Quantification of isometric cervical strength at different ranges of flexion and extension

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Abstract

Background. Studies have demonstrated that cervical strength is affected by injury to the neck. Cervical strength measurements are influenced by the protocol used for the measurements. Previous studies have determined the isometric cervical strength only at a few degrees of range of neck motion. The present study was aimed at quantifying cervical strength at neutral, 25%, 50% and 75% of flexion and extension.

Methods. Using a correlation study design, 39 volunteers in the age range of 18–30 years were recruited in two sessions, one for flexion and the other extension. Their sequence was randomized. The cervical strength was measured using a force measuring device. The device was firmly bolted in the floor. A rotating metal tube was pivoted, adjustably counterweighted and attached to the device at one end and an immovable object with a load cell in its path at the other. The neck was positioned in the desired posture and isometric efforts were exerted on the horizontal resistance arm.

Findings. Cervical strength was found to be highest in the neutral posture for both flexion (19.8N females and 31.4N males) and extension (39.5 females and 45.1 males) and significantly decreased with an increasing angular deviation of the neck (P<0.01). Males exerted significantly higher forces than females. The overall flexion–extension ratio was 1:1.7 (P<0.01).

Interpretation. The maximum force was exerted in the neutral posture of the neck and it was directionally dependent being less in flexion than extension (P<0.01). Males were stronger than females. The findings may assist in targeting rehabilitation goals.

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Keywords: Cervical strength; Range of motion; Neck pain; Strength measurement device; Strength quantification; Cervical rehabilitation

1. Introduction

Headaches and neck aches affect two-thirds of the population, and cost millions of dollars from lost work time (Leggett et al., 1991). Studies have reported an increased prevalence of neck pain especially in industrialized countries (Bovim et al., 1994; Brattberg et al., 1989). In this context, Bovim et al. (1994) reported a 13% prevalence of chronic and persistent neck pain in Norwegian population, whereas in Sweden it was reported as high as 26% (Brattberg et al., 1989). The neck pain has resulted in several consequences including an increase in the financial burden (Harder et al., 1998; Kumar et al., 2001) and the recovery period of more than six months (Jordan et al., 1999). Multiple lines of approaches have been used in the clinical management of neck pain. In this context numerous studies, using different clinical groups, have emphasized the importance of strengthening the neck muscles for the reduction of pain (Highland et al., 1992; Ylinen and Ruuska, 1994; Levoska and Kiukaanniemi, 1993; Berg et al., 1994). The findings of these studies suggested that the strengthening protocol brings about a reduction in pain and an increase in neck mobility. However, only a handful of
studies have examined the force generating capacity of the cervical musculature.

Multitudes of factors influence the outcome of studies involving measurement of cervical strength. To illustrate, using different equipments, authors have quantified the isometric cervical strength in different ranges of motion (flexion and extension) in healthy individuals, which has accounted for the wide variability of force values (Estandler et al., 1994). Commonly used equipments for assessing cervical strength include the isokinetic dynamometers and the hand-held dynamometers (Deones et al., 1994). Isokinetic dynamometers are reliable devices for measuring muscle performance, but also have several disadvantages such as high equipment cost, large space requirements, time consuming testing sessions, and the need for trained personnel (Deones et al., 1994). On the contrary, studies which have been done using hand-held dynamometers to assess cervical strength face the limitation of poor reliability (Deones et al., 1994; Silverman et al., 1991; Garces et al., 2002).

