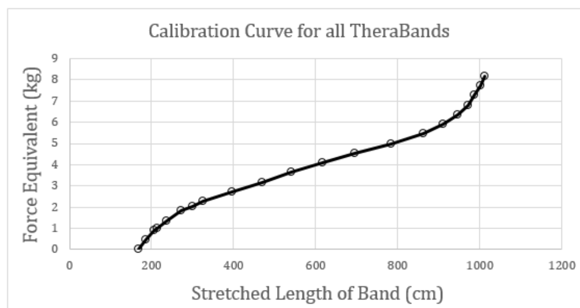

Figure 1: Calibration curve for the average of all eleven TheraBands. The black curve is a guide for the eye.

Next, the free end of the band was pulled, and its stretched length was measured using a dynamometer calibrated in pounds (lbs.) as the force was increased in 1-lb (0.45 kg force equivalent) increments up to 18 lbs. (8.16 kg force equivalent). The relationship between the force and the stretched length of the TheraBand was documented, and this process was repeated for each band. A calibration curve relating the average kg equivalent force for all eleven bands *vs.* stretched length can be found in in the Results section of this study (Figure 1).

A single TheraBand, labeled Band 3 in Figure 2, was arbitrarily chosen to be used by volunteers. Prior to the volunteers using this band, calibration curves were obtained by stretching the same TheraBand in 5 cm increments. This part of the experiment was performed using the 2 kg dynamometer, since it allowed for finer increments.

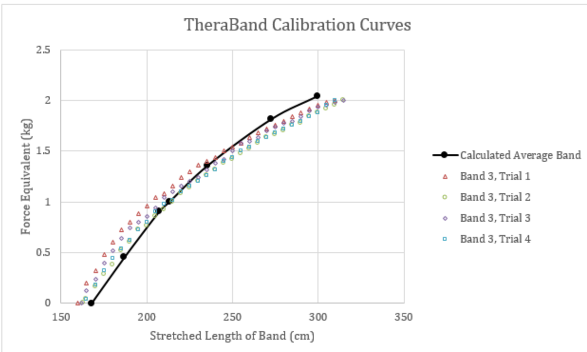

Figure 2: Calibration curve showing kg-equivalent force *vs.* stretched length of Band 3, later used by volunteers, along with that for the calculated average of all eleven bands, excerpted from Figure 1 for comparison. The black curve is a guide for the eye.

Experiment 2 Methods

For the second part of this experiment, volunteers from Hamline University were utilized to determine the average strength of a healthy shoulder. Volunteers were required to be at least 18 years of age with no history of shoulder injuries. Data obtained included date of birth, gender, handedness, height, weight, arm length, and height above the floor of the subacromial space [27], i.e., the space above the shoulder's ball-and-socket joint and below the top-most bony prominence of the shoulder.

The volunteers received both verbal and visual instructions. They were asked to hold their arms horizontally in front of their bodies, making a fist with their thumbs facing the ceiling, a method that is currently used in a clinical setting as per the *AMA Guides*. One end of the elastic band was placed in the door jamb at the height of the subject's subacromial space to ensure that the taut band would be horizontal at the beginning of each measurement. This initial band length was set to 172 cm, knot to knot. The distance from the subacromial space to the end of the subject's fist was measured, since the knot in the TheraBand was held in the fist between the index and middle fingers, as shown in Figure 3.

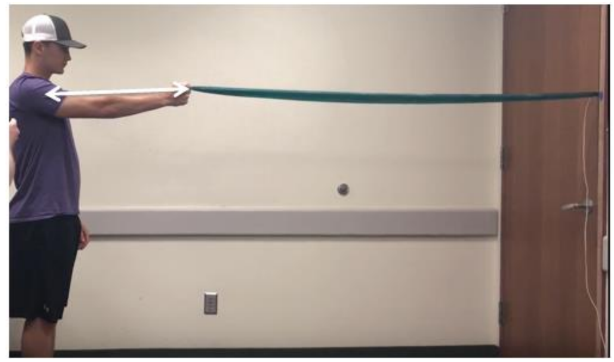

Figure 3: Subject with arm and band at starting position, zero-degree reference. The distance from the subacromial space to the end of the fist is illustrated by the white double arrow.

