Novel Electromyographic Protocols Using Axial Rotation and Cervical Flexion-Relaxation for the Assessment of Subjects With Neck Pain: A Feasibility Study

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Abstract

Objective: The purpose of this study is to examine the feasibility of novel variations to the way cervical flexion-relaxation phenomenon (FRP) studies are conducted and the feasibility of using cervical axial rotation as an alternative objective measure of cervical pain/dysfunction.

Methods: Electromyographic data were collected from cervical paraspinal muscles of 5 participants with neck pain and 5 asymptomatic controls. Cervical FRP was conducted as reported in the literature with the participants seated, except that they started with the head fully flexed instead of being erect. Data were also collected with participants laying prone, starting with their head hanging over the edge of the table. Additional data were collected from cervical paraspinal and sternocleidomastoid (SCM) muscles while the seated participants rotated their head fully to the right and left. Ratios were obtained for each type of test by dividing the electromyographic amplitude when muscles were most active by that when they were relaxed or in contralateral rotation.

Results: In each case, the ratio was higher for the controls than for those with neck pain, suggesting that any of the 4 methods could be used to distinguish between 2 groups. The ratios were most pronounced from SCMs during axial rotation. There appeared to be a negative relationship between pain level and the ratios obtained from each method.

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Conclusion: The findings from this small study are encouraging for all methods used, with axial rotation using SCMs appearing to be the most promising. These results indicate that larger, powered studies are warranted.

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Introduction

Depending on the case definitions used, the 12-month prevalence of neck pain ranges from 12.1% to 71.5% in the general population, and each year, 11%-14.1% of workers are reported as being limited in their activities because of neck pain.¹ Although quite common, neck pain is difficult to quantify in an objective manner. Subjective measures are commonly used, such as the visual analog scale² or the numerical rating scale for pain,³ or questionnaires aimed at the ease/difficulty of performing physical tasks.⁴ Because there is no way to objectively quantify pain directly, efforts have been made to develop objective methods that rate alternative indicators of pain such as pressure pain threshold and electromyographic (EMG) amplitude of specific muscles.⁵⁻⁷ The flexion-relaxation phenomenon (FRP) is a type of neuromuscular response in which the back muscles of healthy individuals become essentially inactive when one flexes the trunk forward to the end range of motion. A review of the literature has indicated that lumbar FRP has been used for many years⁸ and has been shown to be a valuable objective tool to aid in the evaluation of patients with low back pain.⁹ For example, the FRP has been shown to be able to objectively distinguish those with low back pain from those without as well as between subgroups of low back pain.¹⁰

In 1997, Watson et al¹¹ developed the concept of the flexion-relaxation ratio (FRR) to quantify the degree to which the FRP is present. Since then, multiple methods of computing a lumbar FRR have been reported in the literature.^{12,13} To measure lumbar FRR, surface EMG electrodes are placed over the lumbar paraspinal muscles. Muscle activity is recorded while a person begins by standing erect, then bends forward, stays in the fully flexed position for a few seconds, and ends by returning to the erect posture. The FRR is calculated by dividing the maximum value of the EMG amplitude during the raising up of the trunk by the average EMG amplitude recorded while the participant is fully flexed. In healthy individuals, the EMG amplitude is greatly reduced when the person is fully flexed, resulting in a relatively large FRR. However, in persons with low back pain, the EMG

amplitude may not be similarly reduced when that person is fully flexed, thus resulting in a smaller FRR.