Another important factor that influences such measurements includes the protocol used during the assessment of cervical strength. A lack of standardized protocol has also contributed to the variability of results (Kumar et al., 2001) by allowing a significant contribution of strength from extrinsic muscle and other body parts. Some of the studies have focused on measurement of isometric strength at only a few degrees deviation of the neck. In the previous study we measured the flexion and extension forces in the neutral position of the neck (Kumar et al., 2001). Restriction at a few degrees can often be misleading in the interpretation of force values at other neck positions in clinical populations. Furthermore, the limitation of using such measurements is that the range of motion varies among individuals, thus subject’s muscles could be at different points in the length–tension relationship. Unlike peripheral muscles no contra-lateral comparison is feasible within a subject. Hence the present study was aimed at quantifying the isometric cervical strength at different ranges of flexion and extension of the neck. In addition, the relationship between the range of motion and physical parameters (height and weight) along with test–retest reliability of strength measuring device were investigated. Furthermore, knowledge of normative data regarding neck strength at different points of the range of motion is required for a comprehensive comparative clinical evaluation between patients suffering from chronic or recurrent neck pain and those of healthy individuals (Kumar et al., 2001; Jordan et al., 1999; Leggett et al., 1991). The findings of the present study may help in structuring and monitoring rehabilitation program.

2. Methods

2.1. Sample

Thirty-nine volunteers (19 males and 20 females) in the age range of 18–30 years participated in this study. The demographic details of the subjects are provided in Table 1. All subjects were normal, healthy young adults with no history of musculoskeletal problems and had never suffered from neck injuries. They did not have sore neck over the last 12 months due to any reason. Health Research Ethics Board of University of Alberta approved this study. The participants were explained the purpose and protocol of the study and signed an informed consent before taking part in the study.

2.2. Setup

The setup consisted of an adjustable chair, sliding platform and floor mounted strength measuring device as reported by Kumar et al. (2001). The reader is directed to that study for details.

2.3. Force measuring device

The force measuring device used for this study was the same as used by Kumar et al. (2001) and readers are directed to that study for details. Briefly, it consisted of a vertical telescopic metal tube welded to a thick iron plate rigidly bolted to the floor. To this another counter-weighted metal tube was pivoted to rotate vertically at the point of pivoting. This allowed coupling of another horizontal bar adjustable for height and fitted with an

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Descriptive statistics of the physical parameters of the subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Variables</td>
</tr>
<tr>
<td>Females (n = 20)</td>
<td>Weight (kg)</td>
</tr>
<tr>
<td></td>
<td>Height (cm)</td>
</tr>
<tr>
<td></td>
<td>Age (years)</td>
</tr>
<tr>
<td>Males (n = 19)</td>
<td>Weight (kg)</td>
</tr>
<tr>
<td></td>
<td>Height (cm)</td>
</tr>
<tr>
<td></td>
<td>Age (years)</td>
</tr>
</tbody>
</table>

A total of 39 subjects were recruited for this study as described in the methods.
upholstered sliding pad for contact with head during force exertion. (Fig. 1).

2.4. Data recording setup

Our data measuring setup consisted of an I-250 load cell and accompanying force monitor for signal conditioning and display. The output of the force monitor was fed to a 486 computer through a MetraByte® DAS 20 A to D board with a sampling frequency of 1kHz (kilohertz). To account for the sensitivity of the load cell to record the voltage force measuring equipment was calibrated before the start of experiment. Standard weights between 4.5 and 22.7kg were applied to achieve reliable calibration and a high correlation coefficient ($r$) of 0.998. Similarly, the angles were calibrated at 10° increments starting from 0° to 60° and had a correlation coefficient ($r$) of 0.997.

2.5. Procedure

The experimental procedure was same as Kumar et al. (2001) and readers are directed to that study. The cervical strength was measured for flexion in one session and extension in another session. Two sessions were randomized. A total of three trials were conducted at each position of the neck with each trial lasting for 5s. The subjects were given a minimum of 2min rest in between each trial.

2.6. Range of motion measurement

Prior to assessing the range of motion the subjects were given a few warm up exercises (flexion and extension) 3–4 times.

