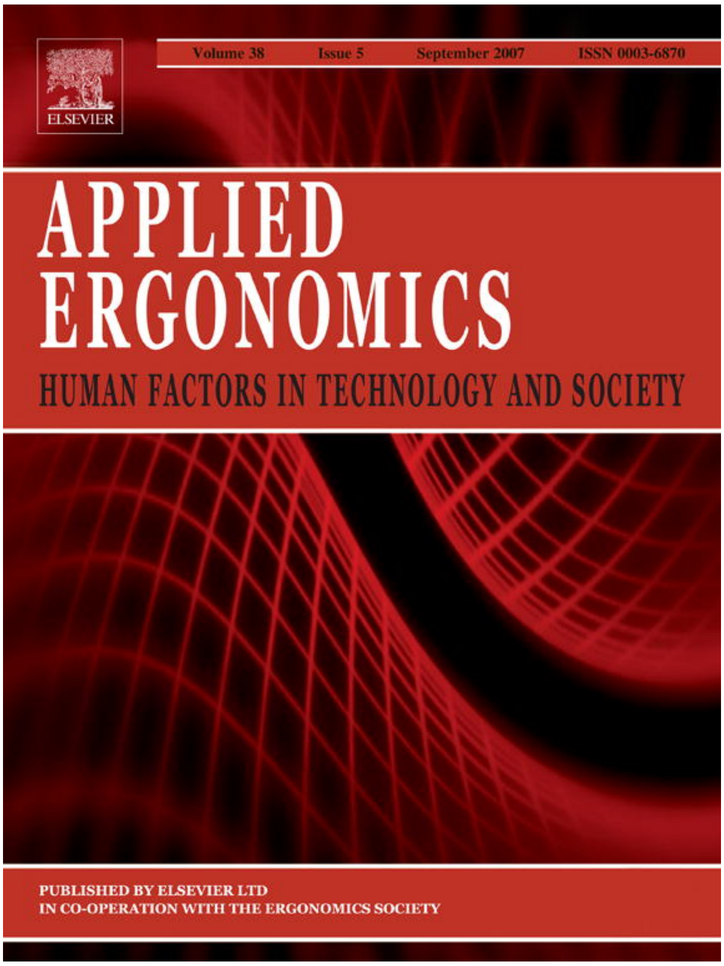
Volume 38
Issue 5
September 2007
ISSN 0003-6870
ELSEVIER
APPLIED ERGONOMICS
HUMAN FACTORS IN TECHNOLOGY AND SOCIETY
PUBLISHED BY ELSEVIER LTD
IN CO-OPERATION WITH THE ERGONOMICS SOCIETY

Applied Ergonomics 38 (2007) 525–531

APPLIED ERGONOMICS
www.elsevier.com/locate/apergo

# The effect of tool handle shape on hand muscle load and pinch force in a simulated dental scaling task

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Received 15 February 2006; accepted 18 September 2006

**Abstract**

Work-related upper extremity musculoskeletal disorders, including carpal tunnel syndrome, are prevalent among dentists and dental hygienists. An important risk factor for developing these disorders is forceful pinching which occurs during periodontal work such as dental scaling. Ergonomically designed dental scaling instruments may help reduce the prevalence of carpal tunnel syndrome among dental practitioners. In this study, eight custom-designed dental scaling instruments with different handle shapes were used by 24 dentists and dental hygienists to perform a simulated tooth scaling task. The muscle activity of two extensors and two flexors in the forearm was recorded with electromyography while thumb pinch force was measured by pressure sensors. The results demonstrated that the instrument handle with a tapered, round shape and a 10 mm diameter required the least muscle load and pinch force when performing simulated periodontal work. The results from this study can guide dentists and dental hygienists in selection of dental scaling instruments.



