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Original Research

Characterization of Neck Strength in Healthy Young Adults

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Abstract

Background: The role of cervical muscle (neck) strength in traumatic brain and spine injury and chronic neck pain disorders is an area of active research. Characterization of the normal ranges of neck strength in healthy young adults is essential to designing future investigations of how strength may act as a modifier for risk and progression in head and neck disorders.

Objective: To develop a normative reference database of neck strength in a healthy young adult population, and to evaluate the relationship of neck strength to anthropometric measurements.

Design: Cross-sectional.

Setting: An academic medical center research institution.

Participants: A total of 157 healthy young adults (18-35 years of age) had their neck strength measured with fixed frame dynamometry (FFD) during 1 visit to establish a normative neck strength database.

Interventions: Not applicable.

Main Outcome Measurements: Peak and average strength of the neck muscles were measured in extension, forward flexion, and right and left lateral flexion using FFD. The ranges of peak and average neck strength were characterized and correlated with anthropometric characteristics.

Results: In all, 157 subjects (84 male, 73 female; average age 27 years) were included in the normative sample. Neck strength ranged from 38 to 383 Newtons in men and from 15 to 223 Newtons in women. Normative data are provided for each gender in all 4 directions. Weight, body mass index, neck circumference, and estimated neck muscle volume were modestly correlated with neck strength in multiple directions (correlation coefficients < .4). In a multivariate regression model, weight in women and neck volume in men were significant predictors of neck strength.

Conclusions: Neck strength in healthy young adults exhibits a broad range, is significantly different in men from that in women, and correlates only modestly with anthropometric characteristics.

Level of Evidence: To be determined.

Introduction

Cervical musculature is essential for maintenance of posture and stabilization of the head. Moreover, cervical muscle strength (neck strength) may modify risk for mild traumatic brain injury in sports and accidents [1,2], and is related to development and progression of chronic postural neck pain [3,4]. The description of the normal reference ranges of neck strength is essential to facilitate characterization of the role of neck strength in different types of head and neck disorders, and to investigate how strength can be leveraged to improve function and to mitigate injury. The aims of this study

are to develop a normative reference database of neck strength in a healthy young adult population, and to evaluate the relationship of neck strength to anthropometric measurements.

The normal ranges of neck strength have been characterized in multiple populations, including high school and collegiate athletes [1,5], children [6], and across the lifespan [7-12]. Across these studies, neck strength has consistently been found to be higher in men than in women and inconsistently correlated with factors including age, handedness, height, weight, body mass index (BMI), and neck circumference. However, there is no database published focusing on healthy young

subjects that may be germane to studies of amateur, collegiate, semi-professional, and professional athletes. In addition, few studies have examined combinations of anthropometric measures that more closely model neck muscle volume as a surrogate of neck strength.

In this study, we characterized neck strength in 157 healthy young subjects using fixed frame dynamometry (FFD), a technique in which resistance to muscle contraction is provided by a dynamometer mounted to a frame or a wall. Handheld dynamometry, by contrast, relies on a human tester to generate resistance to muscle contraction and so is more susceptible to tester-based error or bias. We also obtained multiple anthropometric measures, which were evaluated as potential indices of neck strength individually and in combinations designed to approximate neck muscle volume.

Methods

Study Subjects

Healthy subjects, 18-35 years of age, were recruited from a university student and employee population from December 2015 to June 2016. Subjects were not recruited from any particular athletic subset. Exclusion criteria included neck or shoulder pain or injury that limited mobility or affected daily activity, medical illnesses, surgery, or trauma affecting the spine, or a history of arthritis. Each subject included in the normative database underwent a single testing session with FFD. Ten of these subjects also participated in a substudy to establish the reliability of the method of strength measurement. All data were collected using RedCap, a secure, Web-based application designed to support data capture for research studies [13]. The study was reviewed and approved by the local institutional review board and complied with the Health Insurance Portability and Accountability Act. Written informed consent was obtained from all subjects.

