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ABSTRACT

Background. In comparison with people in other occupations, dentists and dental hygienists are at increased risk of developing work-related musculoskeletal disorders, including carpal tunnel syndrome. An important risk factor in dental practice is forceful pinching, which occurs during dental scaling. Ergonomically designed dental instruments may help reduce the prevalence of MSDs among dental practitioners.

Methods. In the authors' study, 24 dentists and dental hygienists used 10 custom-designed dental scaling instruments with different handle diameters and weights to perform a simulated scaling task. The authors recorded the muscle activity of two extensors and two flexors in the forearm with electromyography, while thumb pinch force was measured by pressure sensors.

Results. Handle designs of periodontal instruments had significant ($P < .05$) effects on hand muscle load and pinch force during a manual scaling task. The instrument with a large diameter (10 millimeters) and a light weight (15 grams) required the least amount of muscle load and pinch force. There was a limit to the effect of handle diameter, with diameters larger than 10 mm having no additional benefit; however, the study did not identify a limit to the effect of reducing the weight of the instrument, and therefore instruments lighter than 15 g may require even less pinch force.

Clinical Implications. The results from this study can guide dentists and dental hygienists in selection of dental scaling instruments.

Key Words. Periodontal instruments; tool design; ergonomics; electromyography; musculoskeletal disorders; carpal tunnel syndrome.

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Work-related upper extremity musculoskeletal disorders (MSDs) are among the most common and debilitating occupational disorders associated with the profession of dentistry.[1-8] A 1997 survey by the American Dental Association[9] reported that 9.2 percent of dentists had been diagnosed by a physician as having an MSD; of this group, approximately 20 percent required surgery and more than 40 percent reduced their work hours.

Both dentists and dental hygienists may be affected by work-related MSDs. Rice and colleagues[10] conducted a study to compare three categories of dental workers—dentists, dental hygienists and dental assistants—and found that dental hygienists were at the greatest risk of developing upper-extremity MSDs owing to the high volume of dental scaling and root-planing work they carried out. MSDs, especially carpal tunnel syndrome (CTS), are common among dental hygienists[11-14]; the prevalence ranges from 6 to 8.5 percent.[11,15-17] The U.S. Bureau of Labor Statistics reported in 1998 that dental hygiene ranked the first among all occupations in the United States in the number of CTS cases per 1,000 employees.[16] Akesson and colleagues[8] assessed musculoskeletal symptoms among female dental personnel in a five-year follow-up study and concluded that painful and per-

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sistent symptoms related to CTS and other MSDs would lead to employees' leaving the profession.

CTS is associated with a number of personal and occupational risk factors. Nonoccupational risk factors include female sex, age, obesity, diabetes, pregnancy, rheumatoid arthritis and wrist fracture.[18-22] Work-related risk factors include repetitive forceful pinching or gripping, sustained nonneutral wrist positions and use of vibrating tools.[19,23-25] Periodontal scaling and root planing may pose an elevated risk of developing CTS. The work requires a high level of pinch force; the average pinch force exerted during dental scaling is 11 to 20 percent of the maximum pinch strength.[26] In addition, gaining and maintaining access to some areas of the oral cavity may require the wrists to be held in awkward positions for prolonged periods.

The literature on the ergonomic design of nonpowered dental instruments is limited. Most of the research has been related to endodontic instruments.[27-30] Ozawa and colleagues[31] used electromyography (EMG) to examine the effects of endodontic instrument handle diameter (3.5 to 6.0 millimeters) on forearm muscle activity, and they found the working time needed to negotiate the canal, the integrated EMG area of each muscle and the maximum amplitude of EMG from the flexor pollicis brevis all improved (that is, decreased) with the increase of handle diameter.

Dental scaling requires hand motions different from those used in endodontic treatment; the instrument is pulled rather than rotated. However, both types of instruments require precision and a high level of pinch force. Most other nonpowered hand instruments used routinely in dentistry, such as hoes and gingival margin trimmers, require a similar type of pinch grip and finger action as do periodontal instruments. Investigating handle design options for nonpowered periodontal instruments may provide useful information on how to reduce the risk of developing upper-extremity MSDs related to dental practice. Therefore, we conducted a study to evaluate the effects of periodontal instrument handle diameter and weight on hand muscle load and pinch force in a simulated dental scaling task.

MATERIALS AND METHODS

In this laboratory study, we recruited dentists and dental hygienists who had experience in performing scaling from community and private dental clinics in the San Francisco Bay area. We excluded from the study potential subjects who had recent hand or wrist injuries, previous surgeries in the hand or wrist area or physician-diagnosed upper-extremity MSDs. Owing to limitations of the experimental apparatus, we also excluded people with a dominant left hand. The study was approved by the Committee of Human Research at the University of California, San Francisco.