*Keywords:* Dentistry; Hand tool; Electromyography



## 1. Introduction

The prevalence of work-related upper extremity musculoskeletal disorders is elevated among dentists and dental hygienists (Milerad and Ekenvall, 1990; Osborn et al., 1990a, b; Rundcrantz, 1991; Oberg and Oberg, 1993; Corks, 1997; Finsen et al., 1998; Fish and Morris-Allen, 1998; Akesson et al., 1999; Anton et al., 2002). In a survey by the American Dental Association (ADA, 1997), 9.2% of dentists reported that they were diagnosed by a physician as having an upper extremity musculoskeletal disorder; of this group, approximately 20% required surgery and more than 40% reduced their work hours. Dental hygienists may be at greater risk than dentists for developing upper extremity musculoskeletal disorders due to the long hours of periodontal work (dental scaling and root planning) (Rice et al., 1996). The prevalence of carpal tunnel syndrome among dental hygienists is estimated to be between 6% and 8.5% (Macdonald et al., 1988; Liss et al., 1995; Lalumandier and McPhee, 2001; Lalumandier et al., 2000; Osborn et al., 1990a, b). Among all occupations in the US, dental hygiene was ranked the highest by the Bureau of Labor Statistics in the number of carpal tunnel syndromes cases per 1000 employees (Leigh and Miller, 1998). The pain associated with these hand/arm disorders may be selecting dental practitioners out of work (Akesson et al., 1999).

Work-related risk factors for carpal tunnel syndrome include repetitive forceful pinching and sustained non-neutral wrist positions (Kao, 2003; Roquelaure et al., 1997; Bernard, 1997; Nathan et al., 2002). Periodontal scaling and root-planing require a high level of pinch force. According to Bramson et al. (1998), the average pinch force exerted during dental scaling is 11–20% of the maximum pinch strength. In addition, gaining access to some areas of the oral cavity may require the wrists to be held in awkward positions for prolonged periods.

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0003-6870/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apergo.2006.09.002

Pinch force during dental scaling can be influenced by tool handle design. A previously published study by our group demonstrated that the weight and diameter of periodontal instrument handles had significant effects on the hand muscle load and pinch force of practitioners performing a simulated manual scaling task (Dong et al., 2006). An instrument with a large diameter (10 mm) and a light weight (15 g) required the least amount of muscle load and pinch force, the traditional smaller instrument diameters and heavier weights were associated with greater muscle activity and pinch force.

The cutting action of scaling is performed by pulling the periodontal tool blade along the surface of the tooth, from the gum line toward the top of the tooth, in order to remove plaque. The cutting motion is done by pulling the periodontal handle along its longitudinal axis by flexing the fingers, extending the wrist or supinating the forearm. The return, push motion does not involve cutting, but just repositions the cutting blade to the gum line. Changes to the tool shape that improve the coupling of the fingers to the tool may reduce the applied pinch force.

This study evaluated the effects of changing the shape of the gripped area of the periodontal handle on hand muscle load and pinch force in a simulated dental scaling task. Four shapes were evaluated: a traditional, round, non-tapered shape; a round, tapered shape; a hexagonal cross-sectional, non-tapered shape; and a hexagonal, tapered shape. Tapering the end of the handle where it is gripped may decrease pinch force by improving the coupling of the finger pads to the tool during the high force pulling motion. Adding a cross-sectional hexagon shape to the handle, similar to the cross-sectional shape of a pencil, may allow the fingers to better resist the rotational forces along the axis of the handle during scraping. The four shapes were tested at two different diameters, the traditional 7 mm diameter and a 10 mm diameter.

This study was conducted simultaneously with another study by our group using the same participants (Dong et al., 2006). This study evaluated the effects of four tool shapes at two diameters while the Dong et al. (2006) study evaluated the effects of four diameters and four weights with just a round, non-tapered handle shape.

## 2. Materials and methods

Dentists and dental hygienists with experience performing scaling were recruited from community and private dental clinics in the San Francisco Bay Area. Individuals with recent hand or wrist injuries, previous surgeries in the hand or wrist area, or physician-diagnosed upper-extremity musculoskeletal disorders were excluded from the study. Due to limitations of the experimental apparatus, individuals with a dominant left hand were also excluded. The study was approved by the Committee of Human Research at the University of California, San Francisco.

