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Exposure to a workday environment results in an increase in anterior tilting of the scapula in dental hygienists with greater employment experience

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ABSTRACT

Background: Dental hygienists suffer a high incidence of shoulder pathology that seems to increase with job longevity. It has been hypothesized that occupational injuries could be due to local muscle fatigue caused by repetitive low level work and awkward and constrained working postures. In the laboratory, scapular kinematics can be temporarily altered using fatiguing protocols. It is unknown whether or not workday fatigue causes changes to scapular kinematics. The aim of this study was to examine if changes in scapular tilt and rotation occurs after a workday in dental hygienists.
Methods: The pre and post workday scapular kinematics were recorded from dental hygienists using an electromagnetic tracking system. All data were recorded within the place of employment of the dental hygienist.
Results: Following the workday, there was significantly more scapular anterior tilt in dental hygienists ($P<0.05$); however, no changes were found for upward or internal rotation. Greater kinematic differences were found for hygienists with greater job longevity.
Interpretation: The increase in scapular anterior tilting could be due to post workday fatigue. Anterior tilting of the scapula may have an influence on the development of subacromial impingement syndrome. Hygienists with greater duration of work experience may be at greater risk for developing shoulder injuries as they have more anterior tilting of the scapula post workday.

1. Introduction

Dental hygienists have a high incidence of shoulder related pain and pathology, which may be associated with the demands of the workplace environment and/or work-related tasks. Repetitive arm motions, especially above 60° and 90° of humeral elevation, are highly associated with the development of shoulder pathology (Svendsen et al. 2004b). In dental hygienists, elevated and repetitive arm motions are common (Akesson et al. 1999). Studies have also shown an association between prolonged elevated arm positions and the development of work-related disorders (Ohlsson et al., 1994; Svendsen et al. 2004a). In 2007, the United States Department of Labor reported that in the private industry over 335,000 musculoskeletal injuries occurred resulting in approximately 3 million missed days of work. For dental hygienists, between 11% and 68% of work-related injuries occur in the upper extremities (Akesson et al. 1999; Bernard, 1997). Although not all manual labor-intensive careers are the same, many result in similar musculoskeletal disorders (MSDs) of the upper extremity, such as carpal tunnel syndrome, shoulder impingement syndrome and neck pain (Akesson et al. 1999). In other occupations such as house painters, machinists and car mechanics, an association between arm abduction exposure and shoulder injuries has been made (Svendsen et al. 2004a)

Dental hygienists are exposed to workday fatigue since their job often requires low level static loads on the shoulder as well as awkward and constrained postures of the trunk (Akesson et al. 1999; Marklin and Cherney 2005). Greenfield et al. conducted a study comparing patients with overuse shoulder injuries to healthy controls. Results from their study suggest an association between prolonged forward head position and overuse shoulder injuries (Greenfield et al. 1995). It has been reported that dental hygienists spend 66% of their working time in a seated position with their neck flexed at 60° and with their trunk flexed to 30° or higher (Marklin and Cherney 2005). Additionally, hygienists maintain an elevated and abducted shoulder position for at least half of the time working with each patient (Marklin and Cherney 2005). A flexed trunk posture has been associated with altered scapular kinematics and decreased muscle force, particularly with the arm in an elevated position (Kebaetse et al. 1999).

In healthy populations, upper extremity fatiguing protocols result in altered scapular kinematics (Borstad et al., 2009b; Ebaugh et al., 2006a, b; McQuade et al. 1998; Tsai et al. 2003). Multiple studies show that with a decrease in muscle performance, a reduction in

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scapular posterior tilting occurs; however, these studies found variable effects of scapular upward and internal rotation (Borstad et al., 2009b; Ebaugh et al., 2006a, b; McQuade and Smidt, 1995; McQuade et al. 1998; Tsai et al. 2003). Weakness, and/or fatigue of the serratus anterior and the trapezius muscles may be responsible for a reduction in posterior tilting of the scapula and may be associated with degeneration of the rotator cuff (Borstad et al., 2009b). These muscles, when functioning properly, are believed to help maintain adequate space between the acromion process and the head of the humerus (Endo et al. 2001).While the direct effects of fatigue have been studied in the laboratory using various fatiguing protocols, the relationship between repetitive arm motions in the workplace and altered scapular kinematics remains unstudied. This would lead to great insights for understanding occupational shoulder injury risk and prevention.

