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Original article

Anthropometrics and electromyography as predictors for maximal voluntary isometric arm strength

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Abstract

Background: Muscular strength can be conceptually determined by two components: muscle activation and size. Muscle activation by the central nervous system can be measured by surface electromyography (sEMG). Muscular size reflects the amount of contractile protein within a skeletal muscle and can be estimated by anthropometric measurements. The purpose of this study was to determine the relative contributions of size parameters and muscle activation to the prediction of maximal voluntary isometric elbow flexion strength.

Methods: A series of anthropometric measurements were taken from 96 participants. Torque and root-mean-square (RMS) of the sEMG from the biceps brachii were averaged across three maximal voluntary isometric contractions. A multiple linear regression analysis was performed based on a Pearson's correlation matrix.

Results: Body weight (BW) accounted for 39.1% and 27.3% in males and females, respectively, and was the strongest predictor of strength for males. Forearm length (L3) was the strongest predictor of strength in females (partial $R^2 = 0.391$). Elbow circumference (ELB) accounted for a significant ($p < 0.05$) amount of variance in males but not females. The addition of sEMG RMS as a third variable accounted for an average of 10.1% of the variance excluding the equation of BW and L3 in females. The strongest prediction equation included BW, L3, and ELB accounting for 55.6% and 58.5% of the variance in males and females, respectively.

Conclusion: Anthropometrics provide a strong prediction equation for the estimation of isometric elbow flexion strength. Muscle activation, as measured by sEMG activity, accounted for a significant ($p < 0.05$) amount of variance in most prediction equations, however, its contribution was comparable to an additional anthropometric variable.

Keywords: Biceps brachii; Biomechanics; Gender differences; Multiple linear regression; Muscle force

1. Introduction

Muscular strength can be determined by two components: muscle activation and muscle size. The first of these two components, muscle activation, is the result of efferent output from the central nervous system (CNS).[1] This includes the control of motor unit recruitment (the number of active motor units) and motor unit firing rate (the rate at which they fire). Motor unit recruitment and firing rate are reflected in the amplitude of the interference pattern of the summated action potentials recorded by surface electromyography (sEMG).[2] The second component of strength is based on the amount of contractile proteins within skeletal muscle.[3–5] The amount of contractile tissue can be measured by cross-sectional area (CSA) and anthropometric measures used to infer muscle size.[4,6]

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It is widely known that CSA is at least moderately correlated ($r = 0.5-0.7$) with voluntary strength regardless of gender, age and training status.[5,7] The relationship between muscle size and force is of sufficient magnitude that the "specific tension" of a muscle is commonly used in musculoskeletal modeling studies to predict force.[8] The specific tension of a muscle is the force normalized with respect to its CSA.

Kroll and colleagues[9] extended the research in this field by developing strength prediction equations using non-invasive, simple measures of body weight (BW), body volume, segmental limb lengths and volumes of the upper limb for both males and females. Multiple regression analysis revealed that the best predictor of elbow flexion strength was BW for males ($R = 0.69$), and total upper limb volume for females ($R = 0.72$). Kroll and colleagues[9] also determined that limb girths and lengths predict elbow flexion strength as well as, or better than, segmental limb volumes thereby simplifying the methodology in this area.

Given the relationship between muscle activation (sEMG) and force[10,11] it would seem logical to add this variable to a multiple regression equation that predicts force. An equation that incorporates both anthropometric data and sEMG measurement should theoretically capture the two components of muscle strength (size and muscle activation) and decrease the standard error of estimate. The present study will therefore determine the relative contributions of body size and muscle activation in a strength prediction equation. The hypothesis of this study is that adding muscle activation (sEMG) to anthropometrics will improve the strength prediction equation.

2. Materials and methods

Ninety-six (46 males and 50 females), right-handed college age participants took part in the present study. Each subject was verbally acquainted with the experimental design and provided written, informed consent (REB #02-284).

2.1. Anthropometrics

Since this paper attempted to extend the work of Kroll and colleagues[9] by adding muscle activation (sEMG), we collected the same anthropometric measurements used in that paper. Anthropometric data (Fig. 1) were collected prior to the testing procedure by an experienced person who took the average of three measurements using a tape measure and the following landmarks:

Lengths

L1: acromion process to deltoid tubercle
L2: deltoid tubercle to olecranon process
L3: olecranon process to styloid process of the ulna
L4: styloid process of the ulna to tip of the third finger

Circumferences

AC: circumference at acromion process
DEL: circumference at deltoid tubercle
ELB: circumference at olecranon process
WJS: circumference at distal space to styloid process of the ulna
HND: thickness of the base of the hand, cross-sectional height of thenar and hypothenar eminence.

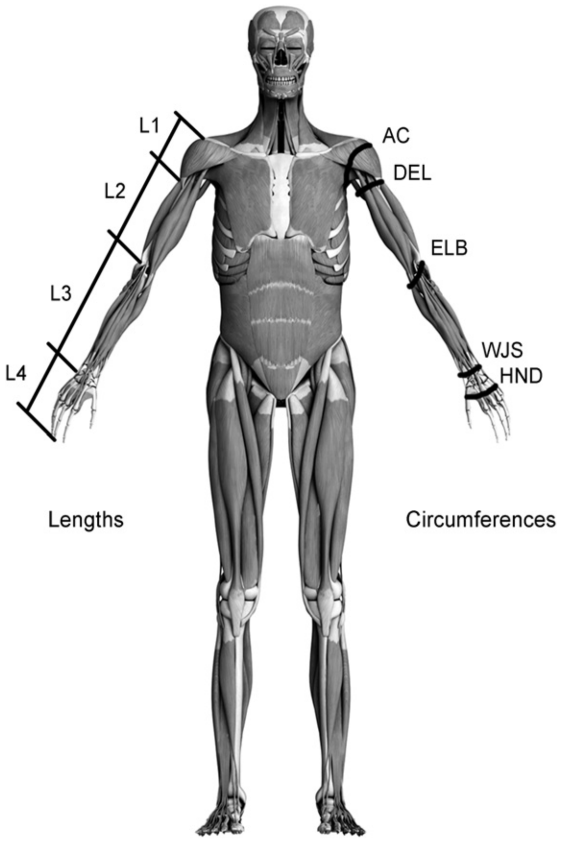

Fig. 1. Illustration of anthropometric length and circumference measurements collected. L1, acromion process to deltoid tubercle; L2, deltoid tubercle to olecranon process; L3, olecranon process to ulnar styloid; L4, ulnar styloid to tip of third finger; AC, girth at acromion process; DEL, girth at deltoid tubercle; ELB, girth at olecranon process; WJS, girth at styloid process (wrist joint space); HND, girth at base of hand.

2.2. Set up and procedure

Testing took place within a Faraday cage, and was completed in one session. Participants were seated in an adjustable chair and fastened with Velcro® straps to reduce movement. The right arm of the participant was positioned in the sagittal plane, with the shoulder and elbow flexed to 90° within a jig designed to isolate the upper limb. With the wrist in neutral position, a cuff was fastened proximal to the styloid process and attached to a load cell (JR3 Inc., Woodland, CA, USA) to record force. Participants were asked to perform three 5-s MVCs separated by 3-min rest intervals. An oscilloscope (VC-6525; Hitachi, Woodbury, NY, USA) displaying the participant's force trace was placed in front of the participant for visual feedback. Surface EMG was recorded while participants performed the contractions.

Each participant's arm was shaved, abraded and cleansed with alcohol to reduce signal impedance to below 10 kΩ