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Abstract

The purpose of this study was to evaluate the reliability and variability of repeated measurements of isometric cervical extension strength and determine the effect of 10 weeks of dynamic variable resistance cervical extension training on isometric cervical extension strength. Seventy-three subjects (age, 29 ± 12 years [mean ± SD]) completed isometric cervical extension strength tests on 4 separate days (D1, D2, D3, and D4). For each test, isometric cervical strength was measured at 126, 108, 90, 72, 54, 36, 18, and 0 degrees of cervical flexion. Between-day correlation coefficients over the eight angles of cervical flexion were high for D2 versus D3 ($r = 0.90$ to 0.96). Test variability (standard error of estimate) between D2 versus D3 was low (7.4% to 10.2% of mean) through the entire range of motion. Regression analysis showed that the isometric cervical extension strength curve is linear and descending from flexion to extension. In a second study, 14 subjects (age, 25 ±3 years) trained the cervical extensor muscles for 10 weeks while 10 subjects (age, 23 ± 3 years) served as controls. Training included 8 to 12 repetitions to volitional fatigue, 1 day per week. The training group improved isometric cervical extension strength at six of eight angles before to after training ($P \leq 0.05$). During the same time period the control group did not change. These data indicate that repeated measures of isometric cervical extension strength are highly reliable and can be used for the quantification of isometric cervical extension strength through a 126 degree range of motion. Also, training the cervical extensors 1 day per week can significantly increase isometric cervical extension strength through most of the range of motion.

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ABSTRACT

The purpose of this study was to evaluate the reliability and variability of repeated measurements of isometric cervical extension strength and determine the effect of 10 weeks of dynamic variable resistance cervical extension training on isometric cervical extension strength. Seventy-three subjects (age, 29 ± 12 years [mean ± SD]) completed isometric cervical extension strength tests on 4 separate days (D1, D2, D3, and D4). For each test, isometric cervical strength was measured at 126°, 108°, 90°, 72°, 54°, 36°, 18°, and 0° of cervical flexion. Between-day correlation coefficients over the eight angles of cervical flexion were high for D2 versus D3 ($r = 0.90$ to 0.96). Test variability (standard error of estimate) between D2 versus D3 was low (7.4% to 10.2% of mean) through the entire range of motion. Regression analysis showed that the isometric cervical extension strength curve is linear and descending from flexion to extension. In a second study, 14 subjects (age, 25 ± 3 years) trained the cervical extensor muscles for 10 weeks while 10 subjects (age, 23 ± 3 years) served as controls. Training included 8 to 12 cervical extensions to volitional fatigue, 1 day per week. The training group improved isometric cervical extension strength at six of eight angles before to after training ($P \leq 0.05$). During the same time period the control group did not change. These data indicate that repeated measures of isometric cervical extension strength are highly reliable and can be used for the quantification of isometric cervical extension strength through a 126° range of motion. Also, training the cervical extensors 1 day per week can significantly increase isometric cervical extension strength through most of the range of motion.

Headaches and neck pain are complaints that affect two thirds of the population and cost millions of dollars from lost work time in industry.[12] Because the cervical muscles must support the weight of the head, head and neck pain often originate as a result of muscular weakness[5,8,17,18] or from fatigue resulting from sustained muscular contraction.[5] In addition to being an area susceptible to minor pain, the neck is frequently injured in accidents and during athletics, particularly in contact sports.[1,7,20,26,28] Although strengthening the neck may help prevent neck pain and injury, effective training programs for the cervical muscles have not been established. Numerous articles in the athletic training and coaching literature refer to the importance of strengthening the neck musculature to reduce the risk of injury.[4,6,7,16,19,21] Unfortunately, most of these studies have not been well-controlled investigations that have evaluated the effectiveness of training programs. In general, testing and training techniques for the cervical muscles have thus far been limited.[2,27,29]

Perhaps a major reason for the paucity of data is the lack of equipment available to safely and accurately quantify cervical extension strength. Thus, there is need for a reliable and accurate machine to test cervical extension strength and help to identify individuals with weak cervical muscles who may be predisposed for cervical problems, and to evaluate the effectiveness of training and rehabilitation programs. Accurate assessment of cervical extension strength requires 1) stabilization of the torso to isolate the cervical extensor muscles and minimize the contribution from the torso and upper extremities, 2) measurement through a full range of motion (ROM), 3) correction for the influence of gravitational forces (head weight) during testing, and 4) standardization of the testing position and procedures.

