Evaluation of Dental Scalers

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Abstract: The current state of the dental industry shows an increasing number of dentists and dental hygienists who are reducing hours and retiring early due to the injuries sustained while working. These injuries, or cumulative trauma disorders, can be reduced by applying ergonomics in dental tool design. An experiment was designed to test a new dental scaler (A) made of a titanium rod with added compressibility in the precision grip area. The experiment utilized a Hu-Friedy sickle scaler (B) and a Practicon Montana Jack scaler (C) as controls to show two design spectrums, weight and material. The subjects (n=23) were taught the basics of scaling and required to scale using a typodont. The change in grip strength (Δ GS), pinch strength (Δ PS), and steadiness of the subject's hand were tested. An absolute and relative rating technique was utilized pinpointing that the new dental scaler was preferred with the eigenvector (A=0.8615, B=0.1279, C=0.0106). Statistical analysis confirmed this tool preference while also finding the interaction of gender and tool and Δ GS Tool A versus Tool B for males to be significant.

Keywords: Dental Tool Design, Ergonomics, Scaling

1. Introduction

In the United States, approximately nine million people work in the health-care industry. This nine million includes 179,594 professionally active dentists and 140,750 licensed dental hygienists as of 2006 (ADA, 2006). The dental industry helps diagnose and treat problems with the teeth and mouth cavity tissues (US BLS, 2009). The work environment is safe in terms of sterilization, yet the repetitive nature of tasks and design limitations in the industry creates a strong need for advancement in the current ergonomics. The motions and high degree of manual dexterity required by dentists and dental hygienists are the main cause of cumulative trauma disorders (CTD) in the dental industry, an issue that needs to be addressed. CTDs are synonymous with many other names, such as, musculoskeletal disorders or even occupational overuse syndrome and are injuries that occur due to repetitive motions that gradually wear away at the body (Konz et al., 2008). Many people in the dental industry have undergone surgery to correct injuries created from years of precision work. The most common reported injuries have resulted from awkward working positions and the poor design of hand-held tooling. A step towards reducing injury comes in evaluating current tool design. Dental tools require meticulousness work, a steady hand, and use of small muscles in the hand.

There are many considerations that need to be addressed while redesigning dental tools. The first is assessing gender shifts in the industry and looking into the diverse anthropometric dimensions related to females versus males. Another consideration is the tool durability along with the ability to sterilize the materials utilized in design. Sterilization is an important factor because diseases can be carried from one patient to the next with reusable dental tools.

As new ergonomically friendly designs are tested, it is important that the people in the industry who will be utilizing the tools on a daily basis have input in the process. Students will become the first generation of dentists to use them in practice. If more students are aware of the current issues, the urgency for change will become more apparent for the future generations in the dental industry. Also, as technology increases and new materials are created, the need for new tools and an ergonomic intervention remains essential. Especially since many individuals in the dental industry are concerned with their ability to do the same job until retirement (Jamjoom, 2008).

1.1 Objective

At this time, there are no industry standards involving dental tools and ergonomic requirements in the industry except for tool sterilization. In 1992, the Occupational Safety and Health Administration (OSHA) issued a proposal to teach ergonomic standards to the entire American workforce (Bramson et al., 1998). This was intended to help educate Americans in terms of workstation design and risk factors they should be aware of while at work. Unfortunately, this proposal did not get accepted. An additional problem specifically in the current dental industry is that there are many companies who market their tools as being "ergonomic" in design. These tools have created a misconception with people working in the dental industry, whether in schools or private practices. Frequently, individuals have overpaid for the dental tools but not received an ergonomic benefit. Often, it is too late after purchasing that the dentist realizes the design does not help them yet only continues to hinder their injuries.