There are also several fairly recent studies examining FRP in the region of the cervical spine in the same manner as has been done in the lumbar spine. Three articles were found in the literature examining FRP in persons without cervical pain. In 1993, Meyer et al¹⁴ applied the FRP to the cervical spine in 10 asymptomatic participants. While sitting erect in a straight backed chair, the participants were instructed to lower their heads with the goal of approximating their chin to their upper chest and then raising them up again. The FRP was demonstrated in all 10 cases as noted by visual inspection of the plots of the EMG data. In 2008, Burnett et al¹⁵ sought to determine whether the FRP exists in cervicothoracic muscles in asymptomatic participants while seated in a standardized neutral spine posture. They did not see the FRP in upper trapezius or thoracic erector spinae (at T4) but did see evidence of it in the cervical paraspinals. In 2009, Pialasse et al¹⁶ found the cervical FRP to be more pronounced (greater values of FRR) in asymptomatic participants if the participant is seated, leaning forward, and supported with the trunk in 45° of flexion.

Four articles were found in the literature examining FRP in persons with neck pain. Although primarily evaluating a wireless EMG system, Airaksinen et al¹⁷ showed a visual difference in the plots of EMG data taken during cervical flexion-relaxation of one person with neck pain and one without. Murphy et al¹⁸ calculated FRRs from EMG recordings taken from 14 persons with chronic neck pain and 14 asymptomatic controls. They found a significant difference in the FRR between the 2 groups, as did Maroufi et al¹⁹ using groups of 21 with neck pain and 20 without. Zabihhosseini et al²⁰ found a difference between the FRR of 13 healthy participants and that of 12 with neck pain. They also found that after fatigue was elicited by repetition of an isometric neck extension task, the FRR decreased for the controls but increased for those with neck pain.

Although not working with neck pain participants, Nimbar et al²¹ also documented changes in FFR when the cervical muscles were significantly fatigued.

The FRR was found to be reduced after the Sorenson protocol was used to induce neck pain fatigue in 20 healthy participants. The effect of various activities on the cervical FRP has been reported including carrying a backpack,²² working on a computer,²³ overhead work,²⁴ visual display terminal work,²⁵ and below-knee assembly work.² Pialasse et al²⁶ have reported on the effects of load and speed on the cervical FRP.

Although not in a peer-reviewed journal, a different but somewhat similar approach has been described by Marcarian²⁷ as a case report—for a person with neck pain and another without. EMG electrodes were placed over the left and right cervical paraspinals, as well as the left and right sternocleidomastoids (SCMs). The participants axially rotated their head to right and to the left while EMG levels amplitudes were recorded from the 4 groups of muscles. When rotating to the right, the right paraspinal muscles and the left SCM are the agonists, whereas the left paraspinals and the right SCM are the antagonists. On the other hand, when rotating to the right, the left SCM is agonist and the right SCM is antagonist. Conversely, when turning to the left, the left paraspinals and the right SCM are the agonists and their contralateral muscles are the antagonists. Marcarian observed that, in an asymptomatic person, the EMG amplitude for each muscle was much greater when it was functioning as the agonist than when it was the antagonist. Similar to FRP, the difference was much less pronounced for the one with neck pain.

In the present study, we used the cervical axial rotation approach as reported by Marcarian as an objective indication of the degree of neck pain and compared it with the cervical FRP. In addition, when performing cervical flexion relaxation, we used 2 variations from previously reported protocols that seem to be easier for participants to perform. It was hypothesized that cervical axial rotation would be at least as effective as cervical flexion-relaxation in providing a quantified indication of the degree of cervical muscular dysfunction. The purpose of this study is to examine the feasibility of novel variations to the way cervical FRP studies are conducted and the feasibility of using cervical axial rotation as an alternative objective measure of cervical pain/dysfunction.

Methods

Participants

Asymptomatic participants with no neck pain were recruited by word of mouth from the student population

of Palmer College of Chiropractic. All study activities involving asymptomatic participants were conducted on campus in our laboratory. Participants with neck pain were recruited from the pain clinic of the Trinity Medical Center. The receptionist at the clinic notified study personnel (KG) of those scheduled in the near future who had listed neck pain as their primary complaint. KG came to the clinic just prior to the appointment. When the patients arrived, the receptionist referred them to KG who then attempted to recruit them into the study. All study activities involving neck pain participants were conducted at the pain clinic of the Trinity Medical Center. All participants signed a written informed consent document which was approved by both the Institutional Review Boards of Palmer College of Chiropractic and the Trinity Medical Center. All data collection was performed by the same person (KG).