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The purpose of the present study was to 1) evaluate the reliability and variability of a machine designed to measure isometric cervical extension strength through a 126° ROM, 2) describe isometric cervical extension strength through a 126° ROM for a sample of healthy men and women, and to 3) quantify changes in cervical extension strength through a 126° ROM resulting from variable resistance training.

METHODS

Subjects

Seventy-three subjects (53 men and 20 women) volunteered to participate in the reliability phase of the study. Once the reliability was established, 24 additional subjects (14 men and 10 women) participated in a cervical extension training study designed to develop strength in the cervical extensor muscles. Descriptive characteristics of the subjects participating in the reliability and training studies are presented in Table 1. All subjects (age range, 18 to 62 years) were healthy and recruited from the University of Florida and Gainesville, Florida, communities. The project was approved by the Institutional Review Board of the University of Florida College of Medicine. Medical history, activity profiles, and documented informed consent were obtained from each subject prior to participation. This information was used as a screening aide to eliminate subjects who had a history of cervical problems or a medical condition that would contraindicate cervical extension exercise.

Reliability study

Subjects reported to the laboratory for testing on 4 separate days (D1, D2, D3, and D4). These test days were separated by approximately 1 week to allow subjects time to recover from any residual fatigue or soreness that might have been associated with the testing. On D1 and D2 subjects completed two isometric cervical extension strength tests (T1 and T2). T1 and T2 were separated by a 20 to 30 minute rest interval. On D3 and D4 subjects completed only one isometric cervical extension strength test (T1). During each test, maximum voluntary isometric cervical extension strength was measured at 126°, 108°, 90°, 72°, 54°, 36°, 18°, and 0° of cervical flexion with a MedX (Ocala, FL) cervical extension machine.

Subjects were instructed not to exercise for at least 24 hours prior to testing. Upon reporting to the laboratory for testing, subjects were seated in the cervical extension machine (Fig. 1). The seat was adjusted so that the subject's thyroid cartilage was in alignment with the axis of rotation of the movement arm. Proper alignment allowed no sliding to occur between the head and the resistance pad during the cervical extension exercise. Subjects were then secured in place by a specially designed restraint system including a shoulder harness, seat belt, and torso restraint (Fig. 1). The shoulder harness prevented any movement of the torso. The seat belt aided in a similar fashion by securing the pelvis in the seat. The torso restraint consisted of two pads mounted on an adjustable crank that were placed against the anterior side of the chest, below the clavicles. Tightening the torso restraint forced the upper torso to the rear against the back of the seat. The combination of these restraining forces stabilized the torso, allowing no lateral, vertical, or rotational movement. Standardized positioning of the arms was achieved by instructing the subjects to maintain a light grasp on the anterior side of the torso restraint. The mass of the head was counterbalanced to eliminate the influence of gravity on the torque measurements. Body position and counterbalance adjustments were recorded and used for all subsequent testing and training sessions.

To initiate a test, subjects were locked into position at 126° of cervical flexion and instructed to slowly and continuously extend their head against the resistance pad for a 2 to 3 second period. Once maximal tension had been achieved, subjects were instructed to maintain the contraction for an additional 1 to 2 seconds and then relax slowly over a 2 to 3 second period. A 10 second rest interval was provided between each isometric contraction while the next angle of measurement was set. Concurrent visual feedback was provided during each contraction on a video display screen that was interfaced with the machine. Subjects were verbally encouraged to give a maximum effort. To ensure torso stabilization, the torso restraint was tightened if any torso movement was observed during testing.

Training study

The 24 subjects who volunteered for the resistance training program reported to the laboratory for pretraining testing on two separate days (D1 and D2). On D1, subjects completed two isometric cervical extension strength tests that served as practice. On D2, subjects completed only one test that was used as the pretraining criterion measurement. Fourteen subjects trained the cervical extensor muscles 1 day per week for 10 weeks and 10 subjects served as controls

TABLE 1
Characteristics of the subjects[a]

Variable	Reliability study		Training study	
	Men ($N = 53$)	Women ($N = 20$)	Control ($N = 10$)	Training ($N = 14$)
Age (years)	29 ± 12	28 ± 12	23 ± 3	25 ± 3
Height (cm)	177.8 ± 7.2	164.0 ± 8.4[b]	171.2 ± 8.4	172.5 ± 9.5
Weight (kg)	76.4 ± 10.3	57.6 ± 9.6[b]	67.8 ± 11.6	70.8 ± 15.5

[a] Values are means ± SD.
[b] $P \le 0.01$ between men and women.

