Pinch Forces and Instrument Tip Forces During Periodontal Scaling

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Background: The prevalence of upper-extremity musculoskeletal disorders, such as tendinitis, is elevated among dental practitioners. An important risk factor for these disorders is forceful pinching; however, the pinch forces and instrument forces during scaling are unknown.

Methods: Six dentists and six senior-year dental students were recruited to use an instrumented periodontal scaler to perform their usual dental scaling work on patients. Thumb pinch force was measured by a pressure sensor, whereas the forces developed at the instrument tip were measured by a six-axis load cell.

Results: Dental students applied greater mean peak pinch force (35.7 ± 3.8 N) compared to dentists (24.5 ± 4.1 N) (P = 0.001). On the other hand, the peak forces generated at the instrument tip, which were directly related to the productivity of the dental scaling task, were higher among the dentists. The application of pinch force by dentists was related to the required scaling forces, whereas students applied excessive pinch force to the tools.

Conclusions: Increased experience in periodontal scaling leads to the application of less pinch force to accomplish scaling. Nonetheless, the applied peak pinch forces in both groups are high and may pose a risk for the development of musculoskeletal disorders of the distal upper extremity. *J Periodontol 2007;78:97-103.*

KEY WORDS

Dental scaling; ergonomics; tendinitis.

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Dentistry is a specialized field in health care that requires repetitive motions of the fingers and wrists, forceful pinching, and prolonged awkward postures. Dental practitioners have a high prevalence of work-related musculoskeletal disorders in the neck, shoulders, upper extremities, and lower back.[1,2] A 1997 survey by the American Dental Association[3] reported that 9.2% of dentists had been diagnosed by a physician as having an upper-extremity musculoskeletal disorder; of this group, ~20% required surgery and >40% reduced their work hours.

Upper-extremity musculoskeletal disorders are the most common and debilitating occupational disorders associated with the profession of dentistry and dental hygiene.[4-11] Rice et al.[12] compared three categories of dental workers (dentists, dental hygienists, and dental assistants) and found that dental hygienists were at the greatest risk for developing upper-extremity musculoskeletal disorders due to the long hours of dental scaling and root planing work. Upper-extremity musculoskeletal disorders are common among dental hygienists; the prevalence of carpal tunnel syndrome ranges from 6% to 8.5%.[13-18] The Bureau of Labor Statistics reported in 1998 that dental hygiene ranked the first among all occupations in the United States in the number of carpal tunnel syndrome cases per 1,000 employees.[19] Akesson et al.[11] assessed musculoskeletal symptoms among female dental personnel in a 5-year follow-up study and concluded

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that painful and persistent symptoms related to carpal tunnel syndrome and other work-related musculoskeletal disorders would lead dental practitioners to select a different occupation.

Carpal tunnel syndrome and wrist tendinitis are associated with personal and occupational risk factors. Work-related risk factors include repetitive forceful pinching or gripping, sustained non-neutral wrist positions, and use of vibrating tools.[20-23] Periodontal scaling and root planing poses an elevated risk for developing musculoskeletal disorders. The work requires repeated high pinch forces. According to a study by Bramson et al.,[24] the average pinch forces exerted during dental scaling were 11% to 20% percent of the maximum pinch strength, as estimated by electromyography. Another study by Zappa et al.[25] reported that the forces exerted during scaling ranged from 1.01 to 10.35 N with a mean of 5.70 N among 10 dentists. Among 10 dental hygienists, the corresponding values ranged from 1.5 to 15.73 N with a mean of 5.38 N. However, no one has simultaneously collected pinch force and instrument tip forces during periodontal scaling on patients.

The purpose of this study was to compare the peak pinch force patterns during scaling between experienced dentists and dental students and determine whether peak thumb pinch force was related to the forces generated at the instrument tip. The hypothesis was that those with greater experience performing scaling apply lower peak pinch forces than those with less experience.