Inclusion criteria included that the subject was between 21 and 75 years of age, in good general physical condition by self-report, ambulatory and self-sufficient, and willing to sign an informed consent document. For the participants with neck pain, other inclusion criteria included a numerical rating scale (NRS) for neck pain score of at least 2 on a scale of 0 for no pain to 10 for the worst pain possible. The inclusion criterion for asymptomatic participants was that they had no current neck pain.

Exclusion criteria included the following: if the person had a pacemaker or artificial implants in the cervical spine; had any fractures in the upper trunk or cervical spine; had any other major health issues such as cancer, neurological diseases, progressive neurological disorders, ticks, or spasms; or if they were taking any medication for neck pain other than nonprescription analgesics

Instrumentation

A MyoVision 2000 system (Seattle, WA) was used to collect the surface EMG data. The silver-silver chloride electrodes have a circular active area of 1 cm in diameter with 3% chloride wet gel, imbedded in a 1.5-in (3.8-cm) diameter foam adhesive pad. Data were collected with a sampling rate of 1200 Hz and a gain of 1000. The data were filtered with a 25- to 500-Hz band pass filter. The raw data were automatically converted to root mean square (RMS) with a window width of 72 resulting in a time interval of 60 milliseconds for each RMS data point.

Procedures

The participants' skin was prepared for attachment of the EMG electrodes by firmly rubbing the skin with an alcohol pad in accordance with the instructions provided by MyoVision. Electrodes were attached to the skin over bellies of the left and right cervical paraspinal muscles and the left and right SCM muscles. The location of the cervical paraspinal muscles was determined by palpating for the mounding of the muscle bellies on both sides just lateral to the center of the posterior cervical region. The location of the SCMs was determined by having the participant axially rotate their head to one side as far as they could. The SCM on the contralateral side then stood out and was easily identified. The process was repeated for the other side. The 2 electrodes for each muscle were centered along the length of the muscle and positioned such that the edges of the foam pads were almost touching, as shown in Fig 1. A ground sensor was attached over the right clavicle.

Electromyographic recordings during axial rotation of the neck were made first using the method described by Marcarian.²⁷ While sitting erect, each participant

Fig 1. Participant performing axial rotation to the left showing the EMG electrodes attached for the right paraspinal and sternocleidomastoid muscles with the ground attached over the right clavicle.

was asked to rotate their head first to the right and then to the left as far as they could in each direction without straining themselves or eliciting pain (Fig 1). This process of right and left rotation was done a total of 3 times in continuous succession while RMS EMG data were recorded. After finishing the axial rotation procedure, the electrodes over the SCMs were detached because they were not needed for FRP data collection.

Seated FRP EMG recordings of the cervical spine were made next. The procedure was similar to conventional routine reported in the literature, except for the starting position. Rather than starting with the participant holding their head up straight, each participant was asked to flex the head forward while seated and relax as much as possible, as if going to sleep. From that starting position, data collection began. After 4 seconds of recording while fully relaxed, the participants lifted their head up to the normal, erect position and then back down to the relaxed, full flexion position in 1 continuous motion to complete a cycle. After maintaining the position for 4 seconds, the participants again raised and lowered their head. A total of 3 such cycles were performed in continuous succession.

Lastly, prone FRP recordings were made. Participants were instructed to lay prone on a pelvic bench with their head hanging over the end of the bench (Fig 2). Similar to the protocol when they were sitting, the participants started with their head hanging down and relaxed before lifting the head enough to be in parallel with the table and then returned back down to the relaxed position. Again, a total of 3 cycles were performed.