Eight custom-designed handles were used in the study (Fig. 1 and Table 1). The handles had four different cross-sectional shapes: round (R), hexagonal (H), tapered round (TR), and tapered hexagonal (TH), and two different diameters: 10 and 7 mm. The diameters were the distances between two parallel surfaces and, in the case of the hexagonal handles, in the middle of the section that is gripped. The tapered handle diameters were 9.3 and 6.5 mm at the center of the grip area (27 mm from the end of the tool). Each instrument (handle with two tips) weighed 24 g. The handles were made of either aluminum or stainless steel to achieve the desired combination of size and weight. The ends of the handles were threaded to fit Gracey number 11 curette tips (Hu-Friedy, Inc., USA).

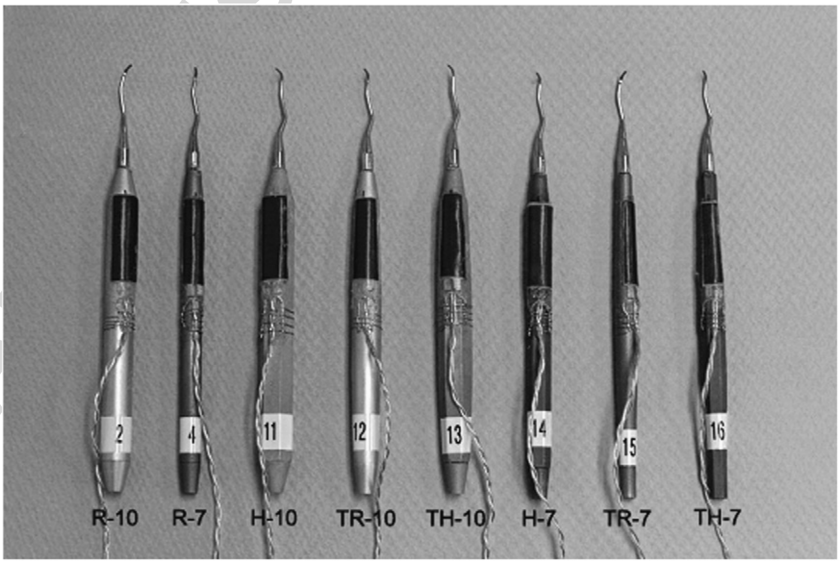


Fig. 1. The eight instruments used in the study are the same (e.g., surface texture, length, weight) except for cross-sectional shape. R = round; H = hexagonal; TR = tapered round; and TH = tapered hexagonal; 7 = 7 mm diameter; 10 = 10 mm diameter. The tool shape is symmetrical from the center to the ends. The force sensors are black.

Subjects performed dental scaling on a typodont (mouth model) fitted into a manikin head (Columbia Dental Corp., New York), which was positioned to simulate clinical situations (Fig. 2). The teeth used in the study were plastic lower right second premolars (number 29). Each tooth was painted on the same cervical portion 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 number 28, apical to the contact area and coronal to the gingiva. To standardize the painting process, a paint mask was placed on the tooth surface before the paint was applied.

Surface bipolar electromyography (EMG) recordings were used to measure muscle activity during the dental scaling task (Fig. 2). Circular Ag/AgCl electrodes with an active diameter of 8 mm and a center-to-center distance of 21 mm were used. The EMG signals were amplified with preamplifiers and an adjustable-gain amplifier. The amplifier produced the root mean square (RMS) of the EMG signal using a 55ms time constant (Therapeutics Unlimited, Iowa City, IA, USA). Data were collected at 100 Hz using LabView software (National Instruments Corp., Austin, TX, USA) through a National Instruments data acquisition card on a Windows based notebook computer.