Upper extremity MSDs in the workplace have been correlated with job longevity, where greater duration of work exposure yields a higher occurrence of injury (Akesson et al. 1999; Anton et al. 2002; Ohlsson et al., 1994). In a five-year longitudinal study, Akesson et al. found that the cumulative exposure to occupational demands in dental hygiene increased the risk of shoulder injury development (Akesson et al. 1999). Additionally, all dental hygienists who had left the profession during the five-year study had symptoms of upper extremity disorders. Anton et al. composed a survey of 109 practicing dental hygienists and the survey indicated that hygienists practicing for more than 22 years had significantly more symptoms of carpal tunnel syndrome as well as other upper extremity MSDs. Moreover, hygienists with less than 12 years of work experience had no pain-related complaints or symptoms of MSDs.

The present study uses biomechanical measures of shoulder motion (scapular kinematics), to investigate the effect of dental hygiene work. We hypothesize that scapular kinematics will be altered at the end of a workday in dental hygienists. Additionally, we hypothesize that hygienists with more years of work experience will demonstrate greater changes in scapular kinematics than less experienced hygienists.

2. Methods

2.1. Subjects

Thirty-four female dental hygienists with a mean age of 44 years (24–58 years), mean work experience of 17 years (2–38 years), mean height of 1.7 m, and mean mass of 70 kg participated in the study. On average, dental hygienists worked for 9 hours and treated 7 patients per day. A disability of the arm, shoulder and hand (DASH) work module questionnaire was given to all subjects (Kitis et al. 2009). The mean DASH score for dental hygienists was 9.5 out of 100 (SD 13.5). Groups based on experience were created to reflect findings from the literature, which demonstrated that hygienists with greater than 20 years of work experience have a higher occurrence of upper extremity disorders (Anton et al. 2002) (Table 2). Inclusion criteria required that subjects worked as dental hygienists for at least a year. Additionally, subjects were required to be currently working a minimum of 20 hours per week. No subjects were excluded from the study for shoulder related conditions although shoulder health history was obtained at the time of data collection. Prior to data collection all subjects signed written consent forms, which were approved by the University of Oregon's Institutional Review Board (IRB).

Data were collected before and after a typical workday for dental hygienists. Data were collected within the place of employment of the subject in order to minimize travel time and time between the end of a workday and kinematic measurements. Subjects arrived for data collection approximately one hour before their first patient arrived and were asked to stay one additional hour after their last patient left at the end of the day.

2.2. Instrumentation

The Polhemus Fastrak (Colchester, VT, USA) was used for collecting 3-D *in-vivo* kinematics of the shoulder complex at the workplace of the dental hygienists. The Polhemus unit consists of a transmitter, three receivers and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. The transmitter served as a global reference frame and was fixed to a rigid plastic base and oriented such that the coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the Polhemus were converted to anatomically appropriate coordinate systems based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology (Wu et al. 2005).