While the participant was performing each type of procedure, the person collecting the data placed markers in the data set by monitoring the amplitude of the EMG signal in real time with the MyoVision

Fig 2. Participant in the starting prone position for flexion-relaxation with the head over the end of the table and fully relaxed.

software while watching the participant perform the task. For the software to place the marker, the space bar on the computer was pressed at each point of interest of the movement of the participant's head during the data collection. For FRP recordings, markers were placed after the participants head was fully flexed (when seated) or fully relaxed (when prone) and the EMG amplitude leveled out. Additional markers were placed when the participant began raising the head and again when the head returned to full flexion. For axial rotation recordings, markers were placed each time the participant's head reached the end range of rotation to either the left or the right.

Data Reduction and Analysis

Ratios of EMG data were obtained using 4 different methods: FRR for the cervical paraspinals while seated, FRR for the cervical paraspinals while lying prone, axial rotation ratios (ARRs) for the cervical paraspinals, and ARR for the SCMs. In the present study, FRR was calculated as the maximum EMG amplitude during the raising up of the head divided by the lowest 1-second average EMG amplitude while the head is fully flexed. For the axial rotation protocol, ARR was calculated as the maximum EMG amplitude recorded when the muscle was acting as the agonist divided by the maximum value recorded when that same muscle was acting as the antagonist. The paraspinal muscles act as the agonist when the head is being rotated to the

ipsilateral side, and the SCMs act as the agonist when the head is being rotated to the contralateral side.

The FRR and ARR were calculated using 2 custom-written, interactive Visual Basic for Applications macros in Microsoft Excel (Microsoft Corp., Redmond, WA), respectively. The macro for the flexion-relaxation data automatically placed markers on plots of the EMG data as they were manually indicated during data collection. The macro allowed the user to reposition any or all of the markers based on visual inspection of the plot of the data, if necessary (Fig 3). The maximum EMG amplitude during the raising up of the head and the lowest 1-second average EMG amplitude while the head is fully flexed were then automatically extracted from each movement cycle based on the placement of the markers, and FRR was calculated accordingly. The macro for the axial rotation data similarly placed markers on the peaks in the EMG data and allowed the user to make manual adjustments based on visual inspection (Fig 4). The maximum EMG amplitude recorded when the muscle was acting as the agonist and the maximum value recorded when that same muscle was acting as the antagonist were then automatically extracted from each movement cycle, and ARR was calculated accordingly. The average of FRR and ARR of 3 cycles was used for data analysis. In the event that the true peak overlapped with a spurious peak, that cycle was omitted. The calculation of the average ratio was then done by taking the mean from the other 2 good cycles instead of all 3.

Fig 3. Plot of EMG data taken from the left and right cervical paraspinal muscles while performing cervical flexion-relaxation. The vertical lines indicate borders of regions where the minimum mean values over 1 second or the maximum peak values are determined.

Fig 4. Plot of EMG data taken from the left and right cervical paraspinal muscles while performing cervical axial rotation by first rotating right and then left, repeated 3 times. The vertical lines indicate borders of regions where the maximum peak values are determined by a custom Microsoft Excel macro.

Statistics

The primary outcome for this study is the ratio calculated for each type of head movement: the ARR and FRR, as described above. The secondary outcome is the current pain level per NRS for participants in the neck pain group. The results are presented as descriptive statistics: means and standard deviations (SDs) for each of the 4 methods. Reported values were calculated using the SPSS software package (IBM Corp, Armonk, NY). Plots of the 4 methods of obtain EMG ratios are provided which show the patterns of the data distribution. Inferential statistics are not provided because of the small number of data points.

Results

There were 11 participants (6 with neck pain, 5 asymptomatic controls) enrolled in the study. For the neck pain group, 2 were male and 4 were females. One male neck pain participant was excluded from data analysis because his pain score (NRS = 1) was lower than the cutoff value of NRS = 2 on the day of the experiment. All participants in the control group were male. The mean age was 52.8 ± 11.1 years for the patient group and 34.2 ± 14.5 years for the control group. The NRS mean pain level was 5.4 ± 2.1 for the patient group.