Each volunteer performed two sets of flexion and extension warm-up stretches before beginning. Flexion and extension in the sagittal plane are shown in Figure 4.

The RateFast goniometer mobile phone application was used to measure the angle formed by the subject's shoulder and arm/TheraBand to ensure that the arm was initially horizontal (as shown in Figure 3), which served as the zero-degree reference. The goniometer was also used to measure all subsequent angles by holding the mobile phone against the bicep while running the goniometer application. Each researcher was trained in the proper use of the RateFast goniometer mobile phone application for shoulder measurements. The accuracy of the RateFast Goniometer in both in-person and telemedicine contexts has been tested in a separate study [28].

Data-taking began with the volunteer reaching the maximum angle of the arm in both flexion and extension twice for each arm, first with the TheraBand (exerting as much force on the TheraBand as possible) and then without the TheraBand (simply moving the arm as far as possible without resistance), for a total of 16 angle measurements per volunteer. With the volunteer's arm at the maximum angle of flexion or extension, the angle was measured using the RateFast goniometer mobile phone application.

Figure 4: Flexion (left) and extension (right) in the sagittal plane.

For each measurement, a picture was also taken using a mobile phone on a tripod level with the plane of the shoulder in the neutral measurement position, and another mobile phone was used to obtain videos of the measurement-taking process. The second mobile phone (used for pictures) was aligned with the volunteer's shoulder, sufficiently far from the shoulder, again level with the plane of the shoulder in neutral measurement position, to minimize issues with parallax.

It was determined that parallax contributed insignificantly if the distance of the second mobile phone from the volunteer was a minimum of approximately 12 foot (3.7 m) and no lower than the waist and no higher than the head. The 12-foot distance from the phone to the subject was chosen because this was the minimum distance for which the observer, when viewing through the camera, could see the entire range of motion of the subject and to verify that the wrist was not bent.

Once all 16 measurements were taken for a volunteer, the angles were re-measured by analyzing the pictures on a computer screen using the "camera mode" on the RateFast goniometer, which allows a user to measure an angle visually. Measuring the angle in the picture on a computer screen emulates how a physician measures the angle of a patient's arm during a telemedicine visit while the patient is performing this strength testing method during a video call. This was done for comparison with the standard default RateFast goniometer measurements taken in person to test the reliability of the RateFast goniometer mobile phone application in a telemedicine application where the physician measures the image of a patient on a screen.

RESULTS

Experiment 1 Results

In the first experiment, four separate trials of stretching the band were performed with the results plotted in Figure 2, along with the relevant range of the average calibration curve for all eleven bands (Figure 1). Recall that the calibration curve of all bands was obtained using the 18 pound (8.2 kg force equivalent) dynamometer that had much rougher increments; therefore, a perfect match was not expected.

The data from four different trials performed on one specific TheraBand, referred to as Band 3, are shown in Figure 2. The black curve in Figure 2 is excerpted from Figure 1. This calculated average band curve therefore corresponds to the calculated average of all eleven bands that were tested and is included here for comparison. The Band 3 trials all come reasonably close to this black curve, even though the latter was obtained using the original 18 pound (8.2 kg force equivalent) dynamometer, with much rougher increments. This close correlation is important, as it implies that the mechanical properties of TheraBands of the same type are consistent in elastic behavior, so a patient using that type of TheraBand in a telemedicine setting will obtain reliable results.

This data serves as a reference for the relationship between the TheraBand length and the force applied in Experiment 2. For example, based on Figure 2, if a volunteer stretches a TheraBand to 250 cm (horizontal axis), we would expect that the force equivalent would be 1.5 kg (vertical axis).

