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Optimal joint positions for manual isometric muscle testing

Stefan C Garcia, **Jeffrey J Dueweke**, and **Christopher L Mendias**[*]
Department of Orthopaedic Surgery, University of Michigan Medical School, Ann Arbor

Abstract

Context—Manual isometric muscle testing is a common clinical technique that is used to assess muscle strength. To provide the most accurate data for the test, the muscle being assessed should be at a length in which it produces maximum force. However there is tremendous variability in the recommended positions and joint angles used to conduct these tests, with little apparent objective data used to position the joint such that muscle force production is greatest.

Objective—To use validated anatomically and biomechanically-based musculoskeletal models to identify the optimal joint positions in which to perform manual isometric testing.

Design—*In silico* analysis.

Main Outcome Measure—The joint position which produces maximum muscle force for 49 major limb and trunk muscles.

Results—The optimal joint position for performing a manual isometric test was determined.

Conclusion—Using objective anatomical models that take into account the force-length properties of muscles, we identified joint positions in which net muscle force production was predicted to be maximal. This data can help health care providers to better assess muscle function when manual isometric strength tests are performed.

Introduction

Manual muscle testing (MMT) is the predominant method used to assess muscle strength in the clinical setting [1]. There are generally two types of test procedures for isometric testing [2]. A "make" test involves the patient exerting a maximum voluntary effort against fixed resistance provided by the examiner. A "break" test requires the patient to exert maximum voluntary effort against an increasing counterforce by the examiner to exceed or "break" the isometric force being generated by the patient. Muscle strength is most frequently graded by the examiner on a six point subjective scale that ranges from no perceptible muscle contraction scored as a 0, to being able to resist the full counterforce of the examiner as a 5 [3]. More objective measurements can also be performed using a dynamometer. While MMT is a commonly used and practical technique, there can be moderate to low inter-rater reliability in the subjective grading of muscle force production [4].

[*]To whom correspondence should be addressed: Christopher L Mendias, PhD, ATC, Department of Orthopaedic Surgery, University of Michigan Medical School, 109 Zina Pitcher Place, BSRB 2017, Ann Arbor, MI 48109-2200, 734-764-3250, cmendias@umich.edu.

The amount of isometric force that a muscle can generate is directly related to the length of the muscle. This force-length property of muscle is due to the overlap between the thick and thin filaments in sarcomeres which generate active tension in skeletal muscle fibers. At a sarcomere length of approximately 2.7μm there is optimal overlap between thick and thin filaments, and the force that is produced by muscle fibers is subsequently maximal at this length [5]. While this relationship is relatively straightforward at the single muscle fiber level, the diverse size and geometry of whole muscle tissue can make it difficult to identify the length at which force production is maximal. Common recommendations for MMT involve positioning the joint in either a neutral right angle position or at the midpoint in the active range of motion [6]. However there is little apparent objective data to support these recommendations. To provide rehabilitation clinicians with more objective recommendations for MMT, our goal was to use data available from existing detailed anatomical and biomechanical software models of the upper and lower extremity musculature [7,8] to identify the joint position in which maximum isometric force is predicted to be greatest.

Methods

OpenSim

We loaded an upper extremity anatomical model [8] and a lower extremity anatomical model [7] into OpenSim version 3.2 software [9] to perform analysis. The muscle force-generating characteristics of these models were determined using muscle parameters derived from anatomical studies, and skeletal characteristics were based on published data consistent with a 50th percentile male (170 cm). The accuracy of the moment-generating capacity of both models was tested based on comparison to experimentally measured moment arms.

OpenSim creates a muscle-driven simulation of movement by formulating a dynamic model of the musculoskeletal system and its interactions with the rest of the body and its surrounding environment. The musculoskeletal system was modeled using sets of differential equations describing muscle contraction dynamics, musculoskeletal geometry and body segmental dynamics. After the creation of each simulation, the accuracy was tested based on how well each simulation agreed with experimentally-measured kinematics, kinetics and EMG patterns. The simulation was further analyzed to determine the contributions each muscle makes to a defined motion. [9]

Identifying Joint Position Predicted to Produce Maximum Isometric Force in OpenSim

Fixation angles were manipulated in equal 10° increments throughout a normal anatomical range of motion. The number of fixed joint positions evaluated is equal to the product of the number of fixation angles manipulated for each particular motion. For example, when testing the shoulder rotators, fixed shoulder positions were manipulated in 10° increments for 13 different positions of shoulder flexion (-30° to 90°) and 19 different positions of shoulder abduction (0° to 180°), giving a total of 247 fixed joint positions.

