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Electromyographical Assessments of Recommended Neck and Trunk Positions for Dental Hygienists

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Abstract

Purpose: Dental professionals are recommended to limit neck and trunk flexion to within 20° of a neutral (0°) body posture, however empirical support for the recommendations is lacking. The purpose of this study was to determine whether there are differences in muscle workload between a range of neck and trunk postures in a population of dental hygiene students.

Methods: Fifteen first semester senior dental hygiene students with no history of neck and trunk injury volunteered to participate. Surface electromyography was used to record muscle activity from two neck extensors muscles, cervical erector spinae (CES) and upper trapezius (UT), and two trunk extensor muscles, thoracic erector spinae (TES) and iliocostalis lumboruni (IL). Participants performed ten conditions, including five neck flexion angles (0°, 10°, 20°, 30°, 40°) and five trunk flexion angles (0°,10°, 20°, 30°, 40°). For each trial, posture was checked with a goniometer and maintained for 20s. Muscle activity for each muscle was normalized to the individual's maximum voluntary isometric contraction (MVIC).

Results: Activity of the CES was significantly lower in the neutral position than all flexed neck positions. Activation of the UT increased with neck flexion but required 30° of flexion to differ significantly from the neutral position. Activity of the TES required 20° of trunk flexion to differ significantly from neutral and IL activity in the neutral position was significantly lower than all other trunk flexion conditions.

Conclusion: Even small amounts of neck or trunk flexion (10°), within the recommended range (≤ 20°), can significantly increase the workload for some muscles in an oral health care provider.

Keywords: ergonomics, posture, musculoskeletal disorders, dental hygienists, oral health care providers, occupational health

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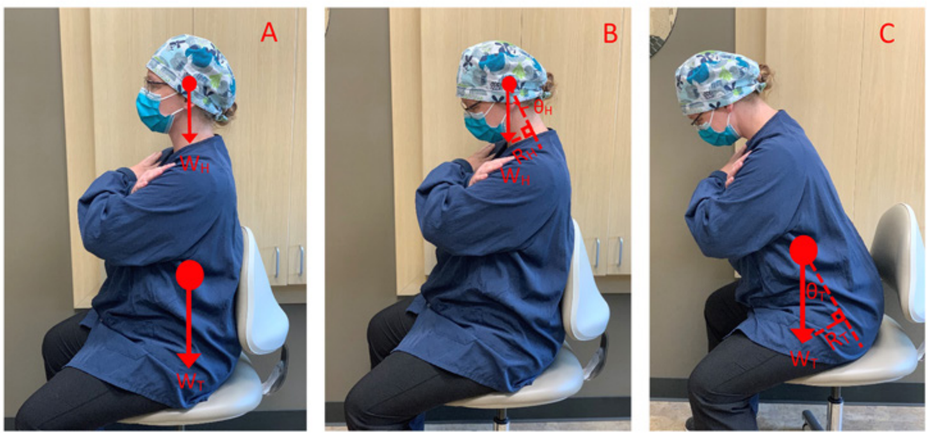
Introduction

The National Institute for Occupational Safety and Health (NIOSH) states that working environments that require awkward postures of the neck and back muscles place the employee at high risk for musculoskeletal disorders (MSDs).[1] Dental hygiene practice is physically demanding, often resulting in dental hygienists holding their neck and trunk in less than optimal positions for long periods of time while using high precision forces and performing highly repetitive motions.[2,3] Unfortunately, the high prevalence of work-related MSDs to the neck (54-69%) and back (24-67%) reported by dental hygienists confirms that the occupational requirements result in increased risk of MSDs.[4-6] These work related MSDs have a significant impact on dental hygienists in clinical practice, leading to reduced productivity or performance, and even to decreased working hours or the need to leave the profession.[7,8] In an effort to reduce MSDs, ergonomic instruction has been included in dental hygiene curricula and continuing education seminars.[9, 10] To reduce the incidence of MSDs of the neck and back, dental hygiene students are instructed to maintain both neck and trunk flexion between 0° and 20°.[11] While the efforts devoted to applying ergonomic principles within academia and dental hygiene clinical practice is to be applauded, these guidelines have received scant empirical examination. There is no evidence to indicate whether the current recommendations are in fact appropriate in preventing or reducing work-related MSDs in dental hygienists.