Dental tools used today do have some design qualities that follow ergonomic principles related to tool design. First, dental tools are special purpose tools. This means that no one tool is used to do another task outside of its scope. For example, there is a suction hose that is used to keep the mouth area dry, a dental scalar used to remove tartar and plaque, and a dental mirror used to reflect images that the human eye cannot see directly. Having special purpose tools is important in design because the user does not have to alter his or her positioning to do jobs outside of the design capabilities of the tool. Another guideline for handtool design is that the tools should be able to be used by either hand (Konz et al., 2008). As of now, dental tools are designed for both hands. Most dentists and hygienists use their dominate hand to clean the teeth while holding the mirror in their nondominate hand. This ambidextrous tool design allows for multiple users although does not take into account important anthropometric differences between people, such as, hand size.

Anthropometry is of Greek origin meaning "to measure man" (Konz et al., 2008). These measurements help explain how people vary. This data also helps quantitatively explain how everyone is not the same, whether it is height, weight, or even hand size. This is one of the main reasons that the dental workstation and tools have not been standardized.

Finally, the dental industry has seen a shift in gender. In the last twenty years, there has been an increase in the number of female dentists entering the industry. In 2007, the American Dental Association (ADA) reported 44.5% female enrollment in dental schools versus only 33% in 1987 (ADA, 2007). In addition, 97.7% of dental hygienists are female (US BLS, 2009) although more hygiene schools are looking for ways to increase the male enrollment rates. Since dentists and hygienists are performing tasks that require precision, it is important that the tools fit a variety of anthropometric dimensions especially with the differences between genders.

An experiment was designed to test the new tool with two dental scalers currently on the market. The purpose of this experiment is to examine the effect of increasing the diameter and compressibility in the finger grasp region on the change in grip strength and pinch strength.

1.2 Literature Review

In 2008, a census was completed to evaluate the distribution of dentists in the United States by region and state. This survey found that there were approximately 237,851 dentists in the United States. Overall, 24.2% are female. The study also found that 79.1% were in general practice with the remaining 20.9% in a specialty area (ADA Survey Center, 2010). Another increasing trend in the dental industry is the number of females enrolling in dental schools in the United States while the number of males enrolling is decreasing. In the 1970 to 1971 school year, females only represented 1.4% of dental school enrollment (Sinkford et al., 2003). Then, by the 2004 to 2005 school year, male enrollment had dropped from 98.6% to 56.2% while female enrollment increased from 1.4% to 43.8% (ADA, 2005).

In 2008, there were 174,100 dental hygienists in the United States. A dental hygienist is a licensed oral health professional who works on preventing and treating oral diseases in order to protect the oral cavity (ADHA, 2010). The gender spread for hygienists is even worse than dentists yet on the other end of the spectrum. The US Census Bureau reported that 97.7% of hygienists are female (US BLS, 2009). Men in the dental hygiene profession have been compared to males entering the nursing field, another occupation traditionally reserved for the opposite gender (Faust, 1999). The trend has not changed either because recently accredited schools around the United States only see a 3% rate of male enrollment and 13.4% minority enrollment (ADHA, 2010).

In 1997, the American Dental Association reported that 9.2% of dentists had been diagnosed with some type of work related disorder. The study also found that among the 9.2%, approximately 19% required surgery and over 40% had to decrease their working hours per week. The prevalence of cumulative trauma disorder (CTS) and other repetitive motion disorders was most commonly seen in females and older respondents (Hamann et al., 2001). Also, around 79% of dental hygienists have reported days away from work due to repetitive trauma (Simmer-Beck et al., 2005). Overall, any repetitive motion disorder can cause a loss of income, increased medical expenses, rising workers compensation claims, an increase in personal days off work, and ultimately, a career change (Simmer-Beck et al., 2005).