2.3. Set up and digitization

For digitization, subjects were asked to stand in a neutral position with their arms relaxed by their sides. Placement of sensors (receivers) was determined using methods previously validated (Karduna et al. 2001). Between sessions, all sensors were removed and repositioned for the second session. Placements of sensors were recorded using permanent marker. In addition, the sensors typically left an outline on the skin (from pressure) which helped determine sensor repositioning. All subjects were re-digitized during the second session and a new three-dimensional calibration matrix was created. The three receivers were placed on different body segments of the dominant side using double sided adhesive tape. The first receiver was placed on the thorax on the manubrium of the sternum at approximately the level of T3. The second receiver was positioned on the humerus by mounting it to an orthoplast device positioned on the proximal humerus with elastic straps. The final receiver was positioned over the scapula after mounting it on a custom scapular tracking device machined from plastic (Karduna et al. 2001). This tracker was attached to the scapular spine and posterior-lateral acromion with Velcro. The transmitter was then positioned approximately 30 cm behind the subject and was elevated to the height of their scapula using a non-metallic tripod. Anatomical landmarks were then digitized using the Polhemus stylus, for the thorax T8, xiphoid process, C7 and jugular notch. For the scapula the root of the scapular spine, inferior angle and posterior lateral boarder (acromial angle) of the scapula were digitized. For the humeral matrix, the medial and lateral epicondyles were digitized and the center of the humeral head was calculated. To calculate the center of the humeral head, the humerus was manipulated in small circular arcs within the mid-range of motion of the humerus. The center of the humeral head was defined by the point that moved the least with respect to the scapula through a least squares algorithm during humeral calibration (Karduna et al. 2001).

2.4. Experimental procedure

On the day prior to the data collection, subjects signed an informed consent form and completed a shoulder health history questionnaire (DASH). All other data, including total arm elevation exposure were collected before and after a typical workday for dental hygienists. The electromagnetic tracking device system was transported to each dental office to collect data within the workspace environment of the subjects. A metallic interference protocol was developed to ensure that each workspace was suitable for data collection and would not interfere with the electromagnetic tracking system. Prior to the kinematics protocol subjects performed a warm up that consisted of Codman's pendulum exercises to gently stretch the shoulder capsule (McClure et al. 2007). After the warm up, subjects removed all metallic objects and jewelry to eliminate interference. Once the digitization and calibration were completed, subjects completed three elevation trials. Each elevation trial consisted of the subject raising their dominant arm in the scapular plane (30° from the frontal plane) and returning along the same path to a count of four in each direction. Real-time angular feedback from the Polhemus Fastrack was observed by the researcher. From these observations, trials were repeated when the subject's arm elevation deviated from the scapular plane more than 5°. Data were collected continuously at a rate of 40 Hz for the three trials, and then were averaged for data analysis.

3. Data analysis

For the different scapular orientations, data were interpolated at the humeral elevation angles of 30°, 60°, 90° and 115°. Humeral angles were selected to represent the range of humeral elevation achieved by the entire study population; therefore 115° was the maximum range of humeral elevation selected.

Kinematic data were analyzed using a 3-way mixed effects analysis of variance (ANOVA) for each scapular rotation (anterior tilting, upward rotation and internal rotation), where humeral elevation angle and time of workday (pre versus post workday) were treated as within-subject factors and group was treated as the between-subjects condition based on work experience (greater than and less than 20 years of working exposure). Significance was set at $P<0.05$ and post hoc tests were run where statistically significant interactions were noted.

4. Results

From a plot of the distribution of scapular kinematic motion, data were considered approximately normal. For scapular tilting, a significant interaction was found between workday (pre–post) and group ($P=0.043$). For scapular tilting, no significant interactions were found between humeral elevation angle and group ($P=0.369$) or for humeral elevation angle and workday ($P=0.873$) (Table 1). For post hoc analysis, scapular tilting angles were averaged by humeral elevation as humeral elevation had no effect on workday or group.

Table 1
Three way analysis of variance table for the effects of workday, arm elevation angle and years of experience on scapular kinematics.

Scapular rotation	*ANOVA factor*	*df*	F-ratio	*P*-value
Anterior tilt	Workday	1	4.796	0.036*
	Elevation angle	3	12.729	0.001*
	Workday × elevation	5	0.232	0.873
	Workday × experience	3	4.425	0.043*
	Elevation angle × experience	5	1.088	0.369
	Workday × experience × elevation angle	7	2.285	0.090
Upward rotation	Workday	1	0.283	0.599
	Elevation angle	3	393.350	0.001*
	Workday × elevation	5	0.091	0.964
	Workday × experience	3	4.458	0.503
	Elevation angle × experience	5	0.943	0.432
	Workday × experience × elevation angle	7	1.219	0.080
Internal rotation	Workday	1	0.001	0.985
	Elevation angle	3	4.410	0.011*
	Workday × elevation	5	0.761	0.525
	Workday × experience	3	0.062	0.804
	Elevation angle × experience	5	1.067	0.378
	Workday × experience × elevation angle	7	1.219	0.320

Note. * indicates statistical significance where $P<.05$.