Table 1 summarizes the mean and SD of EMG ratios from the 4 different assessment methods used in this study. The relationships between the NRS score for

pain as reported by those in the pain group and the 4 ways of calculating ratios of EMG amplitudes are depicted in the plots shown in Figs 5-8.

Discussion

In the present study, 4 different EMG ratios were computed using novel procedures: FRR from paraspinals while seated beginning with the head fully flexed forward, FRR from paraspinals while prone beginning with the head fully flexed forward, ARR from the cervical paraspinals while seated, and ARR for SCMs while seated. All 4 of the different types of EMG ratios of this study were greater for the asymptomatic controls than for the neck pain partici-

Table 1 Means and SDs of EMG Ratios for FRR and ARR of 4 Assessment Protocols for 5 Participants With Neck Pain (P) and 5 Controls Without Neck Pain (C)

Method	Group	Both Sides Mean (SD)
FRR: sitting	C	2.7 (1.4)
	P	1.5 (0.6)
FRR: prone	C	2.9 (1.0)
	P	1.8 (1.0)
ARR: paraspinals	C	2.6 (0.7)
	P	2.0 (1.2)
ARR: SCMs	C	5.4 (2.2)
	P	2.6 (2.3)

ARR, axial rotation ratios; FRR, flexion-relaxation ratio; SCM, sternocleidomastoid; SD, standard deviation.

Fig 5. Plot of FRRs taken while participant was seated vs pain level.

pants (Table 1). Consistent with the literature regarding other related protocols, the patterns seen in the distribution of data points suggest that there is a negative association between these EMG ratios and the neck pain score (Figs 5-8). These findings suggest that it is possible that all 4 methods may potentially be used to distinguish between those with neck pain and those without as well as to provide an objective measure that is indicative of the degree of neck pain. Although formal correlations cannot be made because of the small sample size, the results as shown in Table 1 for the ARR obtained from the SCMs during cervical axial rotation are higher than the ratios from the other 3 methods. In addition, as also shown in Table 1, the difference between the ratio of the controls as compared with that of the neck pain group is greater for ARR from SCMs than that of any of the other 3 methods. This suggests that the ARR from SCMs may provide a better objective indication of those with neck pain as opposed to those without neck pain than the

other 3 ratios of this study. However, larger studies must be done before any definitive conclusions can be made.

When giving the participants instructions, the investigators found it easier to explain the procedure for axial rotation as opposed to flexion-relaxation. Also, it appeared that individuals performing axial rotation were able to move in a smoother, more relaxed manner. Consequently, it was felt that cervical axial rotation provides an advantage over the flexion-relaxation protocols as described in this study and in the literature.

Comparing FRP using different positions, Pialasse et al¹⁶ reported that the FRP was more pronounced when participants were supported while leaning forward at 45°. In our preliminary measurements, we also found that to be true. However, this leaning forward posture was awkward for the participant and required some special structure to provide the support. Having the participant lay prone with the head unsupported not only demonstrated more pronounced

Fig 6. Plot of FRRs taken while participant was prone vs pain level.

Fig 7. Plot of ARRs taken from paraspinal muscles vs pain level.

Fig 8. Plot of ARR taken from sternocleidomastoid muscles vs pain level.

FRP but also was easier for the participant and required no special structure.

In addition, when doing preliminary testing, we came up with the idea of starting seated cervical flexion-relaxation with the head flexed in a fully relaxed position, as if going to sleep. We found that to be easier for the participant than starting with the head straight up as described in the literature. When starting with the head straight, the participant had to go through 4 distinct phases: head straight, lowering the head down, relaxing when fully flexed, and finally raising the head up again. By starting with the head flexed, it was easier for the participant to get more relaxed in that initial position followed by 1 continuous movement of raising the head up and lowering it back down again. It also seemed to be easier to relax when returning to the starting position in between cycles than when the relaxed phase was sandwiched between 2 distinct movements, hence producing a more pronounced FRP (greater values of FRR) than when starting with the head in the straight position. Consequently, we used that approach when collecting data for the study.