One of the main causes of injury in the dental industry is tool design. In dentistry there are four categories of tooling utilized, examination, hand-cutting, restorative, and accessory. Examination tools include mirrors, probes, forceps, and retractors (Bird et al., 2002). Hand cutting instruments contain sharp edges that are utilized in operatory procedures. Examples of hand cutting instruments are excavators, chisels, hoes, and gingival margin trimmers (DON, 2010). Next, restorative instruments are used to place, condense, and carve the restorative dental materials back to the normal tooth anatomy. These include condensers, burnishers, carvers, plastic composite placement instruments, and amalgam carriers. The last group of dental instrumentation is accessory, which is comprised of spatulas, scissors, an amalgam well, and pliers (Bird et al., 2002). Each tool is divided into three sections: the handle, shank, and working end. The handle is the portion of the instrument where the operator grips the tool. The shank attaches to the working end of the handle, and the working end is the tip of the tool that is utilized for a specific task (Bird et al., 2002).

Electromyography (EMG) measurements have shown that there is not enough variety in the most common tasks completed by dentists (Virtanen, 2001). The current design of dental tooling requires similar grips, precision, motions, and cycle times. An important factor in tool design is providing variability, giving the muscles a chance to recover. It has been shown through research that the percentage of time spent probing was 10%, scaling – 50%, polishing – 25%, and flossing – 15% (Bramson et al.,1998). During scaling, flossing, and polishing, the hand and wrist movements occurred more than 30 times per minute. Repetitions of 30 movements per minute can lead to tendon disorders in the hands and wrists.

With an increasing trend in the number of females entering the dental profession and possible decrement of the gender gap in the dental hygienist profession, both genders' anthropometric dimensions need to be designed for. Material selection should look for the best feasible option, whether, metal, composite, or resin, in terms of hardness and durability. Additionally, this material must also be able to withstand strict sterilization requirements in the dental industry. Overall, weight and grip compressibility need to be tested to increase comfort during repetitive tasks while trying to reduce the number of cumulative trauma disorders originating from tool design.

2. Survey and Survey Analysis

In order to identify current tooling design concerns, a survey for dentists was designed and dispersed. The goal of the survey was to help pinpoint the source and frequency of pain or injuries (neck, back, and upper and lower extremities) associated with daily dental procedures and tasks.

The survey was distributed by contacting over 30 private dental practices by phone in two Kansas cities, Kansas City and Manhattan. The survey was also emailed to over 15 dental schools in the United States. Due to stringent university policy, distribution was limited to only two schools, the University of Texas Dental Branch and professors at the University of Missouri-Kansas City School of Dentistry**.** There were 24 responses, 18 through the web-based form and six hard copies by mail. The survey was split into three sections to gather information from the dentists. The three sections included: background information, dental tool design, and work related activities.

Background information was the first section of the survey providing general data about the dentist. It was used to compare the entire responding population in terms of gender, height, weight, and age. Each individual's body mass index (BMI) was also calculated using the height and weight information provided to see if there is any correlation between obesity and work related injuries to dentists. Other questions looked into the duration of the dentist's workday along with an approximate number of patients seen on a daily basis. The last question asks about the particular dentist's specialties to look for any association with specific tool usage and pain regarding procedures utilizing that hand tool.

Out of the 24 responses, there were 18 male and 6 female dentists. This shows a 4:1 male to female ratio, which is similar to the ADA gender distribution based on active versus new active (10 years or less) private practicing dentists. The ADA has reported a range of female dentists from 17.2% to 34.6% based on diminishing years of service. This means the survey responses accurately represent the female population with a 25% response rate.

The next question looked into dominant tool hand, right versus left. Right was reported 22 times. This means that 91.7% of the dentists who responded are right handed. Research has shown that 90% of the population is right hand dominant with no difference based on gender (Konz et al., 2008). An important note is that all of the respondents who listed their left hand as their dominant tool hand were male. Although, based on the number of female versus male respondents, the sample can be taken as a population because, out of six females, less than one should be left handed while approximately two males should, which is represented by the results.