Ten custom-designed handles were used in the study (Figure 1; Table 1); we organized the 10 tools into three groups for later data analysis. The diameters ranged from 7 to 11.5 mm; the total weights (handle with tips) ranged from 15 to 24 grams. The handles were machined in our laboratory of either aluminum or stainless steel to achieve the desired weights. The ends of the handles were threaded to fit Gracey no. 11 curette tips (Hu-Friedy, Chicago).

The subjects performed dental scaling on a typodont fitted into a manikin head (Columbia Dental, New York City), which was positioned to simulate clinical situations (Figure 2). All teeth used in the study were plastic lower right second premolars (tooth no. 29). We painted the same cervical portion of each tooth with nail polish to simulate plaque and calculus deposits. The painted area included the surface between the facial midline and the mesial contact with tooth no. 28, apical to the contact area and coronal to the gingiva. To standardize the painting process, we placed a paint mask on the tooth surface before applying the paint.

We used surface bipolar EMG recordings to measure muscle activity during the dental scaling task (Figure 2). We used circular silver–silver chloride electrodes with an active diameter of 8 mm and a center-to-center distance of 21 mm. We amplified the EMG signals with preamplifiers and an adjustable-gain amplifier. The amplifier produced the root mean square (RMS) of the EMG signal using a 55-millisecond time constant (Therapeutics Unlimited, Iowa City, Iowa). We collected data at 100 hertz using LabView software (National Instruments, Austin, Texas) through a data acquisition card (National Instruments) on a notebook computer.

We localized sites on each subject's right forearm for the placement of the electrodes using recommended anatomical placement.[32] We studied four extrinsic hand muscles that experience high loads during a sustained pinch: the flexor digitorum superficialis, the flexor pollicis longus, the extensor digitorum communis and the extensor carpi radialis brevis. We placed a ground electrode

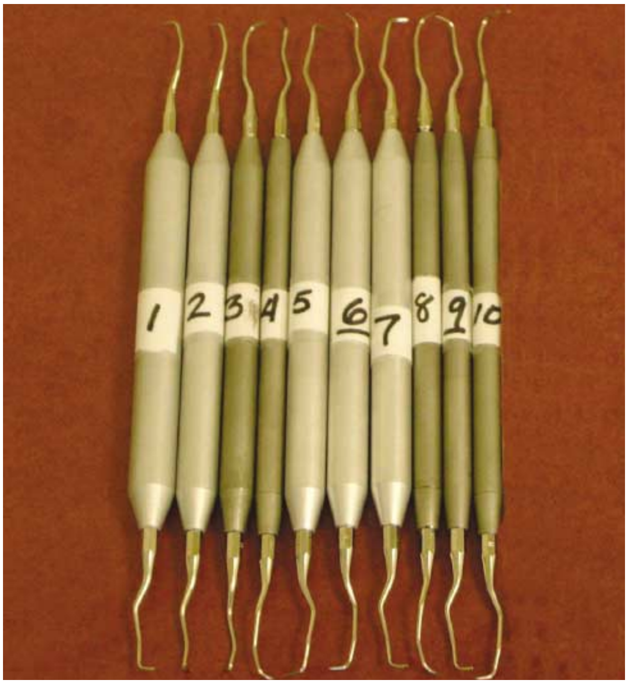

Figure 1. The 10 instruments used in the study. Gracey no. 11 curette tips were manufactured by Hu-Friedy (Chicago). Image of Gracey curette tips reproduced with permission of Hu-Friedy.

Figure 2. Simulated dental scaling, showing manikin positioned to simulate the clinical situations, and surface electrodes attached to the right forearm of the subject.

over the lateral epicondyle. Before the subjects performed the dental scaling tasks, we recorded maximum voluntary contractions (MVCs) of the four muscles. Subsequently, we normalized all EMG signals as a percentage of the MVCs.

In addition to EMG measurement, we attached a custom-designed pressure sensor (ConTacts, Pressure Profile Systems, Los Angeles) to the surface of each instrument to measure thumb pinch force. The thin sensor (0.58 mm) covered approximately one-fourth of the circumference of the instrument and extended 29 mm along the axis of the instrument surface in the region that is pinched. We instructed subjects to place their thumbs directly onto the sensor pad. The sensor measures total integrated pressure—that is, force generated within a surface. A six-axis load cell (ATI Industrial Automation, Apex, N.C.) (error range ± a standard deviation [SD] of 0.1 newton) was used to develop a second order calibration equation to convert the sensor volt output into newtons. The estimated pinch force error due to the regional sensitivity of the sensor was ± an SD of 4.9 percent. The mean error due to time drift was 3.5 percent per 30 seconds, which was the time most subjects needed to complete the scaling task.