The gravity goniometer (single inclinometer) was used to measure the range of motion. The goniometer was placed on the temporal bone of the head with a refastenable strap. Subjects were asked to assume the neutral position of their neck for assessing the range of motion. The gravity goniometer was adjusted in such a way that the pointer rested at 0° and thus was in accordance with the subject’s neutral position of the neck. They were then asked to perform flexion or extension and the deviation of the pointer of the gravity goniometer from the starting position (0°) was noted for each neck positions. For cervical flexion subjects were instructed to make an effort to tuck their chin in and then roll the head further to chest (Cram and Kneebone, 1999). On the contrary for extension they were asked to face the ceiling (Ordway et al., 1997). Based on the total range the percentage was calculated.

2.7. Force measurement

Depending upon the random sequence generated by the computer (flexion or extension and the percentage of the range of motion—neutral, 25%, 50%, or 75%) the horizontal resistance arm was positioned to correspond with the percentage of flexion and extension. The horizontal upholstered bar was slid onto the vertical portion of the resistance arm and adjusted to the appropriate height for the subjects to ensure the placement of this arm in the frontal plane. The subject’s forehead or occiput was placed in direct contact with resistance pad for isometric exertion for flexion and extension respectively (represented “force applied”). The force was measured using a method described previously (Kumar et al., 2001).

2.8. Data collection and data analysis

The average and peak strength were obtained from these data for each subject for all conditions. Mean average force represented average force over a period of trial (5s) for all subjects while the peak force was the mean of the maximum force exerted by all subjects during this period. To determine the reliability of the measurements the average strength values were collected on two different sessions for 10 subjects (4 males and 6 females) with a gap of one week.

SPSS for Windows (Version 11) was used for the statistical analysis. Descriptive statistics (mean and standard deviation) were used to quantify the isometric cervical strength while correlation analysis was performed to examine the relationship between force, range of motion and physical parameters. Two-way ANOVA with post-hoc analysis was used to determine the significance of difference in cervical strengths with changing level of ranges of motion. Similarly the effects of gender and direction of effort on isometric force were analyzed using a two-way ANOVA with post-hoc analysis. In addition, a student-paired $t$-test and correlation analysis were used to determine the reliability of measurements.
3. Results

3.1. Range of motion and force

In males and females, extension of 25%, 50% and 75% represented a range of motion approximately 17°, 34°, 52° respectively, while flexion was 13°, 25° and 38° respectively (Table 2). Table 2 provides force summary for both genders. The average strengths of men and women were 45.1 (SD 24.3 N) and 39.5 (SD 25.1 N) respectively in extension in neutral position. There was a decrease in strength with increased range of motion and correlation analysis revealed a significant inverse relationship between range of motion and force ($P < 0.01$) (Fig. 2). Furthermore, if flexion in neutral posture were considered as reference values (100%) in both genders then flexion 25%, 50%, 75% produced 76%, 64% and 28% of force in females and 71%, 60% and 39% in males (Fig. 3B). Similar pattern was observed for extension in both genders (Fig. 3A).

3.2. Variation in force

3.2.1. Direction of effort and force (mean and peak)

The force generated was higher in the extension compared to the flexion of the neck. At neutral, 25%, 50%, 75% extension the mean forces were 39.5, 27.6, 20.4 and 15.4 N in females while the forces generated in flexion were 19.8, 15.2, 12.7 and 5.7 N at the same percentage deviation (Table 2). Similar pattern was observed for forces generated by men also.

3.2.2. Relationship between gender and force (average and peak)

Men exerted significantly greater mean average and mean peak forces as compared to women ($P < 0.01$) (Table 2). A trend for gender difference in the ratio of

Table 2
Mean average cervical strengths at neutral and different degrees of extension and flexion