Height and weight were also included in the background information in order to calculate body mass index (BMI). The female's height ranged from 5' to 5'9" while weight ranged from 102 to 180 pounds. The males' height ranged from 5'7" to 6'3" with weight ranging from 140 to 250 pounds. Each individual's BMI was then calculated using the following formula (CDC, 2009):

$$BMI = 703 weight\ (lbs)/(height(in))^2 \quad (1)$$

Based on the US Department of Health and Human Services, BMI is a measure of body fat based on height and weight for adult men and women. Higher BMI ratios tend to lead to more risk for certain complications, such as, heart disease, high blood pressure, type 2 diabetes, and breathing problems. Some limitations to only using height and weight are that it may overestimate people who have a more muscular build. It also may underestimate body fat in older individuals who have lost muscle (CDC, 2009). Once calculated, each individual is then categorized into one of four groups. The four categories are underweight, normal, overweight, and obese. The breakdown of the BMI's for the dentists surveyed can be seen in Table 1.

Table 1. Survey Results of Body Mass Index

BMI Category	BMI	Male (n=18)	Male %	Female (n=6)	Female %
Underweight	Below 18.5	0	0	0	0
Normal	Between 18.5 to 24.9	4	22.2	4	66.7
Overweight	Between 25 to 29.9	11	61.1	1	16.7
Obese	30 or above	3	16.7	1	16.7

The last question in the background information section of the survey was to see the breakdown of dental backgrounds included. Of the 24 responses there were 15 General, 4 Pediatrics, 2 Endodontics, 2 Prosthodontics, and 1 Periodontic Dentist. This distribution of general (62.5%) versus specialty (37.5%) dentists is close to ADA survey where 20.9% of dentists reported a specialty practice (ADA Survey Center, 2010). The deviation can be attributed to the small sample size of this dental survey.

The next section of the survey looked into specific tools that may cause pain or discomfort for an individual dentist. The purpose of this section was to look for the tool most recurrent in causing discomfort to redesign. Each dentist was prompted to select all tools that cause any source of pain during their daily practice. This section also provided the dentist with an open-ended question that allowed the individual to provide any suggestions on the redesigning process.

The tool inquiry resulted in a tie between the high speed handpiece and hand scalers. Overall, hand scalers caused the most pain for males with Endo hand files being the second most common. Yet for females, the most significant source of pain was linked to the high speed handpiece followed by hand scalers. The comments listed for tool redesign revolved around making the tool handle diameters thicker with friction grip grooves. Comments for the high speed handpiece were to make it lighter and less noisy.

The next survey section addressed discomfort, pain, or soreness in different areas of the human body ranging from the neck and back to the upper and lower extremities. The dentist was asked to select the body part(s) he or she currently feels or has felt discomfort while noting the frequency of pain (daily or weekly). The last part of this question looked into how many work days of the year the dentist has missed due to this pain. It also attempted to pinpoint any tool or procedure related to the specific body part ache.

The responses for this question showed a wide range of body parts as the source of discomfort, soreness, or pain. The self-reported prevalence of pain regarding a tool or procedure as the source stemmed around the repetition due to similar work positioning, the forces required in scaling and other procedures, and the actual design of the workstation, including chair discomfort and improper patient positioning. The maximum estimated number of missed days per year came from the neck region at five, while the shoulders, lower back, wrist/hand, and upper back were also sources of missed days ranging from one to two per year. The remaining results can be seen in Table 2. Along with the body part discomfort question, each respondent was asked if they have sought medical help for injuries/pain related to work. Out of the 24 total replies, five responded with "yes". The medical suggestions for a reduction in pain ranged from: exercises, yoga prescribed to increase flexibility, and chiropractic work sought to help lower back pain. In the most extreme case, one dentist required surgery to remove a bone spur, which resulted from years of pressure and stress applied to this individual's neck.