TABLE 1

Characteristics of the 10 instrument handles.

GROUP	TOOL	DIAMETER (mm*)	TOTAL WEIGHT (g†)
1	1 2 3 4	11.5 10 8.5 7	24 24 24 24
2	2 5 6 7	10 10 10 10	24 21 18 15
3	4 8 9 10	7 7 7 7	24 21 18 15

* mm: Millimeters.
† g: Grams.

We calculated amplitude probability distribution functions (APDFs) for the EMG and thumb pinch force from a 30-second window of the recorded data. APDF values at the 10 percent, 50 percent and 90 percent level are summary measures equivalent to the static, median and peak values, respectively, of the EMG signal.[33]

Each subject participated in a data collection session that lasted about three hours. We instructed the subject to perform scaling as if working on a real patient (that is, applying just enough force to remove the simulated plaque and calculus deposits without damaging the tooth structure), to adopt a consistent working pattern throughout the experiment, and to scale off all the nail polish in a timely manner. The subject practiced scaling with all the instruments until he or she was comfortable with the procedures. The scaling tasks consisted of using each of the 10 instruments to scale the paint off of one plastic tooth. EMG activities and thumb pinch force were recorded simultaneously during the scaling process. The order of instrument testing was randomized. Approximately we allowed two minutes to complete scaling with each instrument. Subjects rested approximately five minutes between instruments.

All subjects completed questionnaires to indicate their preference and perceived productivity of the instruments. In addition, we measured productivity objectively by photographing the plastic teeth before and after scaling and calculating the percentage of the paint area that was removed during the process.

Statistical analysis was performed with SAS System for Windows Version 8 software (Cary, N.C.). We used analysis of variance with repeated measures (RMANOVA) to analyze the EMG and pinch force values, as well as the subjective evaluations of the instruments. Significant findings were followed up with pairwise comparisons using the Tukey method to adjust for multiple comparisons.

We based the sample size calculation of the study on previous studies of intensive hand tasks in which EMG measures were a primary outcome. Power analysis showed that a minimum of 24 subjects were necessary to achieve a 95 percent confidence interval and a 90 percent power.[34,35]

RESULTS

Twenty-four dentists and dental hygienists (12 males and 12 females) participated in the study. Twelve (50 percent) were licensed dentists, three (12.5 percent) were licensed dental hygienists, two (8.3 percent) were recent graduates of a two-year dental hygiene program, and seven (29.2 percent) were dentists from foreign countries who were enrolled in continuing education programs. The age distribution was one (4 percent) younger than 25 years, 12 (50 percent) from 25 to 34 years, eight (33 percent) from 35 to 44 years, and three (12.5 percent) from 45 to 54 years. The mean heights of the subjects were 166 ± 11 centimeters, mean weights were 67 ± an SD of 15 kilograms, and the mean lengths of the right hands were 18.1 ± 1.2 cm. Among the 24 subjects, four (16.7 percent) had up to two years of experience in practicing dental scaling, five (20.8 percent) had practiced scaling for two to five years, and 15 (62.5 percent) had more than five years of experience. Nine (37.5 percent) of the subjects typically practiced dental scaling for up to five hours every week, two (8.3 percent) practiced for five to 10 hours every week, and 17 (70.8 percent) practiced scaling for more than 10 hours every week. Twelve (50 percent) of the subjects preferred using nonpowered hand scalers to treat patients, and five (20.8 percent) preferred ultrasonic scalers to hand scalers, while seven (29.2 percent) stated that they had no preference between nonpowered and ultrasonic instruments.

Figure 3 shows typical RMS-EMG and force history while a subject performed a scaling task. In this recording, pinch force fluctuates between 5 and 18 N, and each fluctuation corresponds to a pull stroke of the scaling motion. The fluctuations in EMG also roughly correlate with the strokes of the scaling motion.

Figures 4 and 5 (page 1128) demonstrate the influence of instrument diameter and weight on EMG and force measures. When the subjects used tool 2 (diameter 10 mm, weight 24 g), the average median activities of the four muscles ranged from 23 to 27 percent MVC, and the average median thumb pinch force was 16.8 N. The average of the peak muscle activities ranged from 35 to 41 percent MCV, and the average of the peak pinch force was 22.6 N.