MATERIALS AND METHODS

Twelve dental provider-patient pairs participated in the study from March through June 2005. The dental providers (dentists and senior-year dental students) were recruited from two community clinics in Oakland, California. All of the dentists had ≥2 years of experience in dental scaling, whereas the dental students had <2 years of experience. None of the providers reported having had injuries or previous surgeries in the hand and wrist area. Patients were recruited from the same clinics. All patients had moderate to heavy calculus based on radiographic and clinical examinations; patients were evenly distributed between dentists and students by level of disease. Informed consent from both the providers and the patients was obtained prior to data collection. The study was approved by the Committee on Human Research at the University of California, San Francisco.

The providers were instructed to use a specially designed instrument (Fig. 1) to perform scaling and practiced with the instrument for 20 minutes prior to use with a patient. The instrument handle‖ has a diameter of 8.5 mm. A six-axis load cell¶ (error range ± 0.1 N) was incorporated into the instrument so that the forces and moments at the tip of the instrument during the scaling procedure could be measured. In addition, a custom-designed pressure sensor# was attached to the surface of the instrument to measure thumb pinch force. The thin sensor (0.58 mm) covered approximately one-quarter of the circumference of the instrument and extended 29 mm along the axis of the instrument surface in the region that is pinched. The sensor pad was secured on the handle surface with a latex sleeve, which allowed the pad to be adjusted so that the thumb of the operator could be placed in the middle of the sensor pad. The sensor measured total integrated pressure (i.e., force generated within the surface). The six-axis load cell was also used to develop a second-order calibration equation to convert the pinch sensor output into newtons. The estimated pinch force error due to the regional sensitivity of the sensor was ± 4.9%. The mean error due to time drift was 3.5% per 30 seconds. All data were collected at 100 Hz using specialized software through a data acquisition card** on a notebook computer.

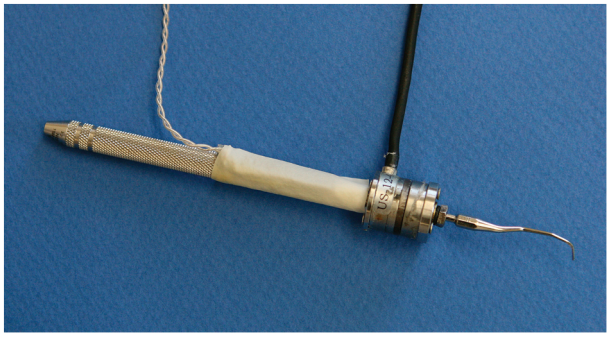

Figure 1.
A periodontal scaler (8.5-mm handle diameter) was modified by adding a six-axis load cell between the handle and the tip and mounting a pinch force sensor on the handle.

Gracey number 11 curet tips were used for scaling. Providers were instructed to perform scaling in eight areas of the dentition: distal-facial and mesial-lingual surfaces of tooth #3, distal-lingual and mesial-facial surfaces of tooth #14, distal-facial and mesial-lingual surfaces of tooth #19, and distal-lingual and mesial-facial surfaces of tooth #30. Although the Gracey 11 curet is designed for instrumentation of the mesial aspect of the posterior teeth, it can be adapted for instrumentation of the distal aspect by changing the hand and wrist positions of the operator as long as the curvature of the curet tip matches that of the tooth surface. A new, sharp curet tip was used for each subject.

‖ Hu-Friedy, Chicago, IL.
¶ ATT Industrial Automaton, Apex, NC.
# ConTacts Pressure Profile Systems, Los Angeles, CA.
** Lab View, National Instruments, Austin, TX.

During scaling, force data were recorded separately for each of the eight areas of the dentition. Before scaling in each area, the provider was allowed to assume her or his most typical and comfortable position to hold the instrument. The sensor pad was then adjusted to allow the thumb to be placed in the middle of the sensor pad. Baseline force measures were recorded before scaling, while no force was applied on the sensor pad. The provider was then instructed to begin scaling, and ~1 minute of the scaling process was recorded. When scaling was completed, the subject was instructed again to hold the instrument without applying any force, while the baseline force measures were recorded again.