				Maximum Angle Obtained (deg)		TheraBand Length, L (cm)		Force Equivalent (kg)	
				Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Female	NO BAND	MAJOR	Flexion	88.1	12.0	233	12.4	1.29	0.14
			Extension	145.6	10.9	279	9.2	1.74	0.08
		MINOR	Flexion	91.6	9.0	237	9.5	1.33	0.11
			Extension	142.8	12.9	277	10.4	1.73	0.09
	BAND	MAJOR	Flexion	83.6	11.5	229	11.6	1.24	0.14
			Extension	137.1	13.0	274	9.7	1.70	0.09
		MINOR	Flexion	88.1	10.2	233	9.9	1.29	0.11
			Extension	136.4	14.9	273	11.3	1.69	0.10
Male	NO BAND	MAJOR	Flexion	91.7	11.0	245	12.3	1.42	0.13
			Extension	140.9	11.0	288	7.7	1.82	0.06
		MINOR	Flexion	91.7	10.8	245	11.6	1.42	0.12
			Extension	141.1	11.4	288	7.3	1.82	0.06
	BAND	MAJOR	Flexion	88.2	11.5	241	12.9	1.37	0.14
			Extension	133.8	10.3	283	8.4	1.78	0.07
		MINOR	Flexion	88.3	9.6	241	10.9	1.38	0.12
			Extension	135.3	10.3	284	8.0	1.79	0.07

Table 1: Average maximum angle obtained and the corresponding values of stretched length of the TheraBand and force equivalent. Results are presented separately for females and males, with range of motion limits with and without the TheraBand, for major and minor hand, and for flexion and extension.

The kg equivalent force as a function of arm angle for various arm lengths is shown in Figure 5, below. Each individual curve, corresponding to a given arm length, is generated using the force lookup table previously mentioned. While a set of tables for an even wider array of arm lengths would likely be of more practical use by physicians, the graph in Figure 5 succinctly demonstrates the relationship in question for the seven arm lengths tested here.

The average arm length of the volunteers tested was determined to be 59.9 cm for females and 66.1 cm for males. The results of the measurements of the relationship between the length of a volunteer's arm and the length of the stretched TheraBand are displayed in (Figure 6 and Figure 7) for females and males respectively for their dominant (major) arms and non-dominant (minor) arms, and for flexion and extension in the sagittal plane of motion.

Experiment 2 Results

In the second experiment, the stretched length of the TheraBand was calculated for a given angle using the initial length of the TheraBand and the volunteer's arm length. A force lookup table was then generated that could be used by examiners to determine the kg equivalent force corresponding to a known angle based on the patient's arm length (Table 1).

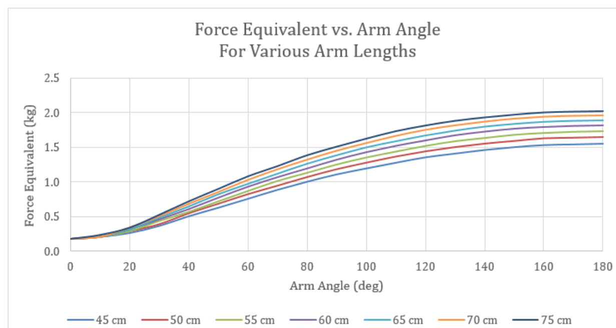

Figure 5: Lookup chart showing the TheraBand kg equivalent force as a function of arm angle for various arm lengths.

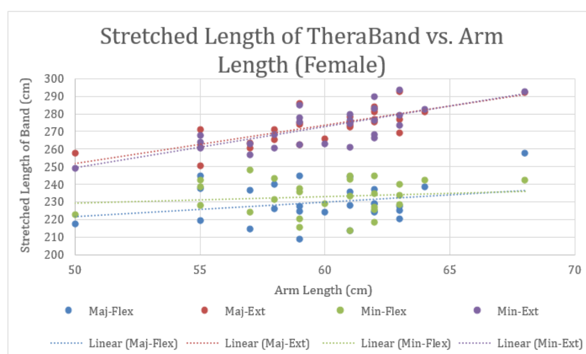

Figure 6: Length of the stretched TheraBand *vs.* arm length for major and minor hands in flexion and extension for female volunteers.