Statistical analysis with RMANOVA showed that both diameter and weight had significant ($P < .05$) effects on most of the 15 outcome measures (Tables 2 [page 1128] and 3 [page 1129]). Statistically significant interactions ($P < .05$) existed between instrument diameter and weight (Table 3). We performed pairwise comparisons with Tukey adjustment for multiple comparisions for each group of instruments (Tables 2 and 3).

The pairwise analyses of instrument diameters (Table 2) demonstrated significant differences between almost all diameters for peak and median values for all muscles and pinch force. The peak and median EMG measures were affected by instrument diameter to a greater extent than was the static EMG measure. Smaller instrument diameters were associated with greater muscle activity and pinch force. Tool 4, the instrument with the smallest diameter (7 mm), produced a peak pinch force 35 percent higher than that of tool 2 (10-mm diameter). Also, the average median pinch force of tool 4 was 32 percent higher than that of tool 2. However, there was little significant difference in EMG and force between the two tools with the largest diameters, tool 1 (11.5-mm diam-

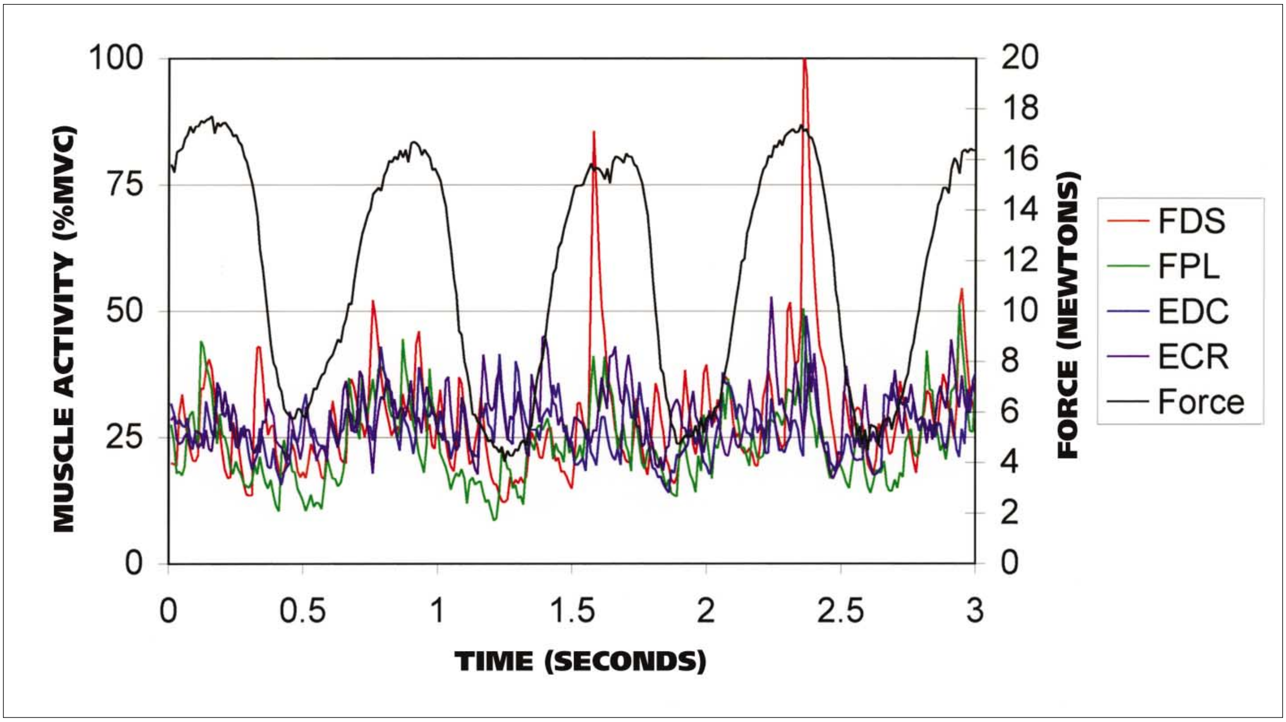

Figure 3. Typical recording of muscle activity (root mean square of the electromyographic signal) and thumb pinch force during scaling demonstrating approximately three strokes. MVC: Maximum voluntary contraction. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus. EDC: Extensor digitorum communis. EDC: Extensor carpi radialis brevis.