<table>
<thead>
<tr>
<th>Gender</th>
<th>Condition</th>
<th>Force</th>
<th>ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>95% CI</td>
</tr>
<tr>
<td>Females</td>
<td>Ext neutral</td>
<td>39.5 (25.1)</td>
<td>33.2–45.8</td>
</tr>
<tr>
<td></td>
<td>Ext 25%</td>
<td>27.6 (16.7)</td>
<td>23.4–31.8</td>
</tr>
<tr>
<td></td>
<td>Ext 50%</td>
<td>20.4 (12.4)</td>
<td>17.3–23.5</td>
</tr>
<tr>
<td></td>
<td>Ext 75%</td>
<td>15.4 (11.3)</td>
<td>12.5–18.2</td>
</tr>
<tr>
<td></td>
<td>Flex neutral</td>
<td>19.8 (10.2)</td>
<td>17.1–22.4</td>
</tr>
<tr>
<td></td>
<td>Flex 25%</td>
<td>15.2 (7.7)</td>
<td>13.3–17.2</td>
</tr>
<tr>
<td></td>
<td>Flex 50%</td>
<td>12.7 (6.0)</td>
<td>11.2–14.3</td>
</tr>
<tr>
<td></td>
<td>Flex 75%</td>
<td>5.7 (4.3)</td>
<td>4.6–6.9</td>
</tr>
<tr>
<td>Males</td>
<td>Ext neutral</td>
<td>45.1 (24.3)</td>
<td>38.5–51.7</td>
</tr>
<tr>
<td></td>
<td>Ext 25%</td>
<td>40.9 (23.1)</td>
<td>34.8–47.0</td>
</tr>
<tr>
<td></td>
<td>Ext 50%</td>
<td>34.4 (21.3)</td>
<td>28.8–40.1</td>
</tr>
<tr>
<td></td>
<td>Ext 75%</td>
<td>27.3 (20.4)</td>
<td>21.9–32.7</td>
</tr>
<tr>
<td></td>
<td>Flex neutral</td>
<td>31.4 (9.9)</td>
<td>28.9–34.0</td>
</tr>
<tr>
<td></td>
<td>Flex 25%</td>
<td>23.1 (9.0)</td>
<td>20.8–25.4</td>
</tr>
<tr>
<td></td>
<td>Flex 50%</td>
<td>19.0 (10.8)</td>
<td>16.2–21.8</td>
</tr>
<tr>
<td></td>
<td>Flex 75%</td>
<td>12.4 (10.6)</td>
<td>9.7–15.1</td>
</tr>
</tbody>
</table>

Average cervical strengths over a period of 3 s were determined at different degrees of flexion and extension, as described in the methods. The data is represented as mean average forces (Newtons) and SD in parenthesis. The range of cervical forces is given in the column 3. The Range of motion (ROM) values were calculated by single inclinometer as described in methods. The data is represented as mean (in degrees) SD in parenthesis.
Flexion and extension was observed (Table 3). At the neutral position, the flexion and extension ratios were 1:2.0 and 1:1.43 for females and males respectively. A similar trend was observed at 25% and 75% of range of motion.

A two-way ANOVA was used to determine the relationship between genders and direction of effort on force values. There was a significant effect of gender and direction of effort on force ($P < 0.001$). However no significant interaction was seen between gender and direction. This means that women and men have similar strength producing characteristics when subjected to a given direction of effort, however their magnitudes were different.

### 3.2.3. Force and physical measures

Bi-variate correlation was used to discern any relationship between the physical measures (height and weight) and strength (average and peak force). The correlation analysis revealed no significant relationship between physical measures and forces.

### 3.2.4. Reliability analysis

The average strength values, collected on two different sessions for 10 subjects (4 males and 6 females) with a gap of one week, were used for reliability analysis as described in the methods. The Student’s $t$-test revealed no statistical difference between the force values on those two days. Furthermore, the force values in both extension ($r = 0.88$) and flexion ($r = 0.7$) on these two days were significantly ($P < 0.001$) correlated, demonstrating the reliability of the measurements.

### 4. Discussion

In the present study we measured the cervical strengths using a reliable device described previously by Kumar et al. (2001). In addition to a high ICC published by Kumar et al. (2001) for this device the current study also found it to be reliable by testing 10 subjects on two days, a week apart.