Table 2. Self-Reported Prevalence of Pain

Body Part	Male	Male %	Female	Female %
Neck	10	55.5	3	50
Shoulder(s)	6	33.3	5	83.3
Upper Back	4	22.2	3	50
Lower Back	8	44.4	2	33.3
Elbow	1	5.6	0	0
Forearm	2	11.1	0	0
Hip	0	0	0	0
Wrist/hand	6	33.3	2	33.3
Upper Leg	2	11.1	0	0
Knee	1	5.6	0	0
Lower Leg	1	5.6	0	0
Ankle	0	0	0	0

The next questions looked into averages per work week. The number of working days per week ranged from three to greater than five with a median of five days. The number of working hours per day ranged from six to greater than nine hours. The median number of hours per day was eight. This work environment is similar to research completed by the U.S. Bureau of Labor Statistics. On average, dentists work four to five days a week with hours per day having a high variance. Although, most full time dentists have reported 35 to 40 hour work weeks, which may include evenings and weekends to accommodate patients' needs (US BLS, 2009). Each dentist was also asked to estimate the number of patients seen per day. The average number listed was 13.4 while responses ranged from five to 40.

Overall, the results of the dental survey show analogous findings with previous studies completed in the dental industry in terms of work-related activities. There were 24 total responses, 18 males and 6 females. The females' ages ranged from 35 to 54 while the males had representation in all age groups with a majority being between 45 to 64 years old. The neck, shoulders, lower back, and wrist/hand were the most selected self-reported body parts associated with pain and missed work. The results of the survey also pinpoint dental scalers as a cause of pain and therefore a primary candidate for redesign.

3. Laboratory Tests

3.1 Tool Design

After researching multiple factors that affect tooling in the dental industry, specific ergonomic design principles were incorporated into a new scaler design. The most important considerations in designing an instrument's handle are size, shape, weight, and maneuverability. When these design aspects are considered, force exertion can be reduced while maintaining neutral wrist positioning. Changes can make significant improvements in the industry because 78% of dentists reported that dental tools are used more than half of the working day (Rucker et al., 2002).

A new hand scaler (A) was designed while taking into consideration tool diameter, compressibility, material, and weight. First, the diameter chosen was 10 mm since this was found to be optimal based on the least amount of muscle load and pinch force required in the 2006 study (Dong et al., 2006). The next goal was to minimize the weight of the tool. The material utilized to achieve a minimum weight was a High-Strength Weldable Titanium tube with an outer diameter of 0.375 inches, inner diameter of 0.337 inches, wall thickness of 0.019 inches, and length of 6.5 inches. The grip selected for this tool was a black rubberized grip found on BIC Velocity® Ball pen. It was added on both ends of the handle near the tool's shank. With this grip, the weight of the new tool was 17.3 grams (Figure 1).

Tool (B) was the Hu-Friedy sickle scaler (#4 Nevi Scaler Posterior DE, EverEdge #9) product code SCNEVI49 seen in Figure 1. The tool handle is made of a hollow stainless steel alloy. The total length of the tool is 6.5 inches. This tool weighed 20.9 grams.

The second control tool, C, is a Montana Jack Scaler Rigid made by Paradise Dental Technologies (PDT) as seen in Figure 1. The length of Tool C is also 6.5 inches. This tool varies greatly from Control Tool B in weight and material composition. The Montana Jack Scaler Rigid weighs only 13.1 grams, which is 7.8 grams less than its Hu-Friedy equivalent. Control Tool C is made of a medical-grade plastic resin. It has a knurling pattern to help control pull and rotation with a lighter grasp required.

Figure 1. Tools used in the experiment – A (top), B (middle), and C (bottom).

3.2 Set-Up of Experiment

The experiment consisted of three 30 minute sessions. At the beginning of the first session a consent form was filled out by the subject. Next, background information about each individual was collected including: age, height, weight, frequency of exercise on average per week, dominant hand (left or right), and hand dimensions. The subjects were then required to watch two minutes of "Sickle Scaling," a short video about dental scaling from the University of Michigan Dental School to provide a visual of stroke length and angles while scaling.

