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Short communication

Effect of dental tool surface texture and material on static friction with a wet gloved fingertip

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Abstract

Hand injuries are an important cause of pain and disability among dentists and dental hygienists and may be due to the high pinch forces involved in periodontal work. The pinch forces required to perform scaling may be reduced by increasing the friction between the tool and fingers. The purpose of this study was to determine whether modifying the tool material, surface texture, or glove type altered the coefficient of static friction for a wet gloved finger.

Seven tools with varying surface topography were machined from 13 mm diameter stainless steel and Delrin and mounted to a 6-component force plate. The textures tested were a fine, medium and coarse diamond knurled pattern and a medium and fine annular pattern (concentric rings). Thirteen subjects pulled their gloved, wet thumb pad along the long axis of the tool while maintaining a normal force of 40 N. Latex and nitrile gloves were tested. The coefficient of static friction was calculated from the shear force history.

The mean coefficients of static friction ranged from 0.20 to 0.65. The coefficient of static friction was higher for a smooth tool of Delrin than one of stainless steel. Differences in the coefficient of static friction were observed between the coarse and medium knurled patterns and the fine knurled and annular patterns. Coefficients of static friction were higher for the nitrile glove than the latex glove for tools with texture. These findings may be applied to the design of hand tools that require fine motor control with a wet, gloved hand.

Keywords: Friction; Finger; Tool; Dental; Scaling

1. Introduction

Hand and arm disorders, such as carpal tunnel syndrome and tendonitis, are the most common cause of disability retirement among dentists and dental hygienists (Burke et al., 1997; Werner et al., 2002; Anton et al., 2002; Gilles and Wing, 2003). The increased risk for these disorders is due, in part, to the high pinch forces applied during the scaling of teeth and root planning (Lalumandier and McPhee, 2001; American Dental Association, 1997; Stockstill et al., 1993). Repetitive hand motions involving high pinch forces can increase the risk for developing musculoskeletal disorders of the hand in the workplace (Roquelaure et al., 1997; National Research Council, 2001; Bonzani et al., 1997).

The periodontal tools used for scaling teeth have blades that are set perpendicular to the long axis of the tool handle. The tools are gripped with a chuck pinch (pad of the thumb in opposition to the pads of both the index and middle fingers) and scaling is performed by pulling the tool along the long axis of the tool handle with the fingers or wrist while the tool blade scrapes the plaque on the surface of the tooth. Peak pinch forces during routine scaling on patients ranged from 32 to

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38 N (Dong et al., 2006b, in press). The pinch force applied during scaling can be reduced by using periodontal tools of larger diameter or tools of lighter weight (Dong et al., 2006a, in press).

Increasing the static friction between the fingers and an object can reduce the pinch force required to lift and move the object (Johansson and Westling, 1984; Frederick and Armstrong, 1995). Modifying the texture of a flat surface can change the coefficient of friction with the finger by up to 50% (Bobjer et al., 1993). It is not known to what extent the surface texture of dental tools will change the coefficient of friction between the fingers and the tool and if it will lead to a reduction in the applied pinch force (Roberts and Brackley, 1996). The situation is more complex for dental scaling because the work is done with a gloved hand and the surfaces may be wet with water or saliva.

The goal of this study was to determine whether the coefficient of static friction between a tool and a wet gloved finger is influenced by tool surface texture, tool material or glove material. The null hypothesis was that the coefficient of static friction is not affected by glove type, tool material or tool surface texture.