Recommending that the head and trunk remain close to an upright, neutral alignment is based on the mechanical principle of torques or force moments.[12] With the head and trunk in a neutral alignment, the force of gravity (weight) of the head (W_H) and trunk (W_T) act down the spine, creating no torques at the vertebrae of the spine (Figure 1A). Leaning the head forward moves the force of gravity outside of the spine, which creates a moment arm for the head (R_H, perpendicular distance between the joint axis and the line of force) resulting in a torque at the vertebrae in the neck (T_H) due to the weight of the head (Figure 1B). Similarly, leaning the trunk forward creates a moment arm (R_T) resulting in a torque (T_T) at the vertebrae in the lower back (Figure 1C). The more an individual leans, the greater the angle at the head (Θ_H) or trunk (Θ_T) and the larger the resulting torques.

Figure 1. Torques on the vertebrae of the neck and lower back due to neck flexion and trunk flexion.



Circles indicate the approximate center of mass of the head and trunk. Arrows represent the force of gravity vectors (weight) of the head (W_H) and trunk (W_T).

A: Approximately neutral alignment with the force vectors acting through the spine.

B: Demonstrates neck flexion (Θ_H). The weight of the head produces a torque proportional to the perpendicular distance from the axis of rotation (R_H).

C: Demonstrates trunk flexion(Θ_T). The weight of the trunk produces a torque proportional to the perpendicular distance from the axis of rotation (R_T).

To demonstrate the relationship between neck flexion angle and torque at the neck, the computed torques for a representative female and male in five different neck flexion positions, are shown in Table I. Human anthropometric data from an average woman and average man reported in De Leva were used for the calculations.[13] Table I shows that 0° of neck flexion results in no torque at the neck, but as neck flexion increases the torque at the neck increases. Similarly, Table II provides calculations of the torque at the lower back produced by flexion at the trunk, based on the same anthropometric data from the literature.[13] For these calculations the weight of the head also contributes to the torque at the lower back. Again, increased flexion results in increased torque. To maintain these postures, equal and opposite torques must be produced by the extensor muscles of the posterior neck and back, which places more stress on the vertebrae. It is also important to realize that due to the mechanical disadvantage of these muscles, the forces produced by the muscles are considerably larger than the forces produced by the weight of the head and trunk.[6] While a simple model has been used to highlight the effects of neck and trunk flexion, more complex models allied with experimental data can provide more detailed understanding of the internal forces on the vertebrae themselves.[14] Recommendations of not flexing the neck or trunk more than 20° suggests that humans can safely handle these torques for a period of time, however it is not clear how much work the muscles are actually performing and there is no empirical research to examine whether 20° neck and trunk flexion guidelines are appropriate.

Currently, the most accurate technique to quantify muscle workload is to record the electrical activity of the muscles through electromyography (EMG).[15,16] Electrodes placed on the surface of the skin over the belly of a muscle detect small voltages that occur from a summation of action potentials produced by motor units, which make up the muscle. Larger voltage indicates more motor units are recruited more frequently and is positively correlated to greater force production. Electromyography has proven to be a useful technique for assessing the application of ergonomic principles to the design of dental instruments. This technology has identified characteristics of scaling instruments and mirrors which reduce muscle loads, in addition to indicating that cordless polishing handpieces have been shown to reduce total muscle workload compared with corded handpieces.[17-21]

To date, ergonomic principles applied to recommendations for particular body postures during clinical dental hygiene practice and muscle workloads have received little attention in the literature. One exception was a study which revealed that use of one or two finger rest positions reduces workload of muscles of the hand and forearm during dental hygiene scaling procedures.[22] In the broader ergonomic research literature, there is little research which has assessed muscle activity under different sitting postures. Sitting with

Table I. Anthropometric neck torque (TH) computed for five different neck flexion angles (θ).*

θ (°)	Female				Male			
	[1]W_H (N)	[2]D_H (m)	[3]R_H (m)	[4]T_H (N.m)	W_H (N)	D_H (m)	R_H (m)	T_H (N.m)
0	40.6	0.12	0.00	0.0	49.7	0.12	0.00	0.0
10	40.6	0.12	0.02	0.8	49.7	0.12	0.02	1.1
20	40.6	0.12	0.04	1.6	49.7	0.12	0.04	2.1
30	40.6	0.12	0.06	2.4	49.7	0.12	0.06	3.0
40	40.6	0.12	0.08	3.1	49.7	0.12	0.08	3.9