Table 1
Description of the eight dental handle shapes grouped by diameter

| Group | Tool | Diameter (mm) | Total weight (g) | Shape |
|---|---|---|---|---|
| 1 | 2 | 10 | 24 | R (round) |
| | 11 | 10 | 24 | H (hexagonal) |
| | 12 | 10 | 24 | TR (tapered round) |
| | 13 | 10 | 24 | TH (tapered hexagonal) |
| 2 | 4 | 7 | 24 | R (round) |
| | 14 | 7 | 24 | H (hexagonal) |
| | 15 | 7 | 24 | TR (tapered round) |
| | 16 | 7 | 24 | TH (tapered hexagonal) |

Four extrinsic hand muscles that experience high loads during a sustained pinch were studied: the flexor digitorum superficialis (FDS), the flexor pollicis longus (FPL), the extensor digitorum communis (EDC), and extensor carpi radialis (ECR). A ground electrode was placed over the lateral epicondyle. Prior to performing the dental scaling tasks, maximum voluntary contractions (MVCs) of the four muscles were recorded. Subsequently all EMG signals were normalized as a percentage of the MVCs.

In addition to EMG measurement, a pressure sensor (ConTacts Pressure Profile Systems, Inc., Los Angeles, CA, USA) was attached to the surface of each instrument to measure thumb pinch force. The thin sensor (0.58 mm) was custom designed for each handle to cover approximately 1/4 of the circumference of the instrument and extended 29 mm along the axis of the instrument surface in the region that is pinched. Subjects were instructed to place the thumb directly onto the sensor pad. The sensor measured total integrated pressure, i.e., force generated within a surface. A 6-axis load cell (error range $\pm 0.1$ N; ATT Industrial Automaton, Apex, North Carolina, USA) 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 $\pm 4.9\%$. The mean error due to time drift was 3.5% per 30 s, which was the time most subjects needed to complete the scaling task.

Amplitude probability distribution functions (APDFs) were calculated for the EMG and thumb pinch force from a 30-s window of the recorded data. APDF values at the 10%, 50%, and 90% levels are summary measures equivalent to



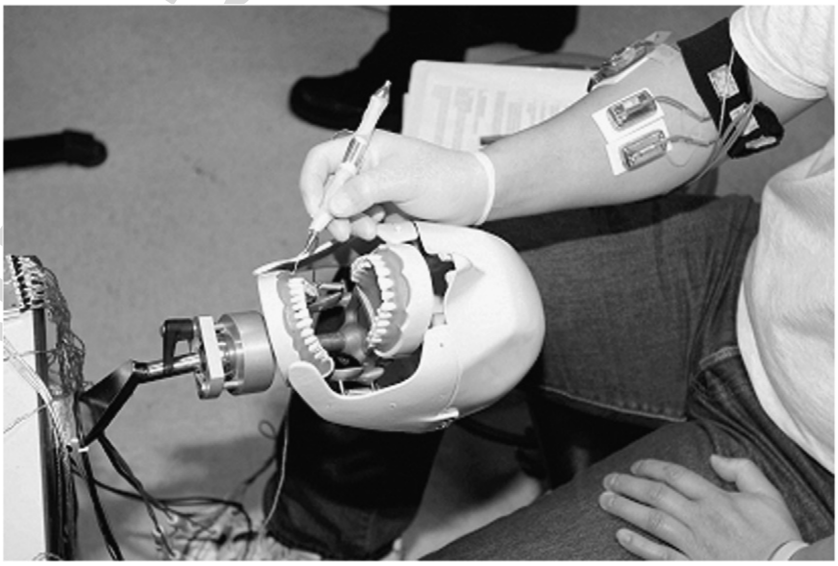

Fig. 2. Simulated dental scaling showing manikin positioned to simulate the clinical situation and surface electrodes attached to the right forearm of the subject. [Reprinted with permission from Dong et al. (2006), Copyright 2006 American Dental Association. All rights reserved.]

the static, median, and peak values, respectively, of the EMG signal (Jonsson, 1982).