The upper extremity model [8] contains 50 muscle groups. The shoulder, elbow, and wrist joints have 3, 1 and 2 degrees of freedom, respectively. The shoulder rotators were fixed in 247 different joint positions and isometric joint moment was found at 100 equally spaced

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angles from 20° external rotation to 90° internal rotation. The elbow extensors/flexors were fixed in 91 different joint positions and isometric joint moment was found at 100 equally spaced angles from 0° to 130° flexion. The wrist extensors/flexors were fixed in 105 different joint positions and isometric joint moment was found at 100 equally spaced angles from 70° extension to 70° flexion.

The lower extremity model [7] contains 35 muscle groups. The hip, knee, and ankle joints have 3, 1, and 1 degree of freedom, respectively. The hip extensors/flexors were fixed in 30 different joint positions and isometric joint moment was found at 100 equally spaced angles from 30° extension to 120° flexion. The hip abductors/adductors were fixed in 108 different joint positions and isometric joint moment was found at 100 equally spaced angles from 50° abduction to 30° adduction. The hip rotators were fixed in 108 different joint positions and isometric joint moment was found at 100 equally spaced angles from 40° external rotation to 40° internal rotation. The knee extensors/flexors were fixed in 55 different joint positions and isometric joint moment was found at 100 equally spaced angles from 0° to 100° flexion. The ankle flexors were fixed in 9 different joint positions and isometric joint moment was found at 100 equally spaced angles from 30° dorsiflexion to 40° plantarflexion.

Data Analysis

Data was exported from OpenSim into Microsoft Excel. Microsoft Visual Basic was used to determine the angle of maximum isometric joint moment.

Results

The position which produces maximum isometric joint moment was found for major muscle groups of the shoulder, elbow and wrist (Table 1), the hip (Table 2), and the knee and ankle (Table 3).

Discussion

MMT is a convenient and clinically useful technique to detect neuromuscular dysfunction and disease, and to track the progress of patients as they undergo rehabilitation. While intra-rater reliability is relatively good, there is room for improvement in the application of MMT across different evaluators [4]. Additionally the commonly recommended positions to perform MMT lack objective validation [6]. In the current report, to predict the optimal patient positions for MMT, we used two detailed anatomical models of the upper and lower extremity [7,8] that have been utilized in several studies in the biomechanics literature. For many of the muscle groups, the predicted position for maximum force production varies significantly from the frequently recommended neutral right angle or midpoint position [6].

There are several limitations to this study. The bony architecture in these two models was based on a male at the 50th percentile of height in the general population, or 170cm. Muscle geometry can also be complex and vary between individuals. As the models are based on muscle fiber lengths and pennation angles, they are likely to be less sensitive to individuals who vary substantially from 170cm in height or who have dramatic differences in muscle pennation angles, such as those who have marked muscle hypertrophy or atrophy. We also did not directly validate the results from the model with experimentally measured forces in subjects. A follow-up study will be aimed towards validating the results of the current study and assuring reasonable ease of implementation of recommended joint positions in clinical practice. Despite these limitations, we think this technical report provides potentially useful data to help rehabilitation clinicians perform MMT using a more objectively determined set of joint positions based on commonly used measured anatomical models.

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Table 1

Shoulder, elbow, and wrist joint positions in which maximum isometric force is predicted to be greatest. Patient positioning should start from a seated, neutral anatomical position.

Joint	Motion	Muscle	Anatomical Position
Shoulder	Ext.Rotation	Infraspinatus	22° SER
		Teres minor	120° SAb, 16° SIR, 10° SE
	Int.Rotation	Subscapularis	41° SER
Elbow	Extension	Anconeus	130° EF
		Triceps lateral head	43° EF
		Triceps long head	130° EF, 90° SF
		Triceps medial head	125° EF, 90° Sup
	Flexion	Biceps brachii long head	125° EF, 90° Sup
		Biceps brachii short head	129° EF, 90° SF, 90° Sup
		Brachialis	95° EF
		Brachioradialis	87° EF, 30° Sup
Wrist	Extension	Extensor carpi radialis brevis	0° EF, 60° Sup, 10° UD, 64° WE
		Extensor carpi radialis longus	0° EF, 30° Pro, 10° RD, 70° WE
		Extensor carpi ulnaris	120° EF, 90° Sup, 10° UD, 30° WE
	Flexion	Flexor carpi radialis	0° EF, 90° Sup, 0° UD, 36° WF
		Flexor carpi ulnaris	0° EF, 90° Pro, 10° RD, 22° WF

Abbreviations: EF, elbow flexion; PRO, pronation; SAb, shoulder abduction; SE, shoulder extension; SER, shoulder external rotation; SF, shoulder flexion; SIR, shoulder internal rotation; SUP, supination; RD, wrist radial deviation,; UD, wrist ulnar deviation; WE, wrist extension; WF, wrist flexion.