The load cell and pressure sensor data were converted to force. The pinch force was represented by F_p. The load cell output along the long axis of the instrument, F_z, represented the push (–) and pull (+) forces applied at the tip. The absolute value of F_z was used for subsequent analyses. The force at the tip, which was perpendicular to the long axis of the tool, F_t, was calculated as the geometric sum of the two moment outputs about the two axes perpendicular to the long axis of the tool divided by the distance between the load cell and the tip of the instrument. Because the long axis of the instrument was roughly parallel to the tooth surface during scaling, F_t estimated the force applied perpendicular to the tooth surface during scaling.

Summary measures of F_p, F_z, and F_t were calculated from a randomly selected 10-second period of the force history for each tooth, using amplitude probability distribution functions (APDFs). APDF values at the 50% and 90% levels represent summary measures that estimate the median and peak force values.[26]

Statistical analysis was performed with a statistical program.†† Analysis of variance with repeated measures (RMANOVA) was used to evaluate the effect of gender, experience, and tooth area on the summary force measures. Significant findings were followed-up with pair-wise comparisons using the Tukey method to adjust for multiple comparisons. The relationships between thumb pinch force (F_p) and the forces at the instrument tip (F_z and F_t) were analyzed using the linear regression methods.

RESULTS

Twelve dental providers (six dentists and six senior-year dental students) along with 12 patients participated in the study. Among the participating dentists, there were five females and one male, whereas among the students, there were three males and three females. The average age of the dentists was 40.5 ± 7.7 years, and the average age of the students was 29.8 ± 3.3 years. All of the dentists had ≥2 years of experience in dental scaling, whereas the dental students had <2 years of experience.

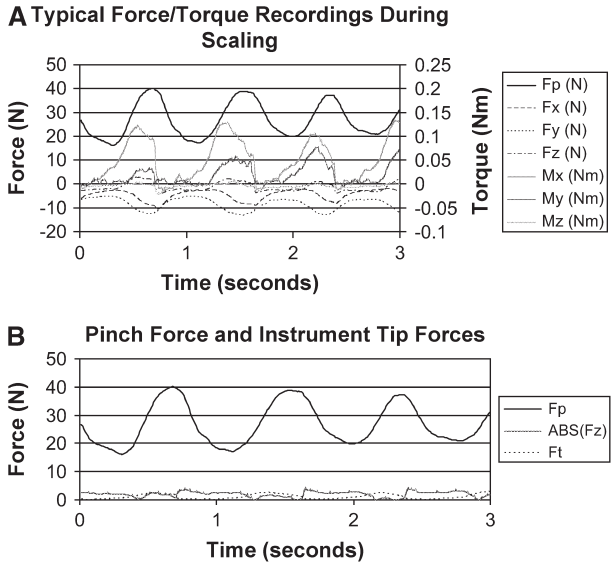

Figure 2.
A) *Typical force-torque recordings from one subject. F_p is the thumb pinch force recorded by the sensor; F_x, F_y, and F_z are forces recorded by the six-axis load cell; M_x, M_y, and M_z are torques recorded by the six-axis load cell.* ***B)*** *Pinch force and instrument tip forces (calculated from the recordings) during the same period of time.*

An example of the force history during scaling is presented in Figure 2. In this recording, pinch force fluctuated between 15 and 40 N and each fluctuation corresponded to a pull stroke of the scaling task. The fluctuations in forces and torques recorded by the six-axis load cell also roughly correlated with the strokes of the scaling motion.

Summary measures of forces by experience and tooth area are presented in Figures 3 through 5. Compared to the dentists, dental students applied more thumb pinch force during scaling, as reflected by the peak and median pinch force measures (Fig. 3); however, the median forces generated at the instrument tip (F_z and F_t) were higher among dentists (Figs. 4 and 5). Summary measures of forces are presented in Table 1. Statistical analysis with RMANOVA (Table 2) showed that gender had no significant effects on peak or median force measures. Experience (dentist versus dental student) had significant effects on the peak and median pinch force (F_p). Experience also had an effect on median F_t and a borderline effect on median F_z ($P = 0.06$). Tooth area had significant effects on peak and median F_t.