The cervical strengths measured during flexion and extension at different positions of the neck revealed an inverse relationship between the degree of motion and magnitude of force produced during both flexion and extension. The measurements reported previously were restricted to only the neutral posture of the neck (Kumar et al., 2001). The strength data reported in this study in flexion and extension were lower than those of others (Kumar et al., 2001; Jordan et al., 1999; Garces et al., 2002; Chiu et al., 2002). This wide variation in the force values across different studies in literature could also possibly be due to equipment and technique used, positioning of subjects, training effect or ethnic differences (Chiu et al., 2002). Jordan et al. (1999) reported 59–91.1 N for flexors and 78.1–133 N for extensors using a strain gauge device. The participants in Jordan et al.’s study (1999) were subjected to a pre-training protocol (resistance training) and lack of proper stabilization (Kumar et al., 2001; Vasavada et al., 1998). The

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**Table 3**

<table>
<thead>
<tr>
<th>Positions</th>
<th>Gender</th>
<th>Mean average force</th>
<th>Mean peak force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>Females</td>
<td>1:2.0</td>
<td>1:1.6</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>1:1.4</td>
<td>1:1.4</td>
</tr>
<tr>
<td>25%</td>
<td>Females</td>
<td>1:1.8</td>
<td>1:1.6</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>1:1.7</td>
<td>1:1.6</td>
</tr>
<tr>
<td>50%</td>
<td>Females</td>
<td>1:1.6</td>
<td>1:1.5</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>1:1.8</td>
<td>1:1.5</td>
</tr>
<tr>
<td>75%</td>
<td>Females</td>
<td>1:2.6</td>
<td>1:2.1</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>1:2.2</td>
<td>1:1.9</td>
</tr>
</tbody>
</table>

The average and peak force values were determined over a period of 3s at neutral and different degrees of extension and flexion. The flexion to extension ratios were calculated for each gender. Note gender effect on the flexion to extension ratio at all the positions of the neck except at 50%.
pre-training protocol in their study consisted of light resistance training of 5–6 kg in flexion and extension with six to seven repetitions in each direction before the start of the experiment. The authors suggested that adequate practice before recording of the measurement could have led to the higher force values in their study. The duration of training was not reported. Furthermore, it has been documented in different studies that resistance training appears to induce a better recruitment of motor units (Tsuyama et al., 2001; Conley et al., 1997) which could probably have led to this increased force values. In Jordan et al.’s study (1999) there was no stabilization of the subjects by any restraint system, such as shoulder harness, and moreover subjects were asked to grip side handholds while exerting force. Garces et al. (2002) used a computerized dynamometer to measure isometric cervical strength. The higher force value in their study as compared to rest of the studies was likely due to the subject’s variation and perhaps greater motivation.

Employing the same force measuring device used in this study, Kumar et al. (2001) reported higher strengths, 57 N for males and 30 N for females in flexion; 96.2 N for males and 79 N for females in extension. Though the experimental design, procedures and protocols of this study were in accordance with their methodology the difference in the strength values could be due to the difference in the sample and their level of motivation, in combination with lifting feet off the floor prior to exertion. The data presented in this study was calculated by taking the average of three trials in each experimental condition whereas the study by Kumar et al. (2001) reported the force measurements over one trial. The average calculated over three trials could have accounted for the lower values of less motivated subjects who were probably less forcefully instructed.

Different postures such as prone, supine and standing have been used in the literature for the assessment of neck force (Queisser et al., 1994; Vernon and Aramenko, 1992; Ylinen et al., 2003). These postures are different from ours. Furthermore, the standing posture could also involve major participation of the extrinsic muscles and body segments such as feet, arms and trunks (Silverman et al., 1991; Garces et al., 2002; Jacobs et al., 1995) due to the difficulty in proper stabilization. The sitting position is not only a functional testing position for both directions, but also offers a representation of the postures in which we can isolate cervical muscles. The shoulder harness used in our study minimized the effect of other extrinsic muscles, and body segments such as feet, arms and trunks. In our protocol subjects had no arm support and were asked to lift their feet off the foot rest during exertion so as to further minimize any extraneous contribution.