*Data based on the average female (body mass = 61.9 kg, height = 1.735 m, head length = 0.2437 m) and average male (body mass = 73.0 kg, height = 1.741 m, head length = 0.2429 m) reported by De Leva.13

1 Weight of the head

2 Distance from the center of mass of the head to the axis of rotation

3 Perpendicular distance of the center of mass of the head to the axis of rotation

4 Torque at the neck due to the weight of the head and trunk

a flexed spine has been found to increase neck and shoulder muscle activity.[23] In contrast, "slump sitting" led to increased cervical erector spinae (neck) muscle activity, but lower thoracic erector spinae (upper back) activity as compared with upright sitting.[24] While these studies compared upright with flexed/slumped sitting, they did not compare different degrees of forward flexion, nor did they separately assess trunk and neck flexion on muscle activity throughout the back.

Dental hygienists have learned in their clinical education experiences to strive to maintain both a head and trunk flexion between 0° and 20°.[11] When the head or trunk is flexed, the extensor muscles of the neck and back are expected to be activated to hold the head or trunk in position against the torque produced by gravity and the muscle activity of the neck extensors (CES and UT) are expected to demonstrate increases with greater neck flexion. The purpose of this study was to examine the established head and trunk postural recommendations for dental hygienists using electromyography.

Methods

Participants

This repeated measures design study received full approval from the Old Dominion University Institutional Review Board. A convenience sample of fifteen dental hygiene students was recruited via an email invitation letter. A screening questionnaire was used to ensure participants were first semester seniors without a history of musculoskeletal disorders or surgeries to the neck and back. Participants were female ranging in age from 21.2 to 29.5 years. Informed consent was obtained from all participants prior to data collection.

Procedures

To test the recommended head and trunk flexions of between 0° and 20°, participants were asked to statically held a total of ten different postures, including five different neck flexion positions (0°, 10°, 20°, 30°, 40°) and five trunk flexion positions (0°, 10°, 20°, 30°, 40°). Pre-amplified surface EMG sensors (Delsys, Inc., Natick, MA,

Table II. Anthropometric lower back torque ($T_{H\&T}$) computed for five trunk flexion angles (θ)*

θ (°)	Female							Male						
	[1]W_H (N)	[2]D_H (m)	[3]R_H (m)	[4]W_T (N)	[5]D_T (m)	[6]R_T (m)	[7]$T_{H\&T}$ (N.m)	W_H (N)	D_H (m)	R_H (m)	W_T (N)	D_T (m)	R_T (m)	$T_{H\&T}$ (N.m)
0	40.6	0.73	0.00	258.5	0.31	0.00	0.0	49.7	0.72	0.00	311.2	0.31	0.00	0.0
10	40.6	0.73	0.13	258.5	0.31	0.05	18.9	49.7	0.72	0.13	311.2	0.31	0.05	23.0
20	40.6	0.73	0.25	258.5	0.31	0.10	37.2	49.7	0.72	0.25	311.2	0.31	0.11	45.3
30	40.6	0.73	0.37	258.5	0.31	0.15	54.3	49.7	0.72	0.36	311.2	0.31	0.15	66.3
40	40.6	0.73	0.47	258.5	0.31	0.20	69.9	49.7	0.72	0.47	311.2	0.31	0.20	85.2

[1] Weight of the head

[2] Distance from the center of mass of the head to the axis of rotation

[3] Perpendicular distance of the center of mass of the head to the axis of rotation

[4] Torque at the lower back due to the weight of the head and trunk

[5] Distance from the center of mass of the trunk to the axis of rotation

[6] Perpendicular distance of the center of mass of the trunk to the axis of rotation

[7] Torque at the lower back due to the weight of the head and trunk

*Data based on the average female (body mass = 61.9 kg, height = 1.735 m, head length = 0.2437 m) and average male (body mass = 73.0 kg, height = 1.741 m, head length = 0.2429 m) reported by De Leva.[13]