Each subject participated in a data collection session that lasted about 3 h. The subject was instructed to perform the scaling procedures as if working on a real patient (i.e., 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 make an effort to scale off all the nail polish in a timely manner. The subject practiced scaling with all the instruments until he/she was comfortable with the procedures. The scaling tasks consisted of using each of the eight instruments to scale off the paint on one plastic tooth. EMG activities and thumb pinch force were recorded simultaneously during the scaling process. The order of instrument testing was randomized. Approximately 2 min was allowed to complete scaling with each instrument. Subjects rested approximately 5 min between instruments.

All subjects completed questionnaires to assess their preference and perceived productivity of the instruments. After testing each handle, subjects recorded their evaluation of the diameter, shape, and perceived productivity of the instrument using a 1–5 scale, with 0 as the least preferable and 5 as the most preferable. At the end of testing, subjects also rank ordered their preference within each diameter group. The most preferable instrument in a group was ranked "1". If the subject was unable to decide the rank between two or more instruments, the same rank was given to all of those instruments. Finally, productivity was measured 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 V8 software (Cary, NC, USA). Analysis of Variance with Repeated Measures (RMANOVA) was used to analyze the summary EMG and pinch force values and significant findings were followed up with pair-wise comparisons using the Tukey method to adjust for multiple comparisons. Subjective ratings were evaluated using RMANOVA for each tool diameter group; rankings were analyzed by the Sign Rank test.

## 3. Results

Twenty-four dentists and dental hygienists (12 males and 12 females) participated in the study. Twelve (50%) were licensed dentists, 3 (12.5%) were licensed dental hygienists, 2 (8.3%) were recent graduates from a 2-year dental hygiene program, and 7 (29.2%) were dentists from foreign countries who were enrolled in continuing education programs. The age distribution was: 1 (4%) under 25 years, 12 (50%) between 25 and 34, 8 (33%) between 35 and 44, and 3 (12.5%) between 45 and 54. The mean heights of the subjects were $166 \pm 11$ cm; mean weights were $67 \pm 15$ kg; and the mean lengths of the right hands were $18.1 \pm 1.2$ cm. Among the 24 subjects, 4 (16.7%) had up to 2 years of experience in practicing dental scaling, 5 (20.8%) had practiced scaling for 2–5 years, and 15 (62.5%) had more than 5 years of experience. Nine (37.5%) of the subjects typically practiced dental scaling for up to 5 h every week, 2 (8.3%) practiced for 5–10 h, and 17 (70.8%) practiced scaling for more than 10 h every week. Twelve (50%) of the subjects preferred using non-powered hand scalers to treat patients, 5 (20.8%) preferred ultrasonic scalers over hand scalers, while 7 (29.2%) stated that they had no preference between non-powered and ultrasonic instruments.

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

Table 2 and Fig. 4 demonstrate the influence of instrument cross-sectional shape on EMG and force measures. Statistical analysis with RMANOVA showed that significant interactions ($p < 0.05$) existed between instrument diameter and shape (Table 2A). Because there was a significant interaction effect, the main effects of the shape and diameter are not presented. Instead, in order to simplify the follow-up analysis, the data were stratified by the two diameters (10 and 7 mm) and the pair-wise comparisons are presented with Tukey adjustment for multiple comparisons performed for each group of instruments (Figs. 4A and B, Tables 2B and C).