Table 2
Mean and standard errors scapular anterior tilting by workday and years of experience.

Group	Pre workday mean (SD)	Post workday mean (SD)	*P*-value	N	Age	Experience	DASH mean (SD)
> 20 years	5.5° (1.9°)	11.9° (2°)	.008 *	14	49.0	26.7	7.35 (2.7)
< 20 years	6.5° (2.1°)	6.7° (1.8°)	.951	20	39.1	10.1	12.5 (4.1)

Note. * indicates significance where $p<.05$

The results of the post hoc independent sample t-tests indicate that hygienists with greater than 20 years of work experience have significantly more ($P=0.008$) scapular anterior tilting post workday (Table 2). However, hygienists with less than 20 years of work experience had no significant changes ($P=0.951$) in scapular tilting post workday (Table 2). No significant interactions or main effects (other than by humeral elevation angle) were found for scapular upward or internal rotation (Table 1).

5. Discussion

The results of our study indicate that dental hygienists have significant changes in scapular tilting at the end of the workday that is affected by job longevity. It has been postulated that weakness and or fatigue of the serratus anterior muscle and overall tightness of pectoralis minor is associated with increases in scapular anterior tilting especially in patients with shoulder impingement syndrome and those who are exposed to occupational overhead work (Borstad et al., 2009b; Ludewig and Cook 2000; McClure et al. 2004). Based on our results, and especially for hygienists with greater total work experience, we speculate that post workday anterior tilting may be due to fatigue of the serratus anterior muscle and over compensation of the pectoralis minor muscles. It should be noted that workday fatigue was not measured; however, based on the total number of hours worked and the number of patients seen, it is likely that dental hygienists experienced some level of workday fatigue.

The three main risk factors that lead to the development of MSDs in the workplace are force (intensity and duration), posture (awkward and constrained) and repetition (Bernard, 1997). The total number of years of work exposure has additionally been suggested as an occupational risk factor in MSDs, where dental hygienists with more than 20 years of work exposure have significantly more complaints of musculoskeletal pain (Anton et al. 2002). Our data suggest that hygienists with more than 20 years of work exposure experienced significant changes in scapular anterior tilting post workday. Dental hygienists with less than 20 years of work exposure, demonstrated no significant changes in scapular kinematics at the end of a workday. Upper extremity MSDs in dental hygienists may therefore be associated with changes in scapular kinematics that occur during a workday and cumulate over a lifetime of work.

Not all muscle fatigue paradigms should be considered the same when measuring scapular kinematics. A review of the literature regarding shoulder fatigue and its influences on scapular kinematics in lab based studies suggests that all three scapular rotations can be temporarily altered depending on which fatiguing protocol is implemented (Borstad et al., 2009b; Ebaugh et al., 2006a, b; McQuade et al. 1998; Tsai et al. 2003). A discrepancy in the literature exists as to which scapular rotations are most affected by fatigue and to what extent (Table 3) (Borstad et al., 2009b; Ebaugh et al., 2006a, 2006b; McQuade et al. 1998; Tsai et al. 2003). Regardless of the fatiguing protocol, scapular tilting seems to be the most consistently altered scapular rotation (Borstad et al., 2009b; Ebaugh et al., 2006b; Tsai et al. 2003). In studies where scapular anterior tilting was increased, the average change from pre- to post fatigue was 4° across humeral elevation angles (Borstad et al., 2009b; Ebaugh et al., 2006b; Tsai et al.

Table 3
Discrepancies in the literature regarding fatigue and altered scapular kinematics.