Each session consisted of four main tasks, a steadiness of the dominant hand test, grip and pinch strength measurements, a stress ball hand workout, and scaling. The grip strength meter used was a Jamar® digital hand dynamometer, and the pinch strength was measured using a Jamar® hydraulic pinch gauge. The steadiness of the dominant hand test consisted of the subject drawing three "straight" lines perpendicular to the lines already drawn on the paper. Three lines would be drawn before and after while maximum deviation from a true straight line was averaged. In addition, activities completed in the last 24 hours utilizing the subjects arm and dominant hand were recorded. The sequence of tasks performed is as follows:

1. Steadiness of the dominant hand
2. Grip Strength measurement (3 times)
3. Pinch Strength measurement (thumb, index finger, middle finger – 3 times)
4. Stress ball dominant hand for 5 minutes
5. Scaling for 10 minutes
    a. Remove all purple nail polish
    b. 3 minutes per chair position (middle, right, left)
6. Steadiness of the dominant hand
7. Grip Strength measurement (3 times)
8. Pinch Strength measurement (thumb, index finger, middle finger – 3 times)

The scaling tool utilized for each session was randomly assigned to each subject with at least seven subjects starting with each tool (A, B, and C). For the remaining two sessions, the tooling was rotated to eliminate the effect of tool order on the subject's performance and preference choice.

In order to replicate a patient-like environment, an eight inch Styrofoam ball was used to reproduce a human head. The mouth was simulated utilizing a typodont. The typodont was a Nissin model P15DP-TR.56C.1 (GSF) made in Japan. At the end of the third session, an absolute and relative rating system was utilized to determine the best alternative. First, the subject was asked to rank the scalers in order of preference. Then, the individual was asked by how much they preferred one tool over another.

3.3 Experiment

The subjects consisted of 23 volunteers from the Industrial Ergonomics class at Kansas State University. There were 13 males and 10 females. The ages of the subjects range from 20 to 23 years old with a mode of 21. Based on the BMI 85% of males and 70 % of females was in the normal weight category. The male height was in the 81st percentile while weight was in the 51st percentile. The female height was in the 76th percentile while weight was in the 60th percentile. This shows that the male and female subjects in the experiment were above average in height while males were at the mean in weight and females slightly above the mean in weight as comparing to the US population.

The male hand breadth was in the 66th percentile while hand length was in the 50th percentile. The female hand breadth was in the 50th percentile while hand length was in the 27th percentile. This shows that the male subjects in the experiment are above average in hand length while at the mean in hand length. Female subjects were also at the mean in terms of hand breadth yet considerably below the average in terms of hand length. Majority of males on average worked out two days per week while majority of females responded with three days per week.

The simulated patient and typodont was set-up on a table that was 27 inches tall. A desk lamp (34 watts) was provided to create more illumination in the oral cavity where the subjects would be working. The neck of the lamp provided adjustable light that would account for the range of heights for all subjects aimed to reproduce the effect of overhead lighting similar to the dental work environment. The subjects were also provided an adjustable chair and taught how to properly adjust it so that their knees were bent at a 90 degree angle with feet flat on the floor during the experiment.

Each subject started at the 12 o'clock position seated directly behind the patient. At this position they were instructed to scale the anterior teeth utilizing a pulling motion with stroke lengths of 2 mm to 3 mm. The subjects were then instructed to switch positions to work on different quadrants of the mouth. Each position, middle, right, and left, were each scaled for 3 minutes and 20 seconds. Figure 2 shows all three tools being utilized in the 12 o'clock position by three different subjects.

Figure 2. Tool A (left), B (middle), C (right)

3.4 Results

During the experiment, the change (Δ) in grip strength (GS), change in pinch strength (PS), and change in max deviation from a straight line before and after were all measured. A paired t-test and Analysis of Variance (ANOVA) was used to test for significance with $\alpha = 0.10$. The significance level of $\alpha = 0.10$ was chosen because of a relatively small sample size, as considered by the dental/medical profession.