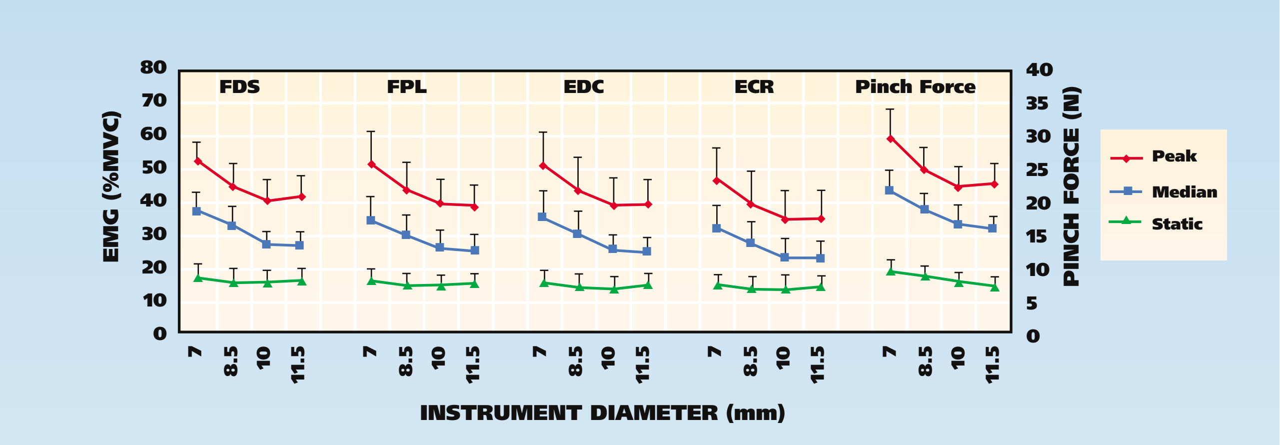

Figure 4. Comparison of instruments with different diameters and the same weight (Group 1). mm: Millimeters. EMG: Electromyograph. MVC: Maximum voluntary contraction. N: Newtons. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus. EDC: Extensor digitorum communis. ECR: Extensor carpi radialis brevis.

eter) and tool 2 (10-mm diameter).

Instrument weight had less influence on EMG and force measures than did instrument diameter. Lighter instruments tended to require less muscle activity and pinch force in the performance of scaling tasks. To assess the interactions between instrument diameter and weight, we studied instruments with two different diameters (10 mm and 7 mm) and four different weights (24 g, 21 g, 18 g and 15 g). The results demonstrated statistically significant ($P < .05$) interactions between diameter and weight for the peak and static EMG measures in all four muscles (Table 3). Interestingly, the median EMG measures in none of the four muscles demonstrated significant interactions between diameter and weight. For the thumb pinch force measurements, the interactions between diameter and weight were statistically

TABLE 2

Pairwise statistical comparisons of instrument diameters within tool Group 1.

TOOL*	MUSCLE												PINCH FORCE		
	FDS†			FPL‡			EDC§			ECR¶					
	P#	M**	S††	P	M	S	P	M	S	P	M	S	P	M	S
1 vs. 2	–	–	+‡‡	–	–	+	–	–	+	–	–	–	–	–	-
1 vs. 3	+	+	+	+	+	–	+	+	+	+	+	–	+	+	+
1 vs. 4	+	+	–	+	+	+	+	+	–	+	+	–	+	+	+
2 vs. 3	+	+	–	+	+	–	+	+	–	+	+	–	+	+	+
2 vs. 4	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+
3 vs. 4	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

* 1: Tool 1 (11.5-millimeters diameter). 2: Tool 2 (10-mm diameter). 3: Tool 3 (8.5-mm diameter). 4: Tool 4 (7-mm diameter). All tools weighed 24 grams.
† FDS: Flexor digitorum superficialis.
‡ FPL: Flexor pollicis longus.
§ EDC: Extensor digitorum communis.
¶ ECR: Extensor carpi radialis brevis.
# P: Peak.
** M: Median.
†† S: Static.
‡‡ +: Statistically significant difference ($P < .05$).