Author	Year	Internal rotation	Upward rotation	Posterior tilting	Fatiguing protocol
McQuade	1998	Not reported	Decreased	Not reported	Dynamic shoulder elevation
Tsai	2003	Increased	Decreased	Decreased	Dynamic external rotator
Ebaugh	2006	Decreased	Increased	No change	Dynamic shoulder Elevation
Ebaugh	2006	Decreased	Increased	Decreased	Dynamic external rotator
Borstad	2009	Increased	No change	Decreased	Isometric push up plus
Ettinger	2011	No change	No change	Decreased	Workday

2003). In a study conducted by Borstad et al., serratus anterior muscle fatigue was induced by using an isometric fatiguing protocol. They suggest that if the fatiguing protocol is isometric versus dynamic, fewer rotations of the scapula are affected. They found that scapular tilting and scapular internal rotation were altered post fatigue; however, scapular upward rotation was unaffected (Borstad et al., 2009b). The only rotation that was altered in the present study was scapular tilting. Our findings seem to support the observations made by Marklin et al., and Oburg et al., who observed that for dental hygienists, the demands of the workplace often require low-level isometric loads of the shoulder (Akesson et al. 1999; Marklin and Cherney 2005). Unlike previous studies which induced muscle specific fatigue, our subjects likely had variable amounts of fatigue within various muscles. Dental hygienists may experience post workday fatigue differently based on the various working styles, number of patients seen, difficulty of patients and total number of years of work exposure. However, for direct comparisons to other fatigue studies, electromyography (EMG) should be used to determine muscle specific fatigued induced by work.

Anton et al., described dental hygienists with greater than 22 years of work exposure as having a higher incidence of upper extremities injuries (Anton et al. 2002). Results of our study suggest that dental hygienists with greater than 20 years of work exposure had a 5.2° change in scapular tilt where the less experienced cohort had no changes in scapular tilt. Scapular anterior tilting may have an association with work-related symptoms of the shoulder due to the narrowing of the subacromial space (Zuckerman and Cuorno, 1992). The change in scapular tilting in the greater than 20 years work experience cohort are similar in magnitude and direction to differences reported by Ludwig et al., in patients diagnosed with shoulder impingement syndrome (Ludewig and Cook 2000). While the source of symptoms of shoulder impingement syndrome is believed to be a degeneration of the rotator cuff tendons and bursa within the subacromial space, the actual cause of degeneration is debated (Neer 1972). Localized ischemia is thought to occur as a result of the compression forces exerted on the subacromial tissues. However, based on rat model experiments by Soslowsky et al., external compression alone may not suffice to produce tendon degeneration. Their data suggest that external compression must be combined with prolonged overuse to produce tendinous breakdown (Soslowsky et al., 2002).

Strengthening interventions and ergonomic modifications may be necessary to help reduce the possibility of workday fatigue in dental hygienists. In a study conducted by Borstad et al., a one-year long exercise intervention was given to workers in the construction industry. Exercises included multiple stretching and strengthening exercises of the serratus anterior and pectoralis minor muscles. Subjects stretched daily and performed strengthening exercises every other day. Results from their study indicated that new-onset cases of shoulder pain were greater in the group that did not receive the home exercise program than in the intervention group (Borstad et al., 2009a). It is possible that dental hygienists could benefit from a similar exercise program. Furthermore, hygienists should be mindful of their working posture and incorporate breaks where necessary to avoid prolonged static postures. Ergonomic modifications to work station layout or patient scheduling may also be necessary in order to reduce the physical loads and demands of the dental worker. In addition, ergonomic devices and proper equipment may help to limit the amount of time hygienists spend with their extremities in static abduction and elevation.

6. Limitations

Each dental hygienist was exposed to variable degrees of work during their workday and fatigue was not directly measured. We did not attempt to control for the number of patients seen, the types of patients seen or other potentially confounding factors associated with their workday. However, all dental hygienists reported that their workday was typical in length and in total number of patients treated. All data were collected within the workspace of the dental hygienists as an attempt to limit the time from work cessation to data collection; however, this amount of time is variable between subjects and could potentially affect our results.

Conflict of interest statement

There were no conflicts of interest with any financial or personal relationships that could influence or bias this work.

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