Reliability of Strength Measurement

To determine the reliability of our method of FFD for measuring neck strength, 10 subjects (5 male and 5 female) participated in an additional 4 testing sessions over a 2-week period. Each testing session occurred on a different day. To account for variability attributable to subject positioning and/or verbal coaching, for each subject, 2 different raters alternated across the 4 visits. The sequence of raters was counterbalanced across subjects.

Neck Strength Testing Procedure

All strength testing was performed using the micro-FET2 dynamometer (Hoggan Scientific, Salt Lake City, UT). Neck strength was measured in 4 directions:

extension, forward flexion, and right and left lateral flexion. The testing order for the 4 directions was randomized by the RedCap Software.

The testing setup for each direction is shown in [Supplementary Figure 1](#). During testing sessions, subjects were seated in a custom-built rigid chair with 2 seatbelts attached just below the axillae and at the waist. To minimize contributions from thoracic and abdominal musculature, seatbelts were tightened until subjects were unable to separate their torso from the back of the chair. To minimize contributions from the scapular and pectoral muscles and to prevent bracing against the chair, subjects' arms were positioned with 90° abduction at the shoulders and 90° flexion at the elbows [14]. To minimize contributions of lower extremity muscles, the subject was asked to rest the feet lightly on top of an empty cardboard box and instructed not to exert any pressure on the box during testing [15]. Trials in which the box was crushed by the subject were discarded and repeated. The position of the dynamometer was adjusted for each direction: on the occipital protuberance for extension, above the eyebrows for forward flexion, and above the corresponding ear for right lateral flexion and left lateral flexion.

Subjects were encouraged to push against the dynamometer continuously with full effort for 3-4 seconds during each trial, with verbal coaching. Three trials were completed for each direction with a 5-second rest between trials and a 30-second rest between directions. The dynamometer records peak force for each 3-second trial in Newtons (N).

Anthropometric Measurements

Height, weight, neck circumference, neck length, and head circumference were measured in each subject. Neck circumference was taken immediately cranial to the thyroid cartilage, with the head in a neutral position. Neck length was measured from the most prominent vertebral spinous process (the seventh cervical vertebra) to the occipital protuberance, with the subject's chin relaxed toward the chest and the tape measure flush against the curve of the neck. Head circumference was measured at the brow ridge and occipital protuberance. Subjects were asked to self-identify handedness as right-handed, left-handed, or ambidextrous. The secondary anthropometric measures included body mass index (BMI; weight divided by the square of the height) and an estimation of cylindrical neck volume calculated using the product of neck length and the square of neck circumference divided by the constant 4π .

Data Analysis

All statistical analyses were performed using STATA version 13.1. All data were tested for normality using

the Shapiro–Wilk test [16]. Because the extant literature has varied in its use of either the peak trial value or the average value across trials for analysis, we performed all analyses using both values. In theory, the peak trial value more closely approximates the true maximal strength generation capacity of the muscle.

Reliability of FFD for neck strength measurement was characterized using the intraclass correlation coefficient (ICC) [17]. These reliability metrics were calculated for the 2 visits with the same rater (intrarater reliability), and comparing 2 visits with different raters (interrater reliability). A random-effects model for absolute agreement between raters was used.

In the normative sample, we characterized the ranges of neck strength in men and women. Unpaired *t* tests were used to compare average and peak neck strength between men and women. Paired *t* tests were used to compare right lateral flexion and left lateral flexion for each subject, with separate tests in right-handed and left-handed subjects. Pearson correlations were performed, separately for men and women, to assess the relationship of neck strength to each of the anthropometric measures (height, weight, head circumference, neck circumference, neck length, BMI, and neck volume) and age. Multiple linear regressions were calculated to predict neck strength in each direction based on height, weight, and neck volume (as a composite of neck length and neck circumference) in men and women separately.

Results

Reliability of Strength Measurement

Both inter- and intrarater reliability were characterized in 10 subjects (5 men and 5 women). For interrater reliability, in women the ICCs ranged from 0.60 (95% confidence interval [CI] -0.16 to 0.90) for right lateral flexion to 0.91 (95% CI 0.66-0.98) for forward flexion; in men the ICCs ranged from 0.88 (95% CI 0.60-0.98) for forward flexion to 0.95 (95% CI 0.81-0.99) for extension. For intrarater reliability, in women the ICCs ranged from 0.70 (95% CI 0.20-0.91) for right lateral flexion to 0.96 (95% CI 0.86-0.99) for extension; in men the ICCs ranged from 0.72 (95% CI 0.21-0.92) for forward flexion to 0.94 (95% CI 0.79-0.98) for extension.