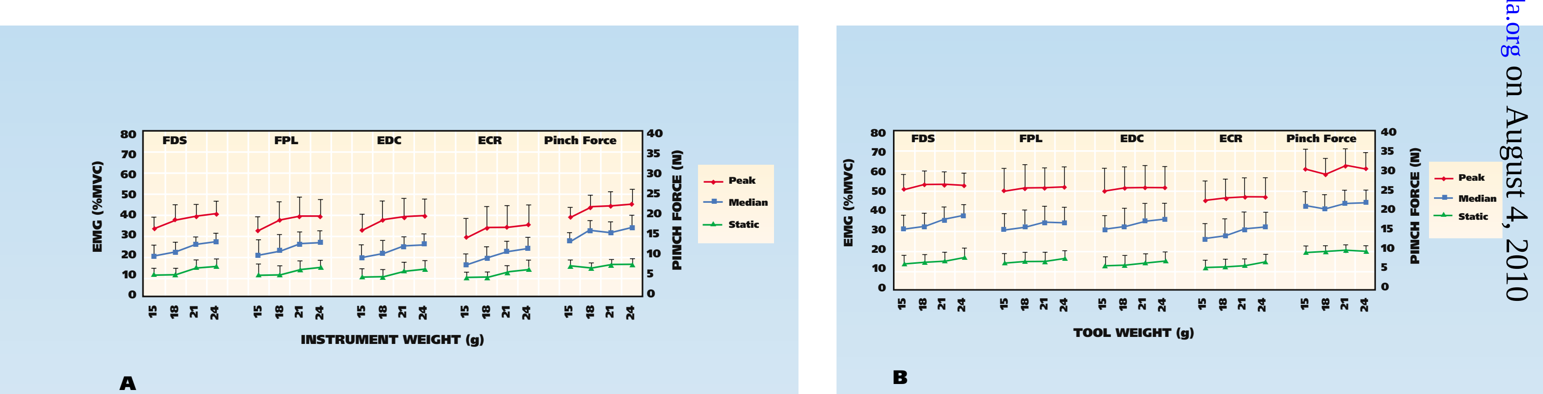

Figure 5. Comparison of instruments with different weights, same diameters. **A.** Group 2. **B.** Group 3. g: Grams. EMG: Electromyograph. MVC: Maximum voluntary contraction. N: Newtons. FDS: Flexor digitorum superficialis. FPL: Flexor pollicis longus. EDC: Extensor digitorum communis. ECR: Extensor carpi radialis brevis.

significant ($P < .05$) for peak, median and static measures. To simplify the follow-up analysis, we stratified the data by the two diameters (10 mm and 7 mm) (Table 3; Figures 5A and 5B). Instrument weight had greater effects on EMG and pinch force measures for the instruments with the larger diameter (10 mm), while in the smaller-diameter (7 mm) group, instrument weight had relatively less effect, particularly on the peak and static measures.

The subjective evaluation yielded findings that were similar to those for the muscle load and force measurement. The most preferred instrument diameter was 10 mm, while the largest diameter (11.5 mm) and smaller diameters (8.5 mm and 7 mm) were less preferable. Lighter instruments received higher preference than heavier ones. Overall, the instruments with a 10-mm diameter and relatively light weights (18 g and 15 g) received the highest rating of perceived productivity.

The ratings of objective measure of productivity and quality—that is, the percentage of paint area that was removed from each tooth during the

TABLE 3

Statistical comparisons of instrument weights.*

TOOL	MUSCLES LOADED DURING PINCH												PINCH FORCE		
	FDS†			FPL‡			EDC§			ECR¶					
	P#	M**	S††	P	M	S	P	M	S	P	M	S	P	M	S
	Interactions between instrument diameter and weight (D*W) ‡‡														
D*W	+	–	+	+	–	+	+	–	+	+	–	+	+	+	+
W	Pairwise comparisons of instrument weights within Group 2 (D = 10 mm)‡‡														
2 vs. 5	–	–	–	–	–	–	–	–	–	–	+	+	–	+	-
2 vs. 6	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+
2 vs. 7	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5 vs. 6	–	+	+	+	+	+	+	+	+	–	+	+	–	–	+
5 vs. 7	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6 vs. 7	+	+	–	+	+	–	+	+	–	+	+	–	+	+	+
W	Pairwise comparisons of instrument weights within Group 3 (D = 7 mm)‡‡														
4 vs. 8	–	–	+	–	–	+	–	–	+	–	–	+	–	–	–
4 vs. 9	–	+	+	–	+	+	–	+	+	–	+	+	+	+	–
4 vs. 10	+	+	+	–	+	+	–	+	+	+	+	+	–	–	–
8 vs. 9	–	+	–	–	+	–	–	+	+	–	+	–	+	+	–
8 vs. 10	+	+	+	–	+	–	+	+	+	+	+	–	–	–	–
8 vs. 10	+	–	–	–	–	–	–	–	–	–	+	–	+	–	–

* Weights were as follows: Tools 2 and 4, 24 grams; tools 5 and 8, 21 g; tools 6 and 9, 18 g; tools 7 and 10, 15 g.
† FDS: Flexor digitorum superficialis.
‡ FPL: Flexor pollicis longus.
§ EDC: Extensor digitorum communis.
¶ ECR: Extensor carpi radialis brevis.
\# P: Peak.
** M: Median.
†† S: Static.
‡‡ Statistically significant interactions ($P < .05$) are represented by "+." mm: Millimeters.

scaling task—were not statistically different among most of the 10 instruments. The only statistically significant difference within a group was between tools 8 and 9 ($P = .02$); tool 9 had a better productivity rating than did tool 8.