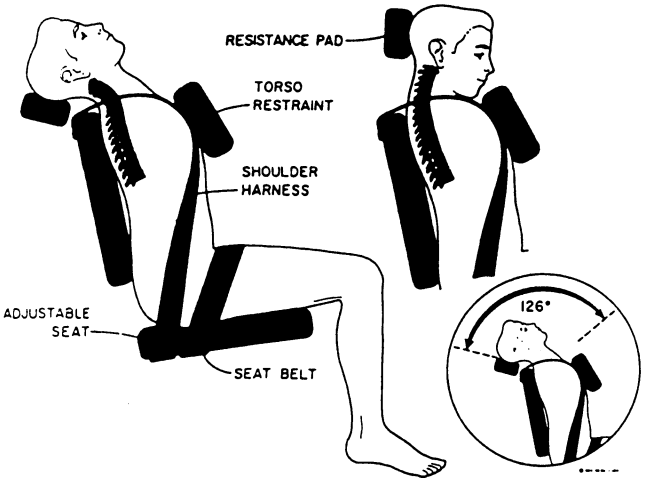

Figure 1. Restraining mechanisms of the cervical extension machine.

and did not train. A conservative training frequency of 1 day per week was chosen because of the unknown potential for overtraining that may occur in the isolated cervical extensor muscles with a greater training frequency.

For each training session, subjects were required to perform one set of variable resistance cervical extensions through a 126° ROM with a weight load that allowed 8 to 12 repetitions to volitional fatigue (maximal effort). When 12 or more repetitions could be achieved, the training weight was increased by 10%. Subjects were instructed to perform the concentric portion of the repetition for 2 seconds, pause in full extension for 1 second, then complete the eccentric portion over a 4 second period (for a total of 7 seconds per repetition). Subjects were trained and retested on the same machine that they were tested on initially.

Data analysis

Maximal voluntary isometric torque was measured in inch pounds and converted to Newton meters. Descriptive statistics (means and standard deviations) were calculated for each angle of each test. All statistical computations were performed using the SAS statistical package (SAS Institute Inc., Cary, NC).[24] An alpha level of $P < 0.05$ was required for statistical significance.

Reliability. A reliability and variability analysis of the isometric cervical extension strength measures was completed by calculating the 1) mean difference, 2) Pearson product-moment correlation coefficient(s) (r), 3) standard error of the estimate (SEE), and 4) total error at each angle for the various combinations of tests completed on D1 through D4. Pearson product-moment correlation coefficients were used as an index of reliability. SEE and error (E) were calculated using the following formulas:

$$\mathrm{SEE} = \mathrm{Sy}_{12}\sqrt{1 - r^2}$$

$$\mathrm{E} = \sqrt{\sum (y_1 - y_2)2/\mathrm{N}}$$

where Sy_{12} = pooled deviation of Y_1 and Y_2 and $\mathrm{Sy}_{12} = \sqrt{(\mathrm{Sy}_1^2 + \mathrm{Sy}_2^2)/2}$.

The SEE provides an indication of the variance (dispersion) of individual scores about the computed line of regression. The error includes two sources of variation, the SEE plus any systematic error that would be indicated by the difference between the regression line and the line of identity. For a more detailed discussion of reliability analyses see Sinning and Wilson.[25]

Analysis of variance (ANOVA) procedure was used to determine the main effect between each day and test. The significance of the calculated mean differences at each individual angle was evaluated using paired t-tests.

A cervical extension strength curve was developed for men and women using the mean torque values from the first test performed on D2. A two-way ANOVA with repeated measures over angles was used to compare the strength curves between males and females.

Training. Changes in strength within groups were analyzed using ANOVA for repeated measures. Between-group comparisons were made using analysis of covariance. Pretraining strength values were used as the covariates. Changes in weight load used in variable resistance training (Week 1 versus Week 10) were analyzed using a paired t-test.

RESULTS

Reliability

Intraday analysis. Isometric torques for the T1 and T2 tests completed on D1 and D2 are presented in Figure 2. On D1 the observed torques for T1 were significantly less ($P \leq 0.05$) than those observed for T2 at 108° of cervical flexion and significantly greater than those observed for T2 at 72°, 54°, 36°, 18°, and 0° of cervical flexion. On D2, T1 torques were significantly greater ($P \leq 0.05$) than those noted for T2 at 90°, 72°, 54°, 36°, 18°, and 0° of cervical flexion.