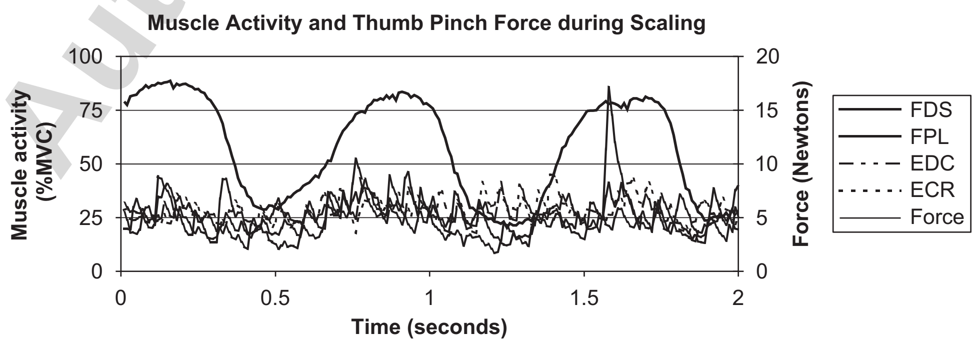


Fig. 3. Typical recording of muscle activity (RMS EMG) and thumb pinch force during scaling demonstrating approximately three strokes. The EMG spike is effectively filtered when calculating summary measures of peak force using the APDF 90%.

Table 2
Statistical comparisons of instrument cross-sectional shapes. Shape (S) = R (round), H (hexagonal), TR (tapered round), TH (tapered hexagonal)

| | FDS | | | FPL | | | EDC | | | ECR | | | Pinch force | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Peak | Median | Static | Peak | Median | Static | Peak | Median | Static | Peak | Median | Static | Peak | Median | Static |
| A. Interactions between instrument diameter and shape (D*S). Statistically significant interactions ($p<0.05$) are represented by "+" | | | | | | | | | | | | | | | |
| D*S | + | – | + | – | – | + | – | – | + | – | – | + | – | + | + |
| B. Pairwise comparisons of instrument cross-sectional shapes within Group 1 (Diameter = 10 mm). Statistically significant differences ($p<0.05$) are represented by "+" | | | | | | | | | | | | | | | |
| RvsH | + | + | – | + | – | – | + | + | – | – | + | + | – | – | + |
| RvsTR | + | + | – | + | + | – | + | + | – | + | + | + | + | + | – |
| RvsTH | + | + | + | + | – | – | + | – | + | + | + | + | – | – | + |
| HvsTR | + | + | – | + | + | – | + | + | – | + | + | – | + | + | + |
| HvsTH | + | – | + | + | – | – | + | – | – | + | – | – | + | – | + |
| TRvsTH | – | + | + | + | + | + | – | + | + | + | + | + | – | + | + |
| C. Pairwise comparisons of instrument cross-sectional shapes within Group 2 (Diameter = 7 mm). Statistically significant differences ($p<0.05$) are represented by "+" | | | | | | | | | | | | | | | |
| RvsH | – | – | – | – | + | + | – | – | – | – | + | + | – | – | + |
| RvsTR | – | + | + | – | – | + | – | – | + | + | – | + | – | + | – |
| RvsTH | – | – | + | – | – | – | – | – | – | + | – | – | – | – | – |
| HvsTR | – | + | + | – | + | + | – | + | + | + | + | – | + | – | – |
| HvsTH | – | – | – | + | + | – | – | + | – | + | – | – | – | + | + |
| TRvsTH | – | – | – | – | – | + | – | – | + | – | + | + | – | + | + |



The shape of instrument handles had greater effects on EMG and pinch force in the larger diameter (10 mm) group than the smaller diameter (7 mm) group. Within the 10 mm diameter group (Fig. 4A and Table 2B) the tapered round handle was associated with lower values in EMG and pinch force, as compared to the most commonly used round (cylindrical) handle. Comparisons of the two handle shapes demonstrate statistically significant ($p<0.05$) differences in all peak (APDF 90) and median (APDF 50) EMG and force measures, although the static (APDF 10) values did not show significant differences between the two handle shapes. In the smaller diameter (7 mm) group, instrument shape had relatively less effect.

There was a trend for the subjective evaluations of shape, weight, and productivity to favor the round, non-tapered shape. However, there were no significant within diameter groups (7 and 10 mm) differences in any of the three outcomes by shape. There was also no significant difference in ranking between shapes. In addition, the objective measure of productivity and quality, i.e., the percentage of paint area that was removed from each tooth during the scaling task, were not statistically different between the eight instruments ($p = 0.57$).