DISCUSSION

This study demonstrates that handle diameter and weight of periodontal instruments can have an effect on the hand muscle load and pinch force of the practitioner performing a manual scaling task. The instruments with larger diameters (10 mm and 11.5 mm) and a lighter weight (15 g) required less muscle load and pinch force. There was a limit to the effect of handle diameter, with diameters larger than 10 mm having no additional benefit. However, the study did not identify a limit to the effect of reducing the weight of the tool. It is possible that instruments lighter than 15 g would require even less force. Generally, tools requiring less force and muscle activity also were the ones the practitioners preferred.

Repetitive forceful pinching or gripping is a risk factor for the development of CTS. Roquelaure and colleagues[23] demonstrated an increased risk of developing CTS (odds ratio = 9.0, CI = 2.4 to 33.4) due to repetitive tasks (cycle time less than 10 seconds) involving a pinch force more than 10 N. This study demonstrated that the average peak pinch force was 22.6 N for tool 2, while it was 19.4 N for tool 7. When the instrument weight was reduced from 24 g (tool 2) to 15 g (tool 7), the average peak pinch force was reduced 14 percent. Dental scalers with smaller diameters were associated with increased muscle activity and pinch force. Tools 3 and 4 (with diameters of 8.5 mm and 7 mm, respectively) required 13 percent and 35 percent more peak pinch force, respectively, than tool 2 (which had a 10-mm diameter). Instruments with such small diameters are used commonly in dental practice.

Limitations. A possible limitation of the study is the potential effect of tool shape on force measurement. However, each pressure sensor was calibrated separately with a high-accuracy load cell. The interface used during calibration was a rubber tip with a shape and stiffness similar to that of a finger. The potential error introduced by the regional sensitivity and time drift is small relative to the findings of the study.

A second potential limitation is that the study was laboratory-based and limited to scaling on one tooth. When scaling is done on a real patient, the muscle load and pinch force may be different than in the laboratory setting. Therefore, these laboratory findings should be confirmed with an intervention study in dental clinics to evaluate the effects of tool design on hand muscle pain and symptoms.

CONCLUSIONS

Dentists and dental hygienists who spend much of their work time on manual scaling can modify their work practice to reduce their risk of developing MSDs by the careful scheduling of patients with heavy calculus, taking appropriate breaks and ensuring that instruments are kept sharp. In addition, this study demonstrates that the risk associated with the high level of pinch force required for scaling can be reduced by selecting instruments with a large diameter and a light weight. ■