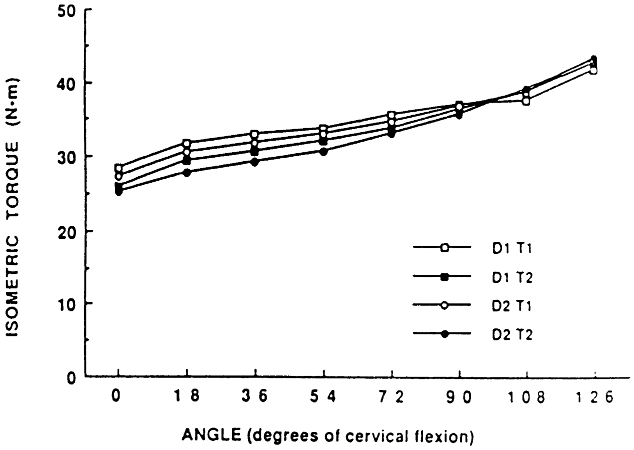

Figure 2. Isometric strength measures for tests completed on two separate days ($N = 73$). D1, Day 1; D2, Day 2; T1, Test 1; T2, Test 2.

TABLE 2
Pearson product-moment correlation coefficients (r),[a] SEE,[b] and total errors (E)[c] for tests completed on D1 and D2[d]

	Angle (degrees of flexion)							
	0°	18°	36°	54°	72°	90°	108°	126°
D1 T1 vs. D1 T2 (N = 73)								
r	0.91	0.90	0.94	0.94	0.93	0.94	0.94	0.94
SEE	3.6	3.7	2.9	3.0	3.6	3.6	4.1	5.0
E	4.5	4.4	3.6	3.5	3.9	3.8	4.1	5.0
D2 T1 vs. D2 T2 (N = 73)								
r	0.87	0.95	0.95	0.96	0.95	0.95	0.95	0.96
SEE	4.0	2.5	2.4	2.3	2.8	3.1	3.8	4.2
E	4.6	3.9	3.6	3.3	3.4	3.4	4.2	4.2

[a] All zero order correlation coefficients significant at $P \leq 0.01$.
[b] $SEE = Sy\sqrt{1 - r^2}$; $Sy = \sqrt{(Sy_1^2 + Sy_2^2)/2}$.
[c] $E = \sqrt{(Y_1 - Y_2)^2/N}$.
[d] Units for SEE and error are Newton meters of isometric torque.

Correlation coefficients, SEEs and errors for T1 and T2 on D1 and D2 are presented in Table 2. On D1, correlation coefficients between T1 and T2 ranged from $r = 0.90$ to $r = 0.94$ over the eight angles of cervical flexion. On D2, correlation coefficients ranged from $r = 0.87$ to $r = 0.96$. Standard errors of estimate between T1 and T2 on D1, ranged from 2.9 to 5.0 Nm. On D2, SEEs, ranged from 2.3 to 4.2 Nm and were slightly less than the D1 SEE at all angles except 0° of cervical flexion. Total error values between T1 and T2 on both D1 and D2 were slightly greater than the SEEs in most cases and ranged from 3.3 to 5.0 Nm.

Reliability

Interday analysis. Isometric torque values for the T1 tests completed on D1, D2, D3, and D4 are presented in Figure 3. Data were analyzed on a sample of $N = 73$ for D1 versus D2 and for D2 versus D3. Due to time restraints and other conflicts, 14 subjects did not complete the test on D4. Therefore an $N = 59$ was used for D4 comparisons. On D2, the observed torque was significantly greater than D1 at 126° ($P \leq 0.05$) while at 36°, 18°, and 0° of cervical flexion, the D2 torques were significantly less ($P \leq 0.05$) than D1. At each angle of cervical flexion, torques were significantly greater ($P \leq 0.05$) on D3 when compared to D2. When D3 torques were compared to D4, torque values were similar.