USA) were placed over four muscles: cervical erector spinae (CES), upper trapezius (UT), thoracic erector spinae (TES), and iliocostalis lumborum (IL). Prior to placement of each sensor the skin was prepared by shaving (if necessary) and rubbing with an alcohol wipe. After the skin had dried each sensor was attached via double-sided sticky tape. The CES sensor was placed 2 cm laterally from the cervical vertebrae four spinous process.[24] An anthropometric tape measure was placed between the posterior aspect of the acromion and the spinous process of cervical vertebrae seven. The UT sensor was placed immediately lateral to the tape.[24] The TES sensor was placed 5 cm lateral from the spinous process at thoracic vertebrae four.[24] For the IL, the EMG sensor was placed at the same level as lumbar vertebrae two and was aligned parallel to a tape held between the posterior superior iliac spine and the lateral border of the muscle at the 12th rib.[25,26] All sensors connected wirelessly to the EMG system and were controlled via a computer with an EMG software program and data was collected at 2000 Hz.

Prior to the experimental trials, each participant performed the maximum voluntary isometric contractions (MVIC) of neck extensor and trunk extensor muscles. This required maintaining a static position over a clinical treatment table while contracting muscles as forcefully as possible against a resistance provided by one of the researchers. Three MVIC trials of 3 seconds each were performed for the neck and trunk extensor muscles separately. The experimental trials were performed following the MVIC. Participants sat in a standardized body position with their arms crossed over their chest, so that their arms could not provide support to the body and shoulder fatigue from holding their arms up was minimized. At the start of each trial, participants were placed in a specific neck or trunk position by one of the researchers using a goniometer. The researchers monitored each participant to ensure the body posture was maintained during each 20 second trial. If the participant moved the trial was repeated. Three valid trials were performed at each of five neck flexion angles (0°, 10°, 20°, 30°, 40°) and five trunk flexion angles (0°, 10°, 20°, 30°, 40°). In an effort to minimize order effects, the order of neck and trunk flexion conditions was counterbalanced across participants, while the order of the flexion angles was randomized. Participants rested for 30 seconds between trials and 60 seconds between conditions to minimize fatigue. While additional rest was permitted if necessary, it was not requested by the participants.

Data analysis

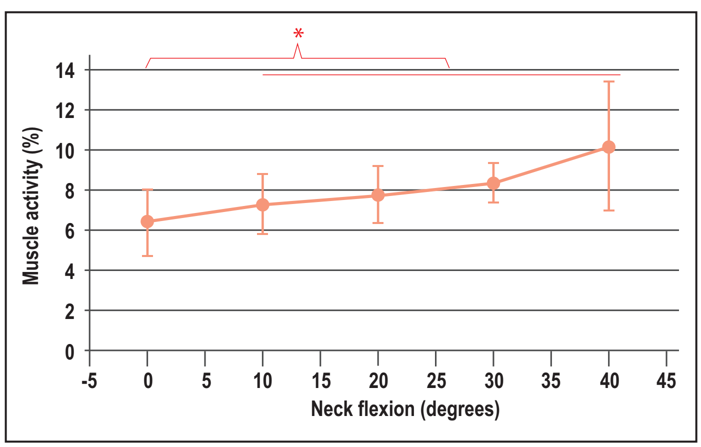
Raw EMG signals were processed using standard techniques, which were all performed using a computer software program (MATLAB version R2018b; Mathworks, Inc., Natick, MA, USA). First, the EMG signals were band pass filtered using 20-400 Hz cutoffs, then rectified. Each processed EMG signal was then integrated to obtain the area under the voltage-time curve, which provides a measure of total muscle activity. The average integrated muscle activity per one second was computed for both MVIC and experimental trials. Finally, EMG activity for each experimental condition was normalized to a percentage of MVIC (%MVIC), an approach that has been shown to be reliable and valid.[27,28]

One-way repeated measures analysis of variance (ANOVA) with the factor flexion was performed on the %MVIC data separately for the neck and trunk, and each muscle. Significant main effects were followed up with Sidak post hoc tests. All statistical tests were performed using a statistical software program (SPSS version 24; IBM, Armonk, NY, USA) and the level of significance was set at $p < .05$.