To examine whether linear relationships existed between the pinch force and the forces generated at the instrument tip (F_z and F_t), the peak (APDF 90) values

†† SAS System for Windows V8 software, SAS, Cary, NC.

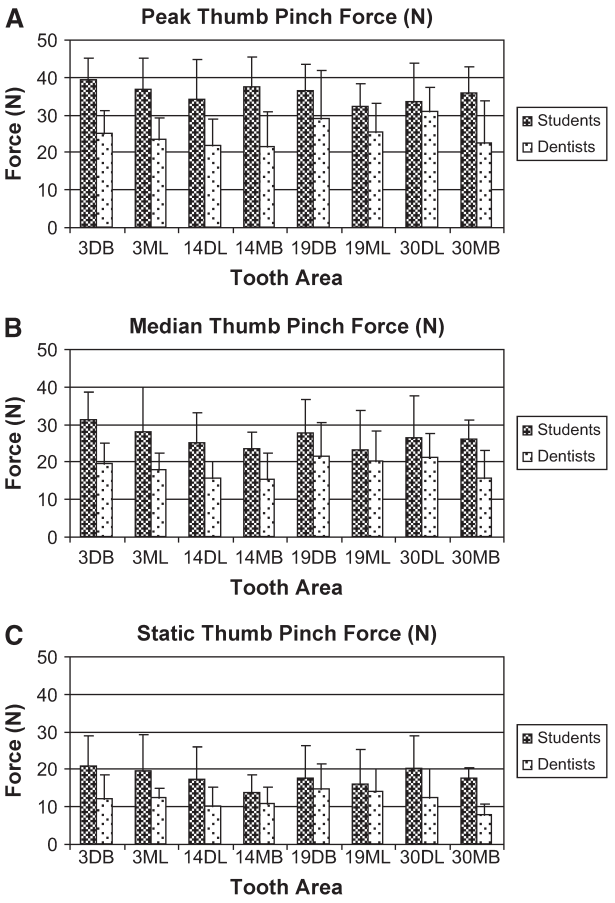

Figure 3.
Thumb pinch force by tooth area and group. ***A)*** *Peak.* ***B)*** *Median.* ***C)*** *Static.*

of the force measurements were fitted to the following multiple linear equation:

$$F_p = a_0 + a_1E + a_2F_z + a_3F_t,$$

where E represented experience and was a binary variable (E = 0 for student; E =1 for dentist); a_0, a_1, a_2, and a_3 were constants.

The results showed that linear relationships existed between the peak pinch force (F_p) and the peak forces generated at the instrument tip ($R^2 = 0.41$; $P = 0.004$ and 0.02 for F_z and F_t, respectively; $a_0 = 36.7 \pm 2.0$, $a_1 = -12.6 \pm 1.7$, $a_2 = -1.0 \pm 0.3$, and $a_3 = 1.5 \pm 0.6$).

The data were then stratified by experience (dentists versus students) to fit to the following equation:

$$F_p = a_0 + a_2F_z + a_3F_t.$$

Among the dentists, similar linear relationships existed ($R^2 = 0.20$; $P = 0.01$ and 0.03 for F_z and F_t, respectively; $a_0 = 23.3 \pm 2.7$, $a_2 = -1.1 \pm 0.4$, and $a_3 = 1.9 \pm 0.8$); however, the linear relationships were not statistically significant among the students ($R^2 = 0.08$; $P = 0.2$ and 0.3 for F_z and F_t, respectively).