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1. Milerad E, Ekenvall L. Symptoms of the neck and upper extremities in dentists. Scand J Work Environ Health 1990;16(2):129-34.
2. Osborn JB, Newal KJ, Rudney JD, Stoltenberg JL. Musculoskeletal pain among Minnesota dental hygienists. J Dent Hyg 1990;64(3):132-8.
3. Rundcrantz BL. Pain and discomfort in the musculoskeletal system among dentists. Swed Dent J 1991;76 (supplement):1-102.
4. Oberg T, Oberg U. Musculoskeletal complaints in dental hygiene: a survey study from a Swedish county. J Dent Hyg 1993;67(5):257-61.
5. Corks I. Occupational health hazards in dentistry: musculoskeletal disorders. Ont Dent 1997;74(6):27-30.
6. Fish DR, Morris-Allen DM. Musculoskeletal disorders in dentists. N Y State Dent J 1998;64(4):44-8.
7. Finsen L, Christensen H, Bakke M. Musculoskeletal disorders among dentists and variation in dental work. Appl Ergon 1998;29(2): 119-25.
8. Akesson I, Johnsson B, Rylander L, Moritz U, Skerfviing S. Musculoskeletal disorders among female dental personnel: clinical examination and a 5-year follow-up study of symptoms. Int Arch Occup Environ Health 1999;72(6):395-403.
9. 1997 Survey of current issues in dentistry: Repetitive motion injuries. American Dental Association: Chicago; 1997;2-8.
10. Rice VJ, Nindl B, Pentikis JS. Dental workers, musculoskeletal cumulative trauma, and carpal tunnel syndrome: who is at risk? A pilot study. Int J Occup Saf Ergon 1996;2(3):218-233.
11. Macdonald G, Robertson MM, Erickson JA. Carpal tunnel syndrome among California dental hygienists. Dent Hyg (Chic) 1988; 62(7):322-7.
12. Liss GM, Jesin E, Kusiak RA, White P. Musculoskeletal problems among Ontario dental hygienists. Am J Ind Med 1995;28(4):521-40.
13. Lalumandier JA, McPhee SD, Riddle S, Shulman JD, Daigle WW. Carpal tunnel syndrome: effect on Army dental personnel. Mil Med 2000;165(5):372-8.
14. Lalumandier JA, McPhee SD. Prevalence and risk factors of hand problems and carpal tunnel syndrome among dental hygienists. J Dent Hyg 2001;75(2):130-4.
15. Osborn JB, Newal KJ, Rudney JD, Stoltenberg JL. Carpal tunnel syndrome among Minnesota dental hygienists. J Dent Hyg 1990; 64(2):79-85.
16. Leigh JP, Miller TR. Occupational illnesses within two national data sets. Int J Occup Environ Health 1998;4(2):99-113.
17. Anton D, Rosecrance J, Merlino L, Cook T. Prevalence of musculoskeletal symptoms and carpal tunnel syndrome among dental hygienists. Am J Ind Med 2002;42(3):248-57.
18. Falkiner S, Myers S. When exactly can carpal tunnel syndrome be considered work-related? ANZ J Surg 2002;72(3):204-9.
19. Kao SY. Carpal tunnel syndrome as an occupational disease. J Am Board Fam Pract 2003;16(6):533-42.
20. Boz C, Ozmenoglu M, Altunayoglu V, Velioglu S, Alioglu Z. Individual risk factors for carpal tunnel syndrome: an evaluation of body mass index, wrist index and hand anthropometric measurements. Clin Neurol Neurosurg 2004;106(4):294-9.
21. Geoghegan JM, Clark DI, Bainbridge LC, Smith C, Hubbard R. Risk factors in carpal tunnel syndrome. J Hand Surg [Br] 2004; 29(4):315-20.
22. Treaster DE, Burr D. Gender differences in prevalence of upper extremity musculoskeletal disorders. Ergonomics 2004;47(5):495-526.
23. Roquelaure Y, Mechali S, Dano C, et al. Occupational and personal risk factors for carpal tunnel syndrome in industrial workers. Scand J Work Environ Health 1997;23(5):364-9.
24. Bernard BP. Musculoskeletal disorders and workplace factors. Cincinnati: National Institute for Occupational Safety and Health; 1997.
25. Nathan PA, Meadows KD, Istvan JA. Predictors of carpal tunnel syndrome: an 11-year study of industrial workers. J Hand Surg [Am] 2002;27(4):644-51.
26. Bramson JB, Smith S, Romagnoli G. Evaluating dental office ergonomic risk factors and hazards. JADA 1998;129(2):174-83.
27. Chandler N, Bloxham G. The influence of two handle designs and gloves on the performance of a simulated endodontic task. J Endod 1990;16(11):541-2.
28. Treble SJ, Chandler NP, Shaw JR. Tactile sensitivity of three endodontic instrument handles. Endod Dent Traumatol 1993;9(2):77-8.
29. Chandler NP, Shaw JR, Treble SJ. Effect of endodontic instrument handle diameter on operator performance. J Endod 1996;22(3):110-1.
30. Warren CJ, Chandler NP. Influence of file handle attachments on tactile discrimination: an evaluation by dental students. Int Endod J 1998;31(2):100-2.
31. Ozawa T, Nakano M, Sugimura H, et al. Effects of endodontic instrument handle diameter on electromyographic activity of forearm and hand muscles. Int Endod J 2001;34(2):100-6.
32. Delagi EF, Perotto A, Iazzetti J, Morrison D. Anatomic guide for the electromyographer. 2nd ed. Springfield, Ill: Charles C. Thomas; 1981.
33. Jonsson B. Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Hum Ergol (Tokyo) 1982; 11(1):73-88.
34. Martin BJ, Armstrong TJ, Foulke JA, et al. Keyboard reaction force and finger flexor electromyograms during computer keyboard work. Hum Factors 1996;38(4):654-64.
35. Jacobson M, Rempel D, Martin B, Keir P, Dennerlein J. Comparison of surface to indwelling extrinsic finger muscle EMG during use of computer pointing devices. In: Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting. Santa Monica, Calif: Human Factors and Ergonomics Society; 1998.