Results

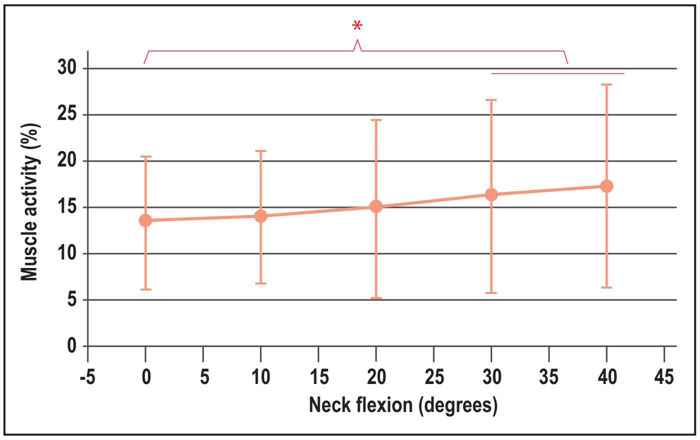
Both neck extensor muscles increased approximately linearly with increases in neck flexion (Figures 2, 3). Activity of the CES muscle activity increased, on average, from 6.2% of the MVIC at the neutral position (0° flexion) to 10.0% of the MVIC at 40° of neck flexion. ANOVA revealed that CES muscle activity differed significantly with changes in neck flexion position ($p<.05$). However, only the neutral position was significantly different from any of the other neck postures ($p<.05$), indicating that only 10° of neck flexion was needed for a significant increase in CES activation. The UT muscle increased activity from, on average, 13.2% to 17.1% of the MVIC. There was an overall significant effect of neck flexion angle on UT activity ($p<.05$). In this case, the neutral position was significantly less than 30° and 40° of neck flexion ($p<.05$). No other differences were significant for neck flexion.

Figure 2. Group mean activity of the cervical erector spinae (CES) muscle as a percentage of maximum voluntary contraction is plotted for five different neck flexion angles



Error bars indicate one standard deviation. The 0° neck flexion condition was significantly different from all other neck flexion conditions

Figure 3. Group mean activity of the upper trapezius (UT) muscle as a percentage of maximum voluntary contraction is plotted for five different neck flexion angles.



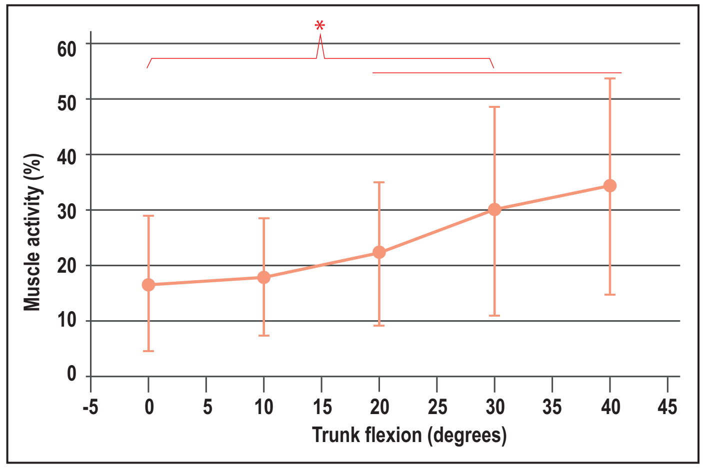
Error bars indicate one standard deviation. The 0° neck flexion condition was significantly different from the 30° and 40° neck flexion conditions.

Increases in trunk flexion resulted in an approximately linear increase in trunk extensor activity in both TES and IL muscles (Figures 3, 4). Thoracic erector spinae muscle activity increased with trunk flexion from, on average, 16.8% to 34.7% of the MVIC. The overall effect of trunk position had a significant effect on TES activity ($p<.05$). A neutral trunk position resulted in significantly lower muscle activity compared with 20-40° of trunk flexion ($p<.05$). No significant differences were found in muscle activity between 0 and 10° of trunk flexion or any other combination. The IL muscle increased activity from 8.9% to 18.6% of the MVIC with increasing trunk flexion, which was supported by a significant effect of condition ($p<.05$). The neutral trunk position resulted in significantly lower IL muscle activity compared with all other trunk postures ($p<.05$). No other postures differed significantly.