For FRR calculation, rather than taking the average RMS EMG amplitude over the entire relaxation phase as other researchers have done, we took the lowest average over a 1-second interval during the relaxation phase. When averaging over the entire relaxation phase, the exact positions for the beginning and the ending of the period may make a significant difference in the resulting average. Furthermore, it is not possible to disregard the occasional spurious spikes in the relaxation phase using such approach. However, by taking the lowest average of a 1-second interval, the results are less sensitive to where the boundaries are placed or to contamination by spurious spikes. The

custom macro that was developed for data reduction allows for the manual repositioning of any of the boundary markers before making the calculations, if needed. The initial placement based on visual observation during data collection was usually close enough, making manual adjustments unnecessary most of the time. We did not average the magnitudes of data points surrounding the peaks of EMG activity levels because each peak represents a single point while the relaxed portion is over a period of time. Because the peak represented only a single point of the RMS data (which is already the average of many raw data points) when the macro was looking for the peak, it was possible to limit the region of data points that contained the peak by visual inspection such that it contained no spurious peaks. Essentially, our approach reduces the subjectivity inherent in determining the boundaries of the relaxation phase and reduces data contamination from spurious spikes.

Limitations

A major limitation of the present study is the sample size. Although distinct differences were found between groups and the relatable results agree in general with the reported literature, future studies with a larger sample size are needed to confirm the findings of this introductory study. It is noteworthy that recruiting participants with neck pain was found to be quite difficult. Having a reasonably accessible source of potential participants with a significant degree of neck pain would be essential for a larger study of this nature. Perhaps a larger study with asymptomatic participants would also be informative by providing a more rigorous comparison of the novel axial rotation approach to the more commonly used cervical flexion-relaxation approach.

There is also some degree of subjectivity when defining the regions of the RMS EMG data to determine maximum and minimum EMG amplitudes used in calculating the ratios for each of the methods that were investigated in this study. Although the patterns were quite well defined, making it fairly easy to mark the beginning and end of relevant sections of data, it is possible that the process could be somewhat more objective if motion data were available along with the EMG data. The issue of not having motion data to identify the relevant sections of the EMG plots was minimized by taking the lowest 1-second average of EMG data across the region corresponding to maximum flexion instead of attempting to identify an exact beginning and end of that region. Although the use of

motion data could not be expected to remove all subjectivity from the process, it is recommended that motion data be collected in any future studies of this sort.

It is noted that there is a difference in the mean age of the participants in the 2 groups that is on the edge of statistical significance ($P = .052$), with the pain group being older than the asymptomatic group (52.8 as compared with 34.2). Also, the neck pain group consisted of both men and women, whereas the control group only had men. It is possible that these demographical differences between groups could account for some of the differences in the various ratios of the 2 groups.

Conclusion

This study presents 4 different novel ways of using EMG measurements as objective indications of the degree of neck pain that, as far as we could determine, have not been reported in the peer-reviewed literature. Although the number of participants is small, the results of this study suggest that all 4 approaches may be able to provide an objective method of distinguishing between those with neck pain and those without. In addition, the results from all 4 methods suggest that there may be a relationship between the EMG ratios used and the degree of neck pain, indicating the possibility of using these measures to objectively quantify the degree of neck pain.

When performing cervical FRP studies, it seemed to be easier for participants to perform the movements when starting from a fully flexed position followed by a continuous motion of extension and flexion rather than starting from the erect position as currently reported in the literature. The axial rotation protocol seemed to be easier for participants to perform than a flexion-relaxation protocol and still provided similar or possibly better results. However, because of the small number of participants, larger studies must be done before any definitive conclusions can be made.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

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