Characterizing Normal Neck Strength and Its Relationship to Anthropometrics

Characteristics of the 157 subjects enrolled are presented in Table 1. Across the 4 directions, peak neck strength range was 46-383 N in men and 24-223 N in women; and average neck strength range was 38-377 N in men and 15-215 N in women (Tables 2 and 3, and Figures 1 and 2). Strength did not differ between right lateral flexion and left lateral flexion in either right-handed or left-handed individuals (paired *t* test, $P > .38$; data not shown). Men exhibited significantly greater strength than women in all 4 directions (unpaired *t* test, $P < .001$).

Associations of neck strength and anthropometrics measurements are presented in Table 4 and Figure 3. For 1 male subject, the neck length and head circumference could not be accurately measured. In both men and women, there were significant positive correlations between neck strength and weight and BMI. In men only, neck strength was positively correlated with head circumference, neck length, neck circumference, and neck volume. In multivariate regression, in men only, neck volume was a significant predictor of right and left lateral flexion strength, with neck strength increasing 0.04 N for every additional 1 cc of neck volume. In women, only weight was a significant predictor of extension and left lateral flexion strength, with neck strength increasing 1.0-1.4 N for every additional 1 kg of weight.

Discussion

Our method of neck strength measurement with FFD demonstrates moderate to high intra- and interrater reliability, suggesting that single visit measurements with FFD are an appropriate way to capture neck strength. Our sample of 157 healthy young adults demonstrates the broad distribution of normal neck strength. Neck strength in extension, for example, varies across individuals by as much as 300 N in men and 180 N in women. A number of other studies have characterized isometric neck strength with similar subject positioning (ie, seated, rather than prone, supine, or standing) in healthy adults, including studies by Jordan et al ($n = 100$ healthy adults, aged 21-69 years), Chiu et al ($n = 91$ healthy adults, aged 20-84

Table 1
Subject characteristics for the normative sample

Subgroup	n	Age (y)	Height (cm)	Weight (kg)	BMI	Neck Length (cm)	Neck Circumference (cm)	Head Circumference (cm)	% Right-Handed
Overall	157	27.0 (3.1)	171.4 (9.0)	72.0 (14.4)	24.4 (3.9)	18.2 (2.4)	35.4 (3.8)	57.4 (1.8)	86.0
Men	84	27.0 (3.2)	176.8 (7.2)	78.6 (13.6)	25.1 (3.6)	18.8 (2.6)	38.2 (2.4)	58.2 (1.7)	85.7
Women	73	27.1 (3.0)	165.0 (6.2)	64.4 (11.8)	23.7 (4.2)	17.5 (1.9)	32.3 (2.2)	56.4 (1.5)	86.3

All values shown as mean (standard deviation) except for percent right-handed.

Table 2
Descriptive statistics for neck strength (in Newtons [N]) in men and women

	Direction	Mean	SD	Median	Min	Max
Men	Extension	223.6	69.2	228.3	63.2	383.1
	Forward flexion	147.3	37.9	146.2	56.5	241.6
	Right lateral flexion	136.0	55.7	134.4	46.3	323.1
	Left lateral flexion	136.5	51.2	127.5	49.4	294.6
Women	Extension	138.8	38.8	135.7	39.2	223.4
	Forward flexion	89.2	21.7	88.6	24.9	150.9
	Right lateral flexion	86.0	25.3	86.8	15.6	149.1
	Left lateral flexion	84.3	24.1	82.3	19.6	133.9
	Direction	Mean	SD	Median	Min	Max
Men	Extension	207.6	65.7	210.6	58.3	377.2
	Forward flexion	138.1	36.8	136.2	51.2	227.1
	Right lateral flexion	126.4	52.3	121.6	38.1	300.2
	Left lateral flexion	127.4	49.6	119.6	46.6	290.1
Women	Extension	129.4	38.5	127.6	34.3	215.1
	Forward flexion	83.6	20.7	83.2	23.3	138.5
	Right lateral flexion	80.1	24.0	83.1	15.1	137.1
	Left lateral flexion	78.9	23.1	76.8	19.0	127.7

Top set of values calculated from peak of 3 trials. Bottom set of values calculated from average across 3 trials.