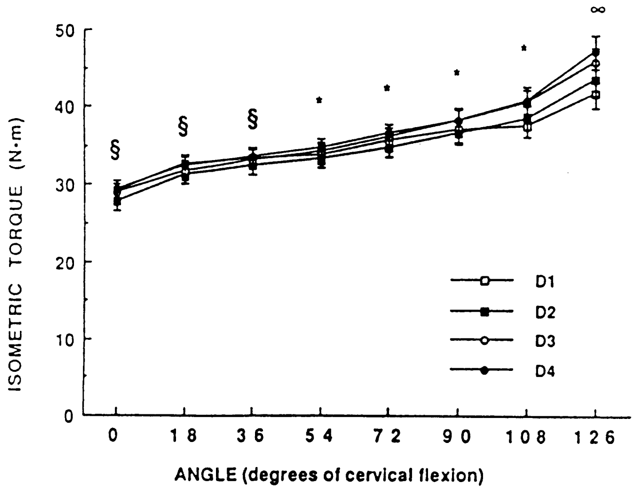

Figure 3. Isometric strength measures for Test 1 completed on Days 1 to 4 (N = 59). * D3 > D1 and D2 ($P \leq 0.05$); § D1 and D3 > D2 ($P \leq 0.05$); ∞ D3 > D2 > D1 ($P \leq 0.05$).

Correlation coefficients, SEEs, and errors between D1 T1, D2 T1, D3 T1, and D4 T1 are presented in Table 3. For the eight angles tested, correlation coefficients ranged from $r = 0.88$ to $r = 0.92$ between D1 and D2; from $r = 0.90$ to $r = 0.96$ between D2 and D3; and from $r = 0.93$ to $r = 0.96$ between D3 and D4. Standard errors of estimate for D1 versus D2 ranged from 3.6 to 5.9 Nm. For D2 versus D3, SEEs ranged from 2.4 to 4.2 Nm. For D3 versus D4, SEEs ranged from 2.6 to 5.3 Nm. Total error values for most comparisons were slightly greater than values noted for the SEEs.

Normal curves. Based on the findings of the intraday and interday analyses, isometric cervical extension strength curves were constructed for men and women from the D2 T1 test data (Fig. 4). These data showed a slight improvement in reliability coefficients and SEEs from D1. The curves are linear and descending from flexion to extension. At each angle, men were significantly stronger than the women.

The variability of the single test used to define the normal curves (D2 T1) was calculated by dividing the SEE between D1 T1 and D2 T1 by $\sqrt{2}$. Relative variability was then expressed as a percent of the mean torque observed at each angle. Absolute and relative values for test variability of the normal curves are presented in Table 4. Single-test variability for isometric cervical extension strength measured at multiple joint angles through a 126° ROM ranged from 2.5 to 4.2 Nm of isometric torque and represented 7.4% to 10.2% of the mean torque values.

Training. The training group was not significantly different from the control group with respect to age, height, and weight ($P \geq 0.05$) (Table 1). The training group improved isometric cervical extension strength at 126°, 108°, 90°, 72°, 54°, and 36° of cervical flexion ($P \leq 0.05$) but not at 18° and 0° when compared to the controls (Fig. 5). The training group significantly increased the amount of weight lifted

TABLE 3
Pearson product-moment correlation coefficients (r),[a] SEE,[b] and total errors (E)[c] for tests completed on D1, D2, D3, and D4[d]

	Angle (degrees of flexion)							
	0°	18°	36°	54°	72°	90°	108°	126°
D1 T1 vs. D2 T1 (N = 73)								
r	0.88	0.89	0.90	0.91	0.90	0.91	0.92	0.92
SEE	4.0	3.9	3.7	3.6	4.2	4.4	4.5	5.9
E	4.3	4.2	3.9	3.7	4.3	4.5	4.8	6.3
D2 T1 vs. D3 T1 (N = 73)								
r	0.90	0.92	0.96	0.94	0.96	0.94	0.95	0.96
SEE	3.7	3.3	2.4	3.0	2.7	3.6	3.7	4.2
E	4.0	3.3	2.8	3.1	2.9	3.8	4.4	5.2
D3 T1 vs. D4 T1 (N = 59)								
r	0.93	0.95	0.96	0.95	0.96	0.95	0.96	0.94
SEE	3.4	2.9	2.6	2.9	2.8	3.4	3.5	5.3
E	3.6	2.9	2.7	3.1	2.8	3.3	3.7	5.8

[a] See Table 2 for footnote explanations.