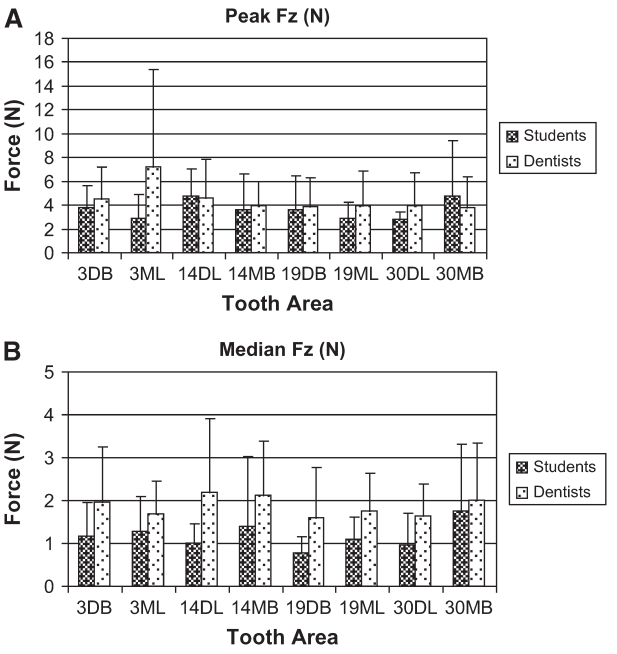

Figure 4.
Mean push and pull force along the long axis of the instrument at the instrument tip (absolute value of F_z) by tooth and group. ***A)*** *Peak.* ***B)*** *Median.*

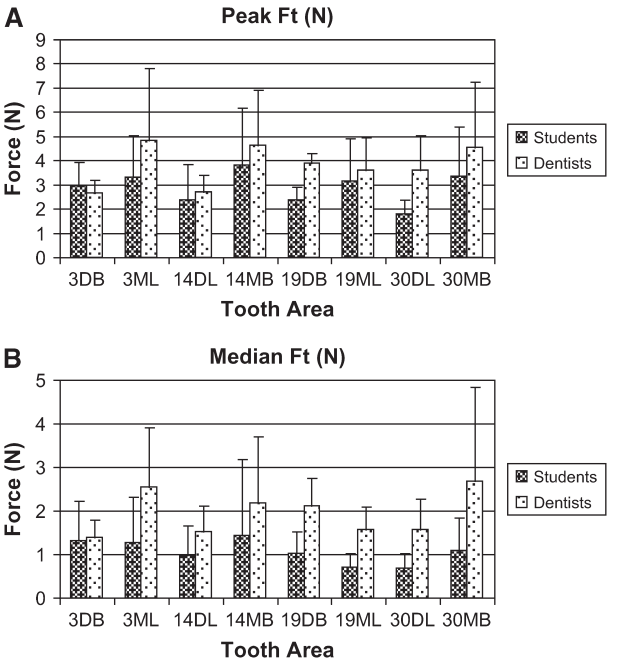

Figure 5.
Mean force perpendicular to the long axis of the instrument at the instrument tip (F_t) by tooth and group. ***A)*** *Peak.* ***B)*** *Median.*

Similar multiple linear models were used to examine whether linear relationships existed between the median pinch force (APDF 50) and the median forces generated at the instrument tip (F_z and F_t). Statistically

Table 1.

Summary Table of Force Measurements in Newtons (±SD) by Group (dentists and students)

	Students	Dentists
F_p peak	35.7 ± 3.8	24.5 ± 4.1
F_p median	26.3 ± 7.1	18.0 ± 2.7
F_p static	17.8 ± 6.8	11.5 ± 2.4
F_z peak	3.6 ± 2.1	4.5 ± 1.8
F_z median	1.2 ± 0.7	1.9 ± 0.8
F_t peak	2.9 ± 1.3	3.8 ± 1.1
F_t median	1.1 ± 0.7	1.9 ± 0.7

significant linear associations were not found in these models, although among the dentists a somewhat linear association was observed between F_p and F_z ($R^2 = 0.13$; $P = 0.09$).

DISCUSSION

This study demonstrated that dental students and experienced dentists applied pinch force in different patterns during dental scaling. Dental students applied ~46% more peak pinch force than the dentists. On the other hand, the forces generated at the instrument tip (F_z and F_t), which were directly related to the productivity of the dental scaling task, were significantly higher among the dentists. Hence, experienced dental practitioners were more efficient in the transfer of pinch force into useful forces at the instrument tip, whereas the dental students applied excessive pinch force. The results demonstrated some variations in F_t by tooth area, with higher F_t values on the mesial aspect of the teeth compared to the distal aspect. This may be caused by the lower pinch strength of the index and middle fingers compared to the thumb.