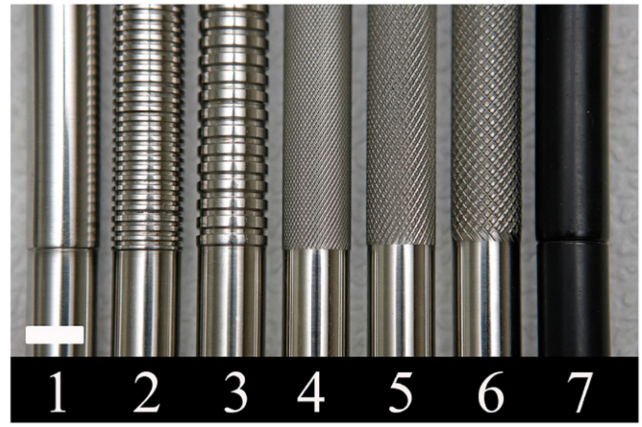

Fig. 1. Tool surfaces studied were (1) stainless steel smooth, (2) stainless steel fine annular (14 teeth per inch), (3) stainless steel coarse annular (8 TPI), (4) stainless steel fine diamond (33 TPI), (5) stainless steel medium diamond (21 TPI), (6) stainless steel coarse diamond (14 TPI), and (7) Delrin smooth. The diamond patterns were roll formed with a right and left 30° spiral knurl with teeth set at 90°. The annular patterns (concentric rings) were cut with the tool set at 90° to a depth of 0.75 mm. The fine annular raised surface width was 1 mm and the coarse annular width was 1.8 mm. The corner radius of the fine pattern was 0.39 mm and the coarse pattern was 0.79 mm. The distance between rings of the fine pattern was 1 mm and for the coarse pattern was 1.5 mm. The white bar is 10 mm long.

2. Methods

2.1. Study design and subjects

This was a full-factorial, repeated measures design, laboratory study. Subjects were recruited from among students at the University of California, San Francisco and Berkeley campuses. Subjects were older than 18 years and had no current injury to the dominant upper extremity. Thirteen subjects participated (7 females and 6 males) with an average age of 31.8 years (range 22–54). The study was approved by the Committee on Human Research at the University of California at San Francisco.

2.2. Tool design

Six tool handles were machined as cylinders (13 mm diameter) from stainless steel (grade 316) and acetal (PolyOxy-Methylene; trade name Delrin) (Fig. 1). Acetal is a lightweight polymer with a high tensile strength (9000 psi), stiffness (tensile modulus 350,000 psi) and melting point (175 °C) that is used for making medical instruments including dental tool handles. The textured surface lengths were 44 mm and are described in Fig. 1.

2.3. Friction measurement

Each tool was mounted to a 6-component force plate (Bertec, Columbus, Ohio; range 0–1900 N, dynamic resolution ±0.25 N) to record the resistive force of sliding the thumb along the tool (Fy) and the force normal to the long axis of the tool (Fx) (Fig. 2). Subjects placed the gloved wet thumb pad on the tool surface so that the axis of the thumb was parallel to the long axis of the tool. A suspended 4 kg mass was placed on the back of the thumb in order to maintain a constant Fx of 40 N. Subjects slowly pulled the thumb along the surface of the tool. The thumb-tool interface was monitored with a video recorder (resolution ±60 μm) during the pull and the force plate outputs and video were synchronized using multimedia video task analysis (MVTA, University of Wisconsin, Madison, WI) at 60 Hz and saved on a computer. Trials were rejected if Fx was less than 30 N or greater than 50 N or if there was a sudden change in force.

2.4. Procedure

The dominant hand was fit with the appropriate sized latex vinyl (Evolution 1 Powderless, Microflex, Reno, NV) or nitrile (Touch-N-Tuff, Ansell Health Care, Red Bank, NJ) glove and the thumb was dipped into tap water; the order of tool testing was randomized. The glove was changed between each tool. Before performing the experiment, subjects viewed a training video and practiced the experiment until they were competent in the procedure. Subjects were seated during the procedure. Three successful trials were completed for each tool.

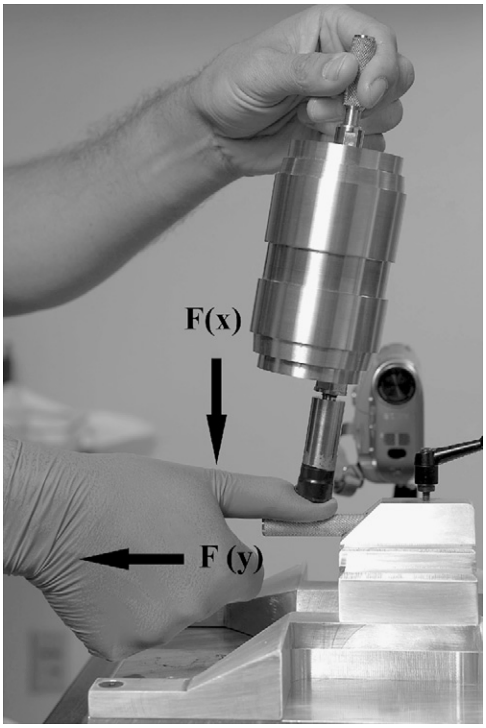

Fig. 2. The gloved, wet thumb is pressed against the tool handle with a 4 kg mass in order to maintain a 40 N normal force (Fx) to the tool. The subject then pulled the thumb along the tool while Fy and Fx were recorded. The thumb motion was also captured by video recorder.