## 4. Discussion

This study demonstrates that instrument handle shape can effect hand muscle load and pinch force among dental practitioners performing a manual-scaling task. The instrument with a round and tapered shape and a large diameter (10 mm) required the least force to use. A taper to the instrument handle (tool 12) resulted in an 11% reduction (from 16.8 to 14.9 N) of the average median pinch force compared to a non-tapered instrument handle. With the tapered handle, the average peak pinch force reduction was 7.5% (from 22.6 to 20.9 N). The hexagonal cross-sectional shape had no important effect on pinch force or muscle activity.

Handle shape had a larger effect on muscle load and pinch force in the larger-diameter group, while in the smaller-diameter group the effect of handle shape was not discernable. The tapered handle shape may allow improved coupling of the finger pads to the handle during the high force pulling motions required for scaling. Although the taper angle was the same for both diameter handles, the biomechanical advantage of tapering may occur at only the larger diameter because of less structural interference of the fingers as they perform a chuck pinch around the handle or a difference in fingertip pulp contact area with the handle. The hexagonal cross-sectional design was not associated with reduced forces or muscle load. In a recent, study by our group, that measured pull and rotational forces during scaling on real subjects, the rotational forces were negligible (Villanueva et al., in press). Therefore, the hexagonal shape, which may help resist rotational forces, may be of little benefit.

Subjective evaluations and rankings of the instruments yielded a trend that was parallel to the EMG and pinch force findings, but the differences were not statistically significant. Subjects may have a tendency to prefer the round, non-tapered handle because it is the handle shape most commonly used by dentists and hygienists. The exposure of subjects to the handles may have been too brief for participants to form strong opinions about the usability or value of the different shapes.