Discussion

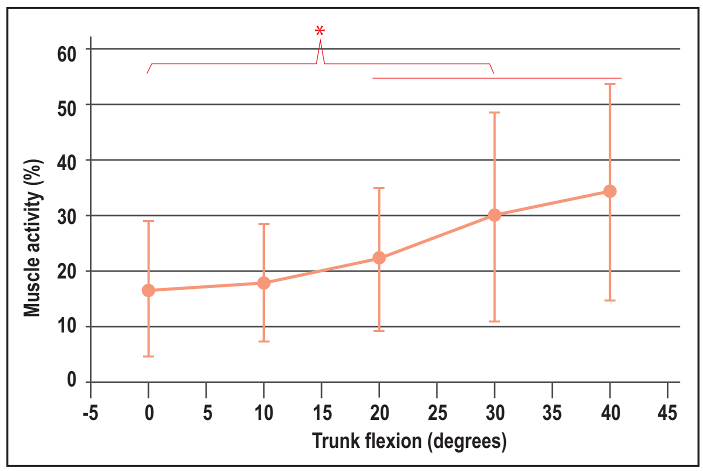
Dental hygienists suffer from a high prevalence of MSDs of the neck and trunk, indicating that many of these injuries are likely to be work related.[4-6] As clinical dental hygiene practice does not usually involve heavy lifting, it is likely that these injuries are related to awkward postures and movements adopted over significant periods of time each day.[1] Recommendations for maintaining head flexion between 0° and 20° and trunk flexion between 0° and 20° have been provided in an effort to prevent future MSDs.[11] These recommendations are taught in dental hygiene curricula in addition to professional workshops across the country. Minimizing neck and trunk flexion is based on the sound ergonomic principle of reducing the torque produced at vertebrae in the spine by the weight of the head and trunk.

Figure 4. Group mean activity of the thoracic erector spinae (TES) muscle as a percentage of maximum voluntary contraction is plotted for five different trunk flexion angles.



Error bars indicate one standard deviation. The 0° trunk flexion condition was significantly different from the 20°, 30°, and 40° trunk flexion conditions.

Figure 5. Group mean activity of the iliocostalis lumborum (IL) muscle as a percentage of maximum voluntary contraction is plotted for five different trunk flexion angles.



Error bars indicate one standard deviation. The 0° neck flexion condition was significantly different from the 30° and 40° neck flexion conditions.

However, there is no empirical evidence that up to 20° is an appropriate target. This study aimed to fill this void by quantifying the workload of extensor muscles of the neck and trunk which act to hold a flexed posture.

Results from this study provide limited evidence for recommending a neck flexion between 0° and 20°. In this study a neck flexion of only 10° resulted in a significant increase in muscle activity of the CES when compared with the 0° neutral position. For the UT muscle, 30° of neck flexion was required before a significant increase in activity when compared to the neutral position was detected. These results should not be interpreted as splitting the difference between the significant effects, as the increased activity of the neck extensors combines, rather than cancels out. Figures 2 and 3 show that muscle activity of the neck extensors increased approximately linearly with greater neck flexion, which is in line with larger torques being created by the head at the spine with increased flexion angle (Table I). It should be noted that no sudden increases in activity in these muscles were found after 20°. Statistical significance indicates the difference in variation between posture conditions was considerably larger relative to the variation within postural conditions and should not be interpreted as an indicator of the risk of developing MSDs. A specific muscle workload to minimize MSDs is unknown, hence the results do not point to a maximum neck flexion range. However, these results show that even 10° of neck flexion significantly increases activation for at least one of the two muscles tested.

Similar to the findings for neck flexion, this study did not provide evidence to support the recommendation of maintaining trunk flexion between 0° and 20°. Only 10° of trunk flexion from neutral was necessary to lead to a significant increase in IL muscle activity, and at 20° of trunk flexion the TES muscle activity was significantly greater than in the neutral position. Figures 4 and 5 demonstrate that trunk extensor muscles increase in an approximately linear fashion with greater trunk flexion, without any abrupt change in activity after 20°. Rather than finding evidence for the 0-20° trunk flexion recommendation, trunk extensor muscle activities were observed even within this small range of movement.