This study observed the maximum strength values (mean average and mean peak) at the neutral position of the neck. An inverse relationship was found between the force production and deviation of neck, which implied a decrease in the force output with increased motion at the neck in both the directions. However, Jordan et al. (1999) and Chiu et al. (2002) recorded the highest strength (average) values at 30° of flexion and extension, while Garces et al. (2002) reported highest strength at 10°. Although, the peak torque was observed at neutral position in Garces et al.’s study (2002), however the difference in the average force values among different degrees of motion tested in this study did not differ significantly (i.e. the average values at different degrees of motion fell within the standard deviation of each other) thus finding almost similar force values at all positions of the neck.

Only one study has reported a significant difference at different ranges of motion. Chiu et al. (2002) quantified the strength at flexion neutral, 20° flexion and 20° extension. They found significant ($P < 0.01$) differences of force between each angles of flexion and extension. However the authors did not give a detailed experimental protocol. Furthermore, they did not state the strength values at the neutral posture of the neck. Studies done by Jordan et al. (1999) and Garces et al. (2002) found the mean difference of approximately 1 N in different neck angles they tested. Both these authors did not find any significant differences in strength values at different degrees of neck motion which is in contradiction to observations made in this study.

The flexion–extension ratio reported in the current study agrees with the findings in the literature (Kumar et al., 2001; Jordan et al., 1999; Garces et al., 2002; Chiu et al., 2002; Vasavada et al., 1998; Valkeinen et al., 2002). The larger extension strength over flexion by 50% reflects the postural role of extensor musculature and obvious muscle mass difference between posterior and anterior muscles of the cervical spine (Jordan et al., 1999; Chiu et al., 2002; Vasavada et al., 1998). This association between the extensors and flexors of the cervical spine was found to be similar to the range of lumbar spine (cited by Jordan et al., 1999). Comparative analysis of flexion to extension strength in men and women indicates that women are proportionately stronger in extension and/or proportionately weaker in the flexion as compared to men. This observation was also reported in Kumar et al.’s study (2001).

The results of our study demonstrated no correlation between the anthropometric measures (height, weight) and force. The findings of the current study were consistent with the findings of Chiu et al. (2002) and Vasavada et al. (1998). However a few studies have related a moderate to high correlation between these variables and the force (Kumar et al., 2001; Jordan et al., 1999; Garces et al., 2002). For example, in athletes, muscular strength and body weight have been shown to have a high positive correlation ($r = 0.80$) (Jordan et al., 1999; Garces et al., 2002).
et al., 2002; Jacobs et al., 1995) which is considerably decreased in normal population (Jordan et al., 1999; Emwemeka et al., 1986). In a study by Emwemeka et al. (1986) on isokinetic trunk muscles strength in healthy subjects a strong correlation was seen between body weight and the torque output. On the contrary, it was found that anthropometric measures were poor predictors of torque output (Estandler et al., 1994). Garces et al. (2002) reported a high association between the physical parameters and force values, whereas Kumar et al. (2001) found the significance only with weight and Jordan et al. (1999) with the height of the subjects. However, in the present study there was no correlation between force and physical parameters such as height and weight of the subjects. Thus the relationship of strength to anthropometric variables has been variable and does not conform to any set pattern. Our findings support this observation.

5. Conclusions

The following can be concluded from this study: (1) both in flexion and extension, the neck produced maximum force in neutral posture; (2) there is a negative relationship between the deviation of neck with respect to neutral and force generation capacity; (3) the neck is stronger in extension as compared to flexion; (4) men have higher cervical strength than women; (5) anthropometric variables correlate poorly with cervical strength.

References