Table 2

Hip joint position in which maximum force is predicted to be greatest. Patient positioning should start from a lateral decubitus position with examiner stabilizing the hip.

Joint	Motion	Muscle	Anatomical Position
Hip	Abduction	Gluteus maximus	50° HAb, 30° HF, 30° HIR
		Gluteus medius-anterior	7° HAd, 0° HF, 30° HIR
		Gluteus medius-middle	10° HAb, 0° HF, 30° HIR
		Gluteus medius-posterior	23° HAb, 30° HF, 30° HIR
		Gluteus minimus-anterior	4° HAb, 0° HF, 0° HIR
		Gluteus minimus-middle	6° HAb, 0° HF, 0° HIR
		Gluteus minimus-posterior	30° HAd, 0° HF, 30° HIR
		Tensor fascia latae	27° HAb, 0° HF, 30° HER, 100° KF
	Adduction	Adductor brevis	6° HAb, 60° HF, 30° HIR
		Adductor longus	26° HAb, 90° HF, 30° HER
		Adductor magnus-distal	42° HAb, 30° HE, 30° HIR
		Adductor magnus-ischial	50° HAb, 30° HE, 30° HER
		Adductor magnus-proximal	7° HAb, 30° HF, 30° HIR
		Gracilis	50° HAb, 30° HE, 30° HIR, 0° KF
	Extension	Biceps femoris long head	82° HF, 15° HIR, 0° KF
		Gluteus maximus-inferior	99° HF, 15° HIR
		Gluteus maximus-middle	4° HE, 30° HER
		Gluteus maximus-superior	30° HER, 6° HF
		Semimembranosus	73° HF, 15° HIR, 0° KF
		Semitendonosus	93° HF, 15° HIR, 0° KF
	Ext. Rotation	Gemelli	0° HAd, 0° HF, 30° HIR
		Quadratus femoris	30° HAd, 60° HF, 34° HIR
	Flexion	Adductor brevis	12° HE, 30° HIR
		Adductor longus	4° HE, 30° HIR
		Iliacus	30° HER, 56° HF
		Pectineus	30° HER, 9° HF
		Psoas	28° HE, 15° HER
		Rectus femoris	8° HF, 30° HIR, 100° KF
		Sartorius	30° HER, 67° HF, 0° KF
	Int. Rotation	Gluteus medius-anterior	0° HAd, 90° HF, 4° HIR
		Gluteus medius-middle	30° HAd, 90° HF, 37° HIR
		Gluteus medius-posterior	30° HAd, 30° HE, 4° HIR
		Gluteus minimus-anterior	0° HAd, 30° HF, 5° HIR
		Gluteus minimus-posterior	30° HAb, 40° HER, 90° HF
		Iliacus	30° HAb, 30° HE, 12° HER
		Tensor fascia latae	0° HAb, 40° HER, 60° HF, 100° KF

Abbreviations: HAb, hip abduction; HAd, hip adduction; HER, hip external rotation; HE, hip extension; HF, hip flexion; HIR, hip internal rotation; KF, knee flexion.

Table 3

Knee and ankle joint positions in which maximum force is predicted to be greatest. Patient positioning should start from a seated, neutral anatomical position.

Joint	Motion	Muscle	Joint Position
Knee	Extension	Rectus femoris	30° HE, 30° HIR, 69° KF
		Vastus intermedius	28° KF
		Vastus lateralis	28° KF
		Vastus medialis	29° KF
	Flexion	Biceps femoris long head	120° HF, 30° HIR, 34° KF
		Biceps femoris short head	62° KF
		Semimembranosus	120° HF, 30° HER, 37° KF
		Semitendinosus	120° HF, 30° HER, 10° KF
Ankle	Dorsiflexion	Tibialis Anterior	5° DF
	Plantarflexion	Gastrocnemius lateral head	5° PF, 0° KF
		Gastrocnemius medial head	0° PF, 0° KF
		Soleus	5° PF

Abbreviations: HE, hip extension; HIR, hip internal rotation; KF, knee flexion; DF, dorsiflexion, PF, plantarflexion,