Recent research shows that dental hygienists often exceed even the recommended limit of 20° of neck or trunk flexion. Average neck flexion during instrumentation (exploring) was observed to be over 30°, while average trunk flexion of 19° indicates that much of the time was spent close and beyond the limit.[26] Similarly, average neck flexion while scaling was 25° and trunk flexion was 19°.[29] While many dental hygienists are aware of the importance of posture in reducing the risk of MSDs, it seems difficult to deliver clinical care while maintaining appropriate body position. Exploring, scaling and polishing require visualizing the tooth surfaces. Clinicians can adjust the patient position, the operator stool, and use a mirror and magnification loupes. However, even with all these strategies, it can be challenging to see the tooth surface while maintaining a neutral neck and trunk position.

Magnification loupes have been promoted as an ergonomic solution; however, evidence has been mixed. While the use of loupes did not result in significant improvements in neck or trunk flexion during exploring, they have been found to reduce trunk flexion during scaling procedures.[26,29] Interestingly, dental hygienists have the perception that the use of magnification improved their posture even when the data revealed no differences.[28] This apparent misperception of neck and trunk flexion during dental tasks maybe also be a significant factor in the difficulty of maintaining ergonomic posture. It may be more efficacious to aim for a neutral alignment of neck and trunk rather than not exceeding a limit. Future research is necessary to determine if a neutral alignment of neck and trunk can be achieved during dental hygiene tasks and how it is best supported by education and technology.[10]

This study had two main limitations. It was designed to maximize internal over external validity. Participants adopted and held static postures without performing a dental hygiene task. This had the benefit of enhancing the experimental comparison between the different postures, however, practicing clinicians perform different tasks while holding different postures. It is anticipated that performing tasks at the different postures would likely increase the difference in muscle activity between neck and trunk flexion angles. Flexing the head while flexing the trunk is expected to increase torques as the moment arm is even further from the fulcrum at the back. Similarly, using ultrasonic and hand instruments to explore, debride, scale or polish would likely further amplify torques at the trunk depending on trunk flexion posture. Having participants maintain particular neck or trunk flexion angles while practicing clinically would reduce the fidelity of the experimental conditions but could be examined in future research.

The second main limitation of this study is that the muscle workloads that result in MSDs are not known. There are several reasons for this knowledge gap. First, MSDs develop from a combination of intensity, duration and frequency of load. Injury can occur due to a single very large load, or small loads over time with repetition. Second, there are significant variations in anatomy and the ability to withstand different kinds of loads, which in turn can vary within the clinician's body. Third, quantifying muscle activity using EMG provides a relative rather than an absolute measure of muscle workload because the electrical signal can be influenced by the placement of the electrodes, preparation of the skin, as well as the degree of adipose tissue overlying the muscles. However, EMG does provide a means to compare the activity levels between experimental conditions (when the electrodes remain in position) to determine what leads to differences, and computing values as a percentage of MVIC provides a useful metric and reduces between individual variation. Currently, EMG provides the best approach to quantifying muscle workload and identifying conditions more likely to increase MSDs. Future research could combine EMG data with modeling of the spine for more detailed understanding of the internal forces on the vertebrae and other structures.[14]

Even with these limitations, results from this study demonstrate that clinicians should minimize the time spent with the neck or trunk flexed away from the neutral position. Even 10° of neck or trunk flexion significantly increases activity of at least one neck or trunk extensor muscle, respectively, and this stress can be compounded over time. The published recommendation that dental hygienists maintain neck and trunk flexion between 0° and 20°, would be expected to reduce the risk of MSDs, however, there is no evidence that maintaining up to 20° of neck or trunk flexion for long periods of time is a safe guideline. Furthermore, despite the ergonomic recommendations made in curricula and workshops, dental hygienists continue to report a high incidence of work-related MSDs.

Conclusion

Even small degrees of neck and trunk flexion (10°) from a neutral position result in significant increases in activity of neck and trunk extensor muscles, respectively. While the particular muscle workload that likely leads to MSDs is unknown, the fact that dental hygienists report a high prevalence of neck and back MSDs indicates that the occupation is placing stress on those areas. Minimizing time spent in a position with the neck or trunk flexed should reduce the risk of MSDs. Further research is needed to provide successful strategies for helping dental hygienists to reduce MSDs to the neck and back which can have significant effects on the health and career of clinicians.

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