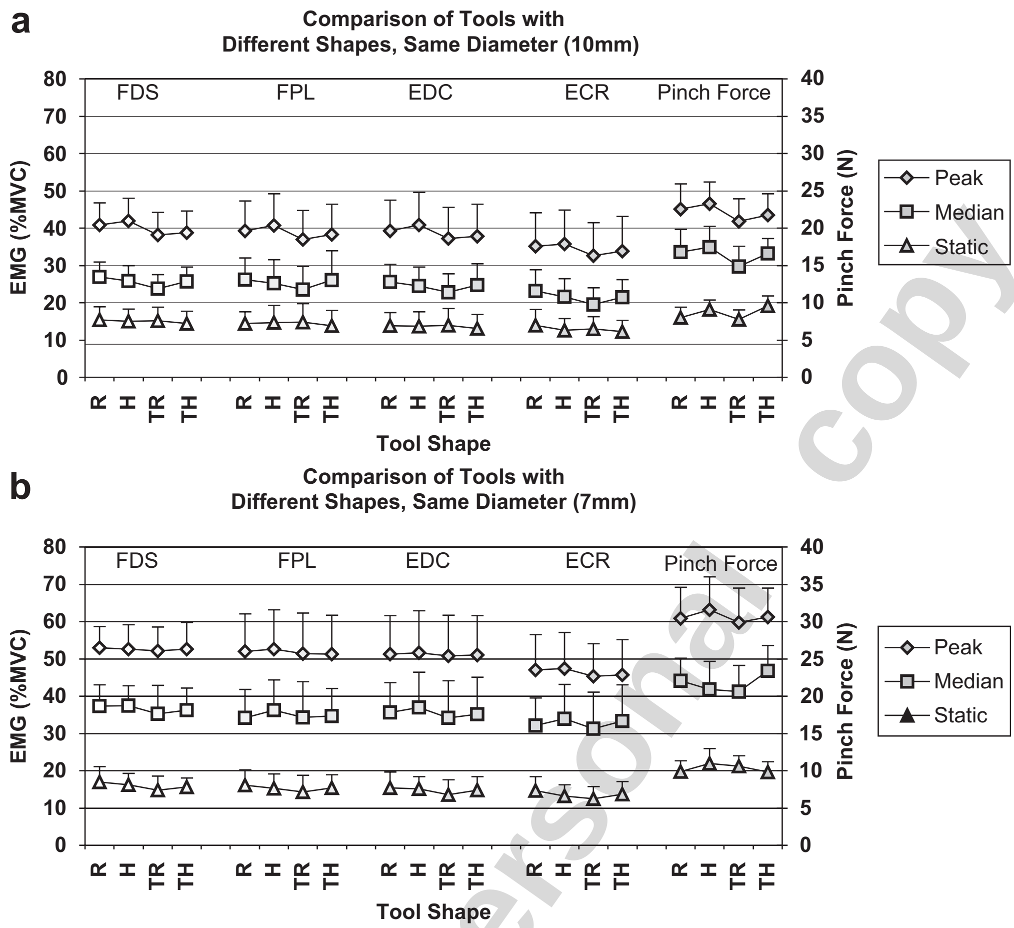


Fig. 4. Comparison of instruments with different cross-sectional shapes. R = round, H = hexagonal, TR = tapered round, and TH = tapered hexagonal. (a) Group 1 (Diameter = 10 mm); (b) Group 2 (Diameter = 7 mm).



Repetitive forceful pinching or gripping is a risk factor for the development of carpal tunnel syndrome. Roquelaure et al. (1997) demonstrated an increased risk for carpal tunnel syndrome (OR = 9.0, CI = 2.4–33.4) due to repetitive tasks (cycle time less than 10 s) involving a pinch force more than 10 N. Silverstein et al. (1987) reported an increased risk for carpal tunnel syndrome for repetitive tasks involving a pinch force of more than 40 N. In our study, for the 10 mm handle, a slightly tapered handle shape resulted in a 1.9 N (11%) or 1.7 N (7.5%) reduction in the average median and peak pinch forces, respectively. For the 7 mm handle, the tapered shape was associated with a 1.5 N (6.7%) reduction in the average median pinch force. The larger handle diameters were associated with less pinch force; the 10 mm handle reduced median and peak pinch forces by 5.3 N (24%) and 7.9 N (26%), respectively, compared to the 7 mm handle (both handles were round). When both factors are combined, for example, when comparing the 10 mm tapered handle with the 7 mm round one, the average median and peak pinch forces are reduced by 7.2 N (33%) and 9.5 N (31%), respectively. Although these force differences may seem small, when considered over many hours and repetitions per day, the differences may be large enough to affect hand symptoms and disorders.

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 a thumb. Another concern is the potential error introduced by the regional sensitivity and time drift of the force sensor; but this error is small relative to the findings of the study. An additional limitation is that the study was laboratory-based and limited to scaling on one tooth. When scaling on a real patient, the muscle load and pinch force may be different than in the laboratory setting. A short time duration of scaling is also atypical in clinical settings; most dental hygienists perform scaling throughout the day, and their force patterns may be different than those observed in the laboratory with a short time duration. Therefore, these laboratory findings should be confirmed with a study among practitioners in dental clinics by evaluating the effects of tool design on pinch force and hand and forearm pain over weeks or months.

Dentists and dental hygienists who spend much of their work-time on manual scaling can modify their work practices to reduce the risks for developing upper extremity musculoskeletal disorders by the careful scheduling of patients with heavy calculus, taking appropriate breaks, and using sharp instruments. According to this study, the pinch force required for scaling may be reduced by selecting periodontal instruments with a large diameter and a cross-sectional shape with a slight taper. A larger taper or flare of the handle may improve the coupling of the finger and tool and further decrease pinch force.

## Acknowledgements

This publication was supported in part by Grant T43/CCT 918726 from the Centers for Disease Control/National Institute for Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of National Institute for Occupational Safety and Health.

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