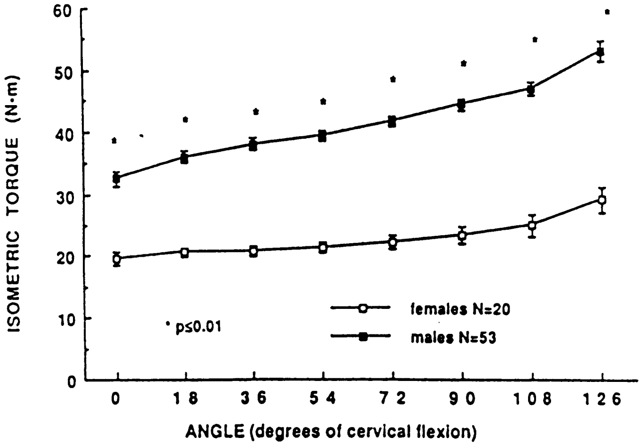

Figure 4. Isometric cervical extension strength curves for men and women based on the Day 2, Test 1 data ($P \leq 0.05$).

during variable resistance training from 12.8 to 17.3 kg ($P \leq 0.01$).

DISCUSSION

Reliability

Clinical evidence points to the efficacy of muscular strengthening in neck and back rehabilitation programs.[5,17] Thus, there is a need for a reliable and accurate test of cervical extension strength for the evaluation of exercise training protocols for the development and rehabilitation of the cervical extensor muscles. The results of the present study show that isometric measurements of cervical extension strength are highly reliable and associated with low variability through a 126° ROM. To our knowledge there are no studies that report isometric testing of the cervical extensors at more than one position in the ROM. Petrofsky and Phillips,[22] Franco and Herzog,[11] and Foust et al.[10] have reported mean cervical extensor strength at one joint angle. These authors did not report the reliability or variability associated with their measurements.

The variability associated with muscular strength measurement is rarely reported. Muscular strength has been shown to vary from 1.5% to 11.6% for women and 5.3% to 9.3% for men (human day-to-day variation) when variability is calculated as the standard deviation from the mean of repeated measurements.[30] The variability associated with multiple joint angle measurements for isometric knee extension and lumbar extension strength range from 10% to 20% and 6.7% to 11.6%, respectively, when SEEs are expressed as a percent of the observed mean torques.[13,15] Single-test variability for the normal cervical extension strength curves in the present study (7.4% to 10.2%) is well within the expected range of daily variation for muscular strength.

Reliability coefficients for intraday comparisons were high (r = 0.87 to 0.96). Total error terms progressively increased over the SEEs from 126° to 0° of flexion (Table 2), indicating a small systematic error in the latter half of the ROM (extended portion). Greater torques were noted at five of the eight angles measured for the T1 tests on D1 and D2 when compared to the T2 test (Fig. 2). Thus, it is likely that a small amount of fatigue was associated with the maximal effort required at each of the eight test positions following

TABLE 4
Single-test variability for the normal isometric cervical extension strength curves for men and women (N = 73)

	Angle (degrees of flexion)							
	0°	18°	36°	54°	72°	90°	108°	126°
SEE/2[a]	2.8	2.8	2.6	2.5	3.0	3.1	3.2	4.2
Percent[b]	9.8	8.8	8.0	7.4	8.4	8.4	8.6	10.2

[a] Values are Newton meters.
[b] Values are $[(\text{SEE}/\sqrt{2})/\text{mean torque}] \times 100$.

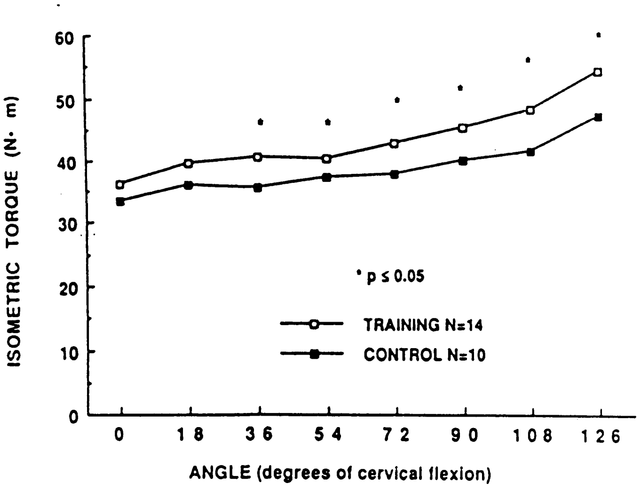

Figure 5. Torque measurements for isometric strength of the cervical extensor muscles at specific angles of cervical flexion before and after 10 weeks of variable resistance training. Values are adjusted posttraining means from analysis of covariance.

the T1 tests on D1 and D2. The fact that this fatigue was noted on both days indicated that subjects were repeatedly giving adequate efforts on each day of testing and that a good effort was achieved by most subjects on D1.