SD = standard deviation; Min = minimum; Max = maximum.

years), Garces et al (n = 94 healthy adults, aged 20-60+ years), and Salo et al (n = 220 healthy women, aged 20-59 years). In addition, 2 younger reference populations include those of Lavalée et al (n = 91 healthy children, adolescents, and young adults, aged 6-23 years) and Hildenbrand et al (n = 149 high school and college athletes, aged 14-23 years). Another very large sample of adolescents (n = 6662 high school athletes), using handheld dynamometry, was described by Collins et al. The normal ranges of neck strength found in our sample are similar to those of prior studies that used similar methodology. As has been previously

reported [18], we found men to be significantly stronger than women in all directions tested. In contrast to prior studies, we did not identify a difference in right lateral flexion and left lateral flexion based on handedness.

It is worth noting that although many studies capture maximal isometric concentric contraction, there are a variety of approaches to measurement of neck muscle strength that reflect eccentric muscle strength, dynamic force generation, and sustained contraction strength (muscle endurance) [18-20]. There are also other directions of muscle contraction including rotational strength that we did not measure here. These different parameters have a range of potential applications and may be strong predictors of dysfunction in injury prevention and progression [21], and should be the focus of future descriptive studies.

Correlations of Anthropometrics With Neck Strength

If anthropometric measures indexed neck strength, they might provide a simple and inexpensive surrogate for neck strength measurement. However, we found that anthropometric measures, such as weight, height, and neck circumference and length and BMI only modestly correlate with neck strength ($r < 0.32$). Overall, the most significant predictor of neck strength that we identified was biological gender, with men stronger than women in all directions. Prior studies have identified relationships between neck strength and height, weight, and BMI [9,10,12] and have shown gender differences in these relationships [8]. Neck volume, calculated as a proxy for neck muscle volume, was found to correlate with force in all directions in men but not in women. The lack of correlation

Table 3
Percentile cut points for neck strength (in Newtons [N]) in men and women

	Direction	5th	10th	25th	50th	75th	90th	95th
Men	Extension	113.9	126.4	171.1	228.3	273.0	305.7	332.9
	Forward flexion	80.1	100.1	121.3	146.2	172.7	190.9	202.9
	Right lateral flexion	64.5	69.4	87.2	134.4	173.6	209.6	233.2
	Left lateral flexion	64.1	76.1	101.2	127.5	168.4	208.3	231.8
Women	Extension	67.2	86.3	117.9	135.7	168.2	187.8	197.6
	Forward flexion	57.4	62.7	75.2	88.6	103.2	113.0	127.3
	Right lateral flexion	41.8	55.6	69.4	86.8	102.8	113.0	127.7
	Left lateral flexion	41.8	54.7	69.4	82.3	102.8	116.6	124.2
	Direction	5th	10th	25th	50th	75th	90th	95th
Men	Extension	104.0	118.4	162.8	210.6	250.5	292.2	314.3
	Forward flexion	73.0	92.6	113.2	136.2	165.5	183.5	194.8
	Right lateral flexion	59.3	66.2	83.0	121.6	161.4	199.4	217.8
	Left lateral flexion	58.0	68.1	91.7	119.6	159.9	194.0	217.6
Women	Extension	58.7	80.7	105.9	127.6	160.6	179.0	185.6
	Forward flexion	51.0	58.7	70.0	83.2	97.8	110.2	113.9
	Right lateral flexion	40.0	49.2	64.1	83.1	95.1	108.1	118.1
	Left lateral flexion	39.8	50.4	63.8	76.8	96.7	106.1	114.2

Top set of values calculated from peak of 3 trials. Bottom set of values calculated from average across 3 trials.