2.5. Data analysis

The trial with the Fx force history that varied the least from 40 N was selected for calculating the coefficient of static friction (Fy/Fx). Repeated measures ANOVA (SAS version 8.1, Cary, NC) with interaction (Tool X Glove) was used to compare difference between materials (stainless [1] vs. Delrin [7]) and glove type. A separate analysis was performed evaluating texture [2–6] and glove type. Significant differences were followed-up with the Tukey–Kramer test.

3. Results

A typical resistive force (Fy) pattern during the task is presented in Fig. 3 and demonstrates a relatively constant normal force at 40 N throughout the task. Fy gradually increases until the gloved finger slides on the tool handle at which point the force begins to decline. The slip point was confirmed with the video recording. The mean duration of time from the start of pulling to slippage was 2.5 ± 1.5 s.

The mean coefficients of static friction and statistical analysis by tool material (tool 1 vs. 7) and glove are presented in Fig. 4 and ranged from 0.20 to 0.34. The mean coefficients of static friction and statistical analysis by tool texture (tools 2 to 6) and glove are presented in Fig. 5 and ranged from 0.39 to 0.65.

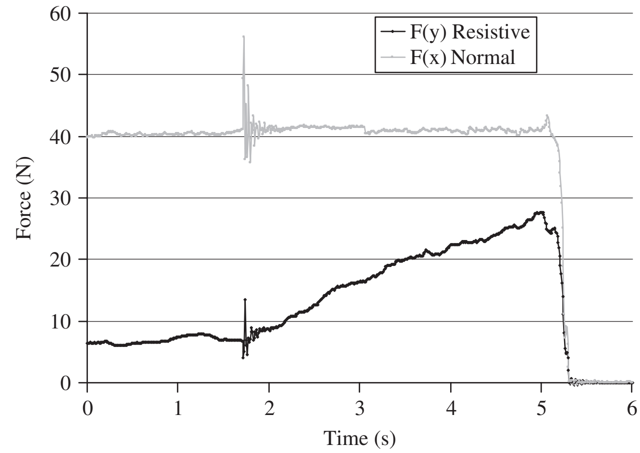

Fig. 3. Typical example of the force profile during a thumb pull trail. In this case Fy at the moment of slippage is 27 N. The force artifact at 1.7 s corresponds to a switch being pressed by the experimenter to synchronize the video data with the force data. Trials were rejected if Fx was less than 30 N or greater than 50 N or if there was a sudden change in the force profile.

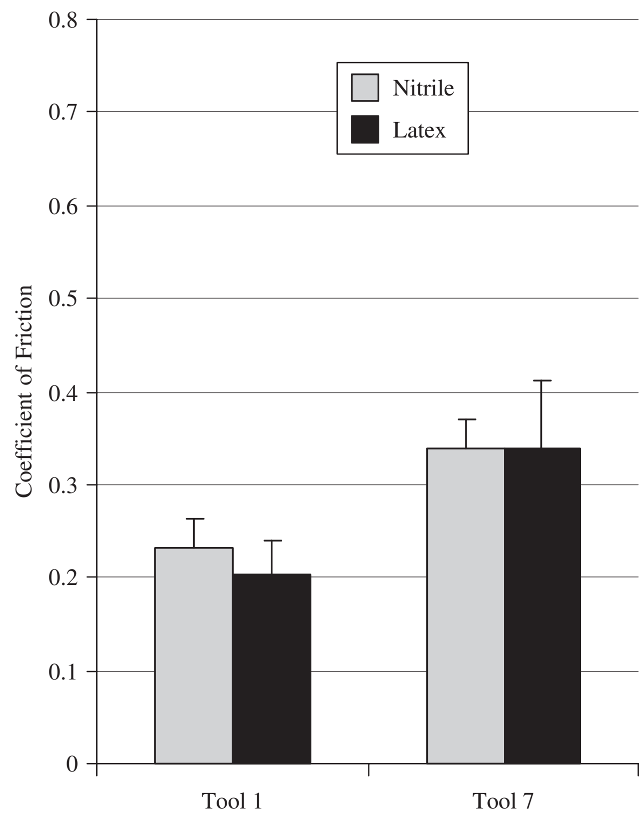

Fig. 4. Mean ($\pm$ S.D.) coefficients of static friction for each glove and tool material. Tools 1 and 7 are smooth stainless steel and Delrin, respectively. The effect of tool material was significant ($p < 0.0001$) but the effects of glove ($p = 0.27$) and the interaction term (tool $\times$ glove; $p = 0.36$) were not [$N = 13$].