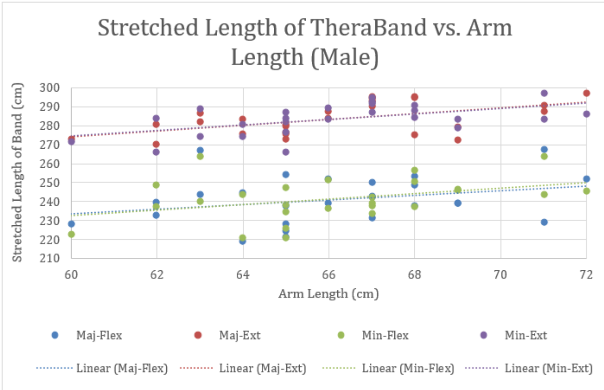

Figure 7: Length of the stretched TheraBand vs. arm length for major and minor hands in flexion and extension for male volunteers.

DISCUSSION

In the first experiment, the consistency in the data presented in (Figure 1 and Figure 2) suggests that a patient performing the quantitative strength test with a green TheraBand (i.e., a TheraBand with the same specifications) can expect reliable results. While the relationship between the stretched length of the band and the force equivalent is not predictably linear, one could still determine the force used to stretch a TheraBand on the basis of the TheraBand's length by referencing a calibration curve such as those presented in (Figure 1 and Figure 2).

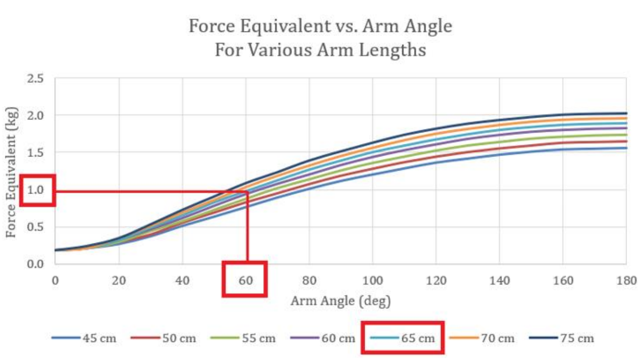

Figure 8: An example scenario illustrating the use of Figure 5. Here, a patient's arm is 65 cm in length, and the arm angle is 60°, resulting in a force equivalent of 1.0 kg.

As seen in Figure 6 and Figure 7, the maximum stretched length of the TheraBand varies noticeably with the subject's arm length. Therefore, a medical examiner using this method of muscle strength testing in clinical practice could reference a lookup table that associates a patient's arm length and the length of TheraBand, such as the data used to generate the graph in Figure 5. For example, if the patient's arm length is 65 cm (the light blue line) and the arm angle is measured to be 60°, then according to Figure E the force equivalent is 1.0 kg, as illustrated in Figure 8, below.

In Figure 6 and Figure 7, note the remarkable consistency between the trendlines for major and minor arms both in flexion and extension for females and males. Each such pair of trendlines roughly overlaps, demonstrating a minuscule difference between major and minor arms that is unlikely to affect the outcomes of a muscle strength testing exam.

CONCLUSION

In conclusion, as outlined in this paper, a TheraBand may be used as a quantitative diagnostic tool for the purposes of testing strength as outlined in the *AMA Guides*. This strength testing method would likely find practical application in workers' compensation claims or other injuries involving impairment ratings, or any other clinical scenario that requires a medical examiner to ascertain shoulder strength. Based on the study, this quantitative strength testing method can be used in both in-person and telemedicine settings, provided that the patient has access to a TheraBand with the same specifications and the medical examiner remotely evaluating the patient uses the methods described here.

The results of this study suggest opportunities for more research, including larger studies involving other types of injuries, other types of elastic bands, and additional standards or administrative rule sets that govern medical-legal cases where strength testing is routinely required. If widely adopted, this quantitative strength testing method may offer meaningful improvements to not only the practices of medical providers and the experiences of their patients, but the efficiency of workers' compensation systems and similar medical-legal systems as a whole.

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