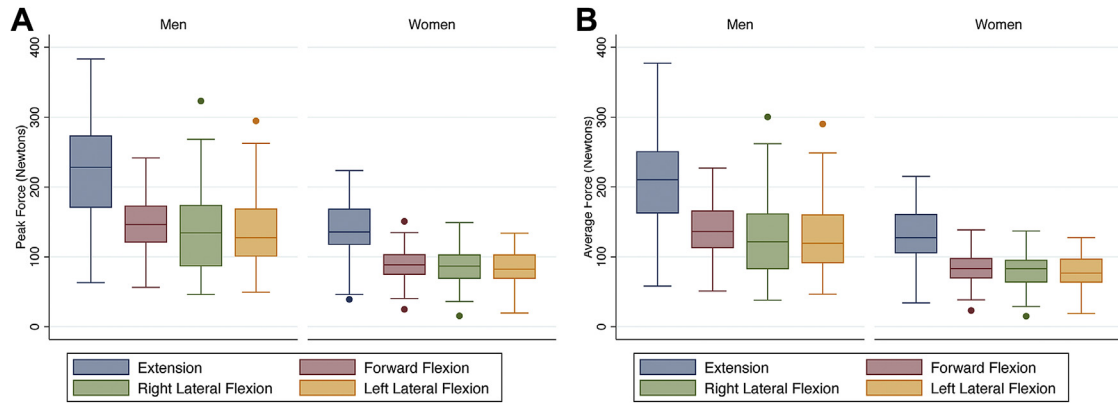


Figure 1. Box plots showing normal ranges of (A) peak and (B) average neck strength in men and women in extension, forward flexion, and right and left lateral flexion.

between neck strength and neck volume in women may reflect relative sexual dimorphisms in body fat composition or distribution [22], with neck size being less reflective of muscle mass in women compared with men. This was supported by the results of the multivariate analysis, which showed that neck volume was an independent predictor of neck strength in men but

not in women. Previous studies have also shown a decline in neck strength with age [8,11,12]. The lack of a significant correlation of neck strength and age, given the restriction of the sample to individuals less than 35 years old, is not surprising; prior results have shown that neck strength is maintained until at least the seventh decade [8,10].