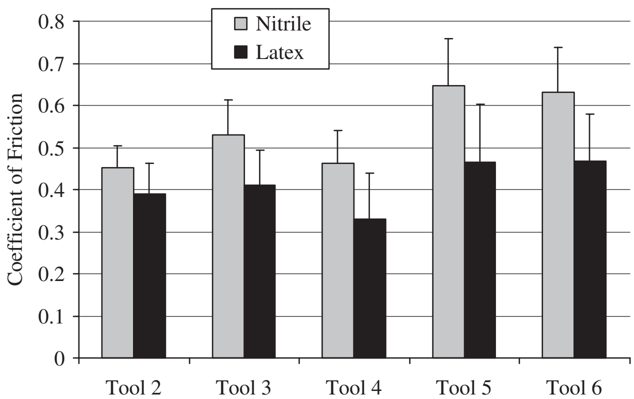

Fig. 5. Mean (± S.D.) coefficients of static friction for each glove and tool texture. The effect of tool surface texture ($p<0.0001$) and glove ($p<0.0001$) were significant, but the effect of the interaction term (tool × glove; $p=0.28$) was not. Tukey–Kramer follow-up tests revealed significant differences between tool 5 (medium knurled) and tools 2 (fine annular), 3 (coarse annular), and 4 (fine knurled) and between tool 6 (coarse knurled) and tools 2 and 4 [$N=13$].

4. Discussion

As far as we are aware, this is the first study to evaluate the coefficient of static friction between a gloved, wet finger and a tool surface. The study is relevant because Universal Precautions (Centers for Disease Control, 1988) recommend the use of gloves for all oral and surgical work on patients. This study demonstrates a higher coefficient of static friction for a tool made of Delrin than stainless steel. There was no difference in coefficient of static friction by glove type (nitrile or latex) for the smooth tool surface. However, across the textured surfaces, the coefficient of static friction was greater for a nitrile glove than a latex glove. Generally, the knurled surface had a higher coefficient of static friction than the annular surface. Within the knurled surface textures, there was no difference between the medium and coarse pattern, only between the fine pattern and the two other patterns.

A few studies have addressed the effect of material and texture on coefficient of friction with a bare finger or on pinch force. Bobjer et al. (1993) measured the coefficient of dynamic friction of the finger under normal, sweaty and oily conditions. He did not study a gloved or wet finger, but did note that static friction is important for dental or surgical tools to prevent sudden tool slippage under wet or contaminated conditions. Frederick and Armstrong (1995) tested the effect of static friction and load on pinch force. In their study a container was transferred between two targets by pinching a handle with bare fingers. The pinch force was reduced if the handle was coated with sandpaper instead of aluminum only when the mass was greater than 4.2 kg.

A limitation of this study was that the procedure did not simulate real work conditions. A future study should determine whether the textured surface modifies the applied pinch force when performing tooth scaling on a mannequin or dental patient. Another limitation is that a Delrin handle with texture was not tested; therefore, whether Delrin has a higher coefficient of friction than stainless steel with a textured surface is not known.

In conclusion, tools with high coefficient of friction surfaces may allow dental hygienists to perform tooth scaling with less pinch force. The findings of this study demonstrated that tools with a medium or coarse knurled textured pattern or tools made from Delrin will provide the largest coefficient of static friction. Nitrile gloves provide a higher coefficient of friction with tools with textured surfaces. Whether texture or material will reduce the pinch force during teeth scaling, and therefore, decrease the risk for distal upper extremity disorders, should be evaluated in a field study. The findings of this study may be relevant to other tasks that require fine motor control with a wet, gloved hand, such as surgery, invasive cardiology, and invasive radiology.

Acknowledgements

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