Because the mean torques improved by only a small amount over the 4 days of testing and the *r* and SEE values were similar for the between-day comparisons, it is felt that reliable maximal isometric cervical extension strength measures are achievable on the initial day of testing. Since there was a slight improvement in the *r* and SEE values on D2, D2 values may be more appropriate for research purposes. Improvements beyond D2 in mean torques may be attributed to a training effect. Using a similar test protocol to quantify lumbar extensor strength, Graves et al.[13] showed that 1 day of practice was needed to achieve the most reliable and accurate test results for quantification of lumbar extension strength. Correlation coefficients increased while SEE and error decreased from Test Day 1 to Test Day 2. This test effect was not found for the cervical extensors. The difference in initial test reliability and variability between the lumbar and cervical tests may be partly explained by the complexity of the lumbar extension machine and muscle group being tested. A greater effort is required to isolate the lumbar extensors because it is difficult to stabilize the pelvis. Thus, subjects may be more apprehensive about the lumbar extensor test protocol on the initial day of testing than for the cervical extensor test. In addition, lumbar extension may be an unfamiliar task since the lumbar extensors are rarely isolated through pelvic stabilization.

Prior to using any measurement tool in a clinical environment, it is essential to establish the reliability of the measurements made with that tool. Once reliability is established, one can confidently evaluate intervention programs. The present study established the reliability of isometric cervical extension strength measurements under carefully controlled conditions. The normative cervical extension strength curve noted for males and females provides a reference from which to compare clinical patients. Strength deficits specific to areas in the ROM or strength deficits through the entire ROM allow documentation of specific problem areas.

Training

Increases in isometric cervical extension strength following training in the present study ranged from 6.3% to 14.3%, which represent moderate improvements. Unfortunately, no studies have reported changes in isometric strength for cervical extensor training. Previously, we have reported relatively large gains in lumbar extensor strength for groups training with one set of 8 to 12 repetitions to volitional fatigue 1 day every 2 weeks, 1 day per week, 2 days per week, or 3 days per week.[14] We have also reported that, in contrast to the lumbar extensor data, training the knee extensors 3 days per week was superior to 2 days per week for up to 18 weeks of training.[3]

Normally, one would expect a 20% to 30% improvement from an effective strength training program.[9,23] Therefore, a limitation of the present study is that it may not have provided an appropriate training stimulus at a frequency of 1 day per week to achieve optimal benefit. Further training at a greater frequency and for a longer duration is required before a more definitive statement can be made concerning the optimal amount of training necessary for the cervical extensor muscles.

A unique feature and purpose of the training study was the quantification of training responses of the isolated cervical extensor muscles through a full ROM. Describing strength increases at only one joint angle can misrepresent strength changes at other positions in the ROM. Weakness in a specific area of cervical extension may go undetected using one angle to quantify strength through a full ROM. In the present study if peak torques (only) were used, we may have assumed full ROM strength increases. By measuring cervical extensor strength through a 126° ROM we found strength did not improve in the extended portion of the ROM.

The training response of the cervical extension muscles for healthy people provides a guide for expected results with clinical patients treated with the exercise machine. Although patients may respond differently because of more conservative protocols, it is important to provide realistic, rehabilitative goals based on responses by healthy subjects.

In summary, a new cervical extension testing device that stabilizes the torso and counterbalances the mass of the head allowed us to evaluate the reliability and variability associated with measuring isometric cervical extensor strength at multiple joint angles through a 126° ROM. Reliability at all testing positions was high ($r = 0.88$ to $r = 0.96$). Test variability was 7.4% to 10.2% of the mean torque values observed. These findings are consistent with the reliability and variability reported for assessing the strength of other muscle groups.

It is concluded that the MedX cervical extension machine is highly reliable and specific for the quantification of isometric cervical extension strength and training responses through a 126° cervical extension ROM. The mean isometric cervical extension curve for men and women is linear and descending from flexion to extension. Evaluating dynamic cervical training responses with a multiple joint angle test proved to be appropriate for evaluating isometric strength through 126° of cervical extension. Variable resistance training at a frequency of 1 day per week elicited moderate strength gains through most of the ROM.

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