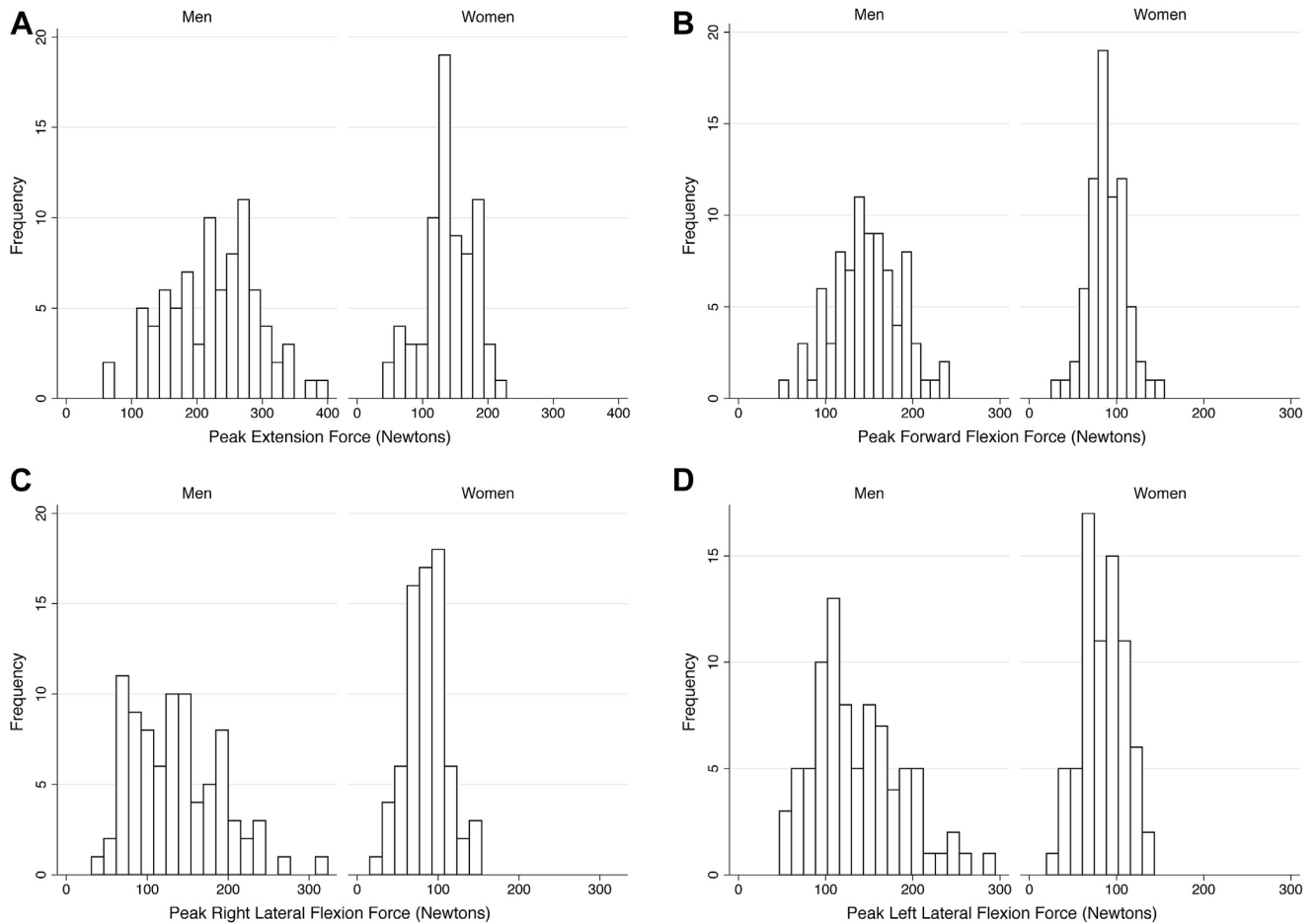


Figure 2. Histograms showing the distribution of neck strength in men and women in (A) extension, (B) forward flexion, and (C) right and (D) left lateral flexion. Values are calculated from the peak of 3 trials.

Table 4
Pearson correlations of neck strength with anthropometric measures

	Direction	Age	Height	Weight	Neck Length	Neck Circumference	Head Circumference	BMI	Neck Volume
Men	Extension	-0.1	0.2*	0.3*	0.2	0.3*	0.2	0.2	0.3 [†]
	Forward flexion	0.0	0.1	0.3*	0.2	0.2	0.2	0.2*	0.2*
	Right lateral flexion	-0.1	0.3 [†]	0.3 [†]	0.3 [†]	0.3*	0.2*	0.2*	0.2 [‡]
	Left lateral flexion	-0.1	0.3 [†]	0.3 [†]	0.3 [†]	0.3*	0.3*	0.2*	0.4 [‡]
Women	Extension	-0.1	0.08	0.3*	-0.1	0.1	0.1	0.2*	0.0
	Forward flexion	-0.2	0.08	0.3*	-0.1	0.2	0.1	0.2	0.1
	Right lateral flexion	-0.1	0.00	0.3*	0.0	0.1	0.1	0.3*	0.1
	Left lateral flexion	-0.1	0.07	0.3 [†]	-0.1	0.2	0.1	0.3*	0.1

	Direction	Age	Height	Weight	Neck Length	Neck Circumference	Head Circumference	BMI	Neck Volume
Men	Extension	-0.1	0.2*	0.3 [†]	0.2	0.3 [†]	0.2	0.2*	0.3 [†]
	Forward flexion	0.0	0.2	0.3*	0.2	0.2 [†]	0.2*	0.3*	0.3*
	Right lateral flexion	-0.1	0.3 [†]	0.3 [†]	0.3 [†]	0.3 [†]	0.2*	0.2*	0.4*
	Left lateral flexion	-0.1	0.3 [†]	0.3 [†]	0.3 [†]	0.3 [†]	0.3*	0.2*	0.4 [‡]
Women	Extension	-0.1	0.1	0.2	-0.1	0.1	0.1	0.2	0.0
	Forward flexion	-0.2	0.1	0.2*	-0.1	0.1	0.1	0.2	0.1
	Right lateral flexion	-0.1	0.0	0.3*	0.0	0.2	0.1	0.3*	0.2
	Left lateral flexion	-0.1	0.1	0.3 [†]	-0.1	0.2	0.1	0.3*	0.1

Top set of values calculated from peak of 3 trials. Bottom set of values calculated from average across 3 trials.