Repetitive forceful pinching or gripping is a risk factor for the development of carpal tunnel syndrome and other distal upper-extremity musculoskeletal disorders. Roquelaure et al.[21] demonstrated an increased risk for carpal tunnel syndrome (odds ratio [OR] = 9.0, confidence interval [CI] = 2.4 to 33.4) due to repetitive tasks (cycle time <10 seconds) involving a pinch force of more than 10 N. Silverstein et al.[27] reported an increased risk for carpal tunnel syndrome for repetitive tasks involving a pinch force of more than 40 N. This study demonstrated that while performing dental scaling on patients, the mean peak pinch force applied by dental students was 35.7 ± 3.8 N, and for dentists it was 24.5 ± 4.1 N. These force measures were comparable to the data from our previous laboratory studies on simulated dental scaling, which showed the mean peak pinch force of 22.6 ± 3.3 N when experienced dentists and hygienists used a regular dental scaling instrument with a 10-mm handle.[28]

Among the experienced practitioners, there was a moderately linear association between the thumb pinch force and the forces at the instrument tip, whereas among dental students there was no association. The pinch force patterns were more predictable among the dentists than among the dental students. The thumb pinch force applied by dental students was not related to the required forces at the instrument tip to accomplish the scaling task; the extra pinch force was more likely caused by the inability to efficiently transform pinch force to the useful forces at the instrument tip.

Because of a small sample size, some differences of the force measurements (e.g., the static pinch force and the median F_z) did not achieve statistical significance, although the data demonstrated a trend. Another limitation of the study was the bulkiness of the load cell, which may have caused the operators to alter their normal finger positions during scaling. It

Table 2.

The Statistical Effects of Gender, Experience, and Tooth Area on Six Measurements Using RMANOVA

	Thumb Pinch Force		Force at Instrument Tip			
			F_z		F_t	
	Peak	Median	Peak	Median	Peak	Median
Gender	0.17	0.17	0.63	0.41	0.95	0.61
Experience	0.001	0.03	0.31	0.06	0.17	0.009
Tooth area	0.9	0.34	0.79	0.19	0.01	0.05

Values shown are *P* values.

may be worthwhile to measure pinch force with an instrument that does not have the load cell on the end.

Rising et al.[29] studied body pain among dental students; >70% of both genders reported musculoskeletal pain by their third year in dental school. The authors concluded that chronic musculoskeletal pain appeared early in dental careers, and dental educators should further examine the mental, physical, and ergonomic factors that could be contributory. The present study identified an important ergonomic factor that may contribute to the early development of musculoskeletal symptoms among dental practitioners in training: the inability to efficiently transform pinch force to the useful forces at the instrument tip leads to increased pinch force. Applying excessive pinch force may cause the development of musculoskeletal symptoms and disorders in the hand, wrist, or elbow. Dental students and dental hygiene students should be taught how to manipulate the instruments more efficiently by experienced instructors during the early phase of their training programs.

Thornton et al.[30] noted that dental students experienced various physical and psychosocial stressors during their training in dental school. A survey conducted by the American Dental Association revealed that 62% of dentists in private practice stated they received inadequate training on the applications of ergonomics when attending dental school.[31] Although didactic trainings on biomechanics and occupational stress have been included in the dental curriculum as early as 1995,[32] reinforcement of biomechanics at the clinical level was largely overlooked by dental educators. A focus on didactic training in biomechanical principles, followed by practical application of the principles at the clinical level, may help reduce the risk for developing musculoskeletal symptoms among dental and dental hygiene students. The biomechanical principles may include specific training on reducing peak pinch force during scaling, relaxing the pinch grip between tooth areas, and knowledge of the proper orientation of tool tip to tooth surface.

Although the dentists applied less pinch force than students, the forces among dentists were also high and may pose a risk for carpal tunnel syndrome and other hand and wrist disorders. To reduce the risk of developing work-related musculoskeletal disorders, dental providers who spend much of their work time on manual scaling should select appropriate instruments and modify their work practice by carefully scheduling patients with heavy calculus and taking appropriate breaks.

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