BMI = body mass index.

* $P < .05$.

[†] $P < .01$.

[‡] $P < .001$.

Given the substantial degree of normal variation in any given anthropometric measurement, it is unlikely that a single metric would be an accurate and reliable index of neck strength, which depends on multiple physical factors and in large part on subject effort during testing. Thus it is unlikely that direct neck strength measurement can be replaced by estimations derived from anthropometric measurements. However, when considering neck-related injuries (eg, whiplash, cervical sprain, concussion), these anthropometrics may modify or predict outcomes independently of their association with strength, and should be measured in concert with explicit strength measurements.

Study Limitations

This study aims to provide reference ranges for neck strength in a sample of healthy young adults and to correlate strength with anthropometrics. Our reference population was defined using FFD with a custom apparatus, and thus the normative data may not be comparable to studies using other FFD resistance systems or handheld dynamometry. In addition, we characterized exclusively maximal isometric contraction strength, and thus these data may not be applicable to investigations examining other dimensions of neck muscle function, including muscle endurance or rotational strength.

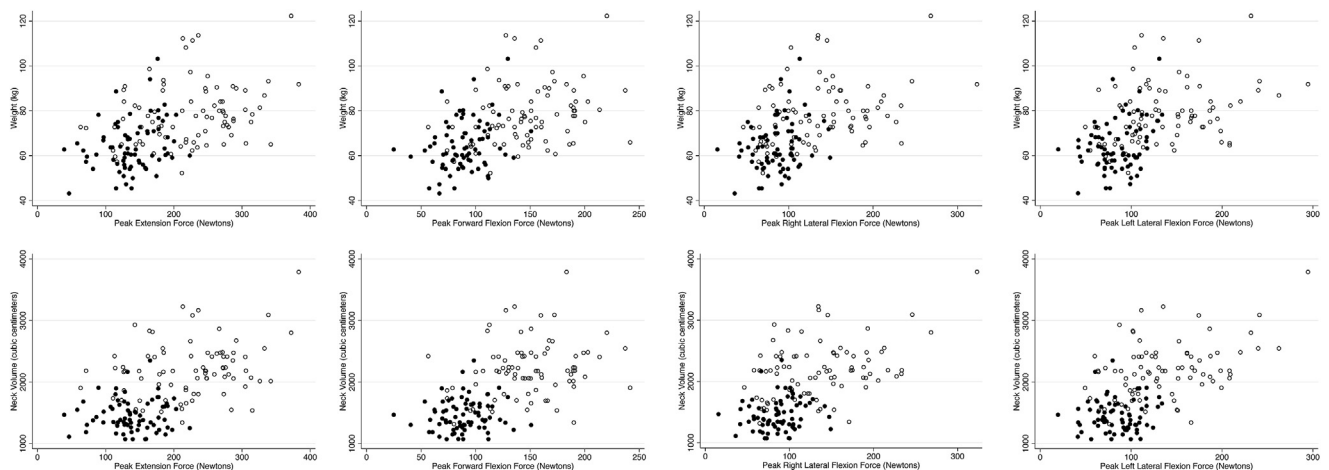


Figure 3. Correlations between anthropometric measures (weight and neck volume) and neck strength in men and women in extension, forward flexion, and right and left lateral flexion. Open circles denote male participants; filled circles denote female participants. Values are calculated from the peak of 3 trials.

Conclusion

Our study found that neck strength ranges widely across healthy young adults and differs significantly between the genders, but is only modestly correlated with anthropometric characteristics. Studies that aim to characterize the role of neck strength in modifying risk for injury and dysfunction will require relevant, well-characterized control populations against which athletes and young adults with head and neck injury can be compared. Our findings take a step toward addressing these scientific and clinical needs.

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Supplementary Data

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.pmrj.2017.01.005>.

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Disclosure

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