Before and after scaling each person was required to test their GS three times with the average calculated and recorded. The ΔGS was calculated as the reading before minus the reading after. The average, standard deviation, and range for the GS change can be seen summarized in Table 3. The positive ΔGS values occurred when the subject's grip strength decreased after scaling. On the contrary, GS would be a negative value if the person increased from their before test to the after test. One possible reason for negative values could be due to the subject not having a strong grasp on the meter during the initial readings.

Table 3. Summary of Δ Grip Strength (lbs)

Statistical Parameter	Δ GS Tool A	Δ GS Tool B	Δ GS Tool C
Average	6.22	3.58	5.16
Standard Deviation	5.94	6.85	6.36
Range	-10.03 – 16.27	-8.70 – 16.5	-8.8 – 16.47

In order to use the pair t-test, the test of homogeneity of variances (F-test) for the grip strength differences was performed. There was not statistically significant difference in grip strength variances for all three tools, meaning the variances are homogenizes and coming from the same population. The change in grip strength calculation aimed to look for the tool that would cause the least change in grip strength. Tool A versus B, Tool A versus C, and Tool B versus C yielded p-values of 0.094, 0.537, and 0.447, respectively. With $\alpha = 0.10$ the only significant p-value was Tool A versus Tool B. This significance was investigated further by looking at the Δ GS based on gender. The significant p-value comes from the male population with a p-value = 0.076 meaning that the Δ GS for Tool A is not equal to the ΔGS for Tool B when $\alpha = 0.10$.

An ANOVA test was completed to look at the effect of factors and covariates on the response of change in grip strength. The factors tested were gender, BMI, exercise, and tool. The covariates included were hand breadth, hand length, and wrist width. The ANOVA test showed that only the interaction of gender and BMI was significant.

Similar test procedures were followed for the subject's pinch strength (PS) testing. The Δ PS was tested for the thumb, index, and middle finger before and after. At first glance, it appears that the Δ PS for the thumb and middle finger is greater with Tool A and for the index finger with Tool B. The Δ PS was also tested for statistical significance using a paired t-test. All p-values were greater than 0.10 (α). Therefore, no difference in pinch strength before and after was found from one tool to another. The p-values can be seen in Table 4. Correlation was also analyzed between gender and Δ PS for each finger. The results show similar findings as all p-values, except one, were not significant at $\alpha = 0.10$. There is a correlation between gender and the change in pinch strength for the index finger when subjects were using Tool B. The r value for this scenario was 0.407.

Table 4. Δ PS P-Values

Tool	Thumb	Index	Middle
A vs. B	0.117	0.599	0.877
A vs. C	0.276	0.674	0.606
B vs. C	0.635	0.174	0.634

The final test was to look at how tool design would affect the steadiness of the subject's hand. Each subject was asked to draw three straight lines perpendicular to the lines provided on the half sheet of paper before and after scaling. A straight line was then drawn with the same starting point as the subjects. The maximum deviation was measured in fractions of an inch for each line with the average of all three recorded. The change in steadiness was then measured as the average deviation after minus before. A positive value would signify the individual's line deviated more after than before while a negative value more before than after.

The data was found to have two values deemed outliers that were at least three standard deviations from the mean associated with a particular tool. A paired t-test was calculated for the maximum average line deviation for Tool A, B, and C without the two outliers. Similarly to the change in grip strength test, each pair was tested. The three pairings: A versus B, A versus C, and B versus C, yielded p-values of 0.972, 0.742, and 0.818, respectively. All p-values were not statistically significant meaning that there is no statistical difference between the mean line deviation before and after the scaling.

Finally, at the end of the third session, an absolute and relative rating system was utilized to determine the subjects preferred tool. First the subject was asked to rank the scalers in order of preference in an absolute rating method. The tool determined to be most favorable by subject preference was Tool A followed by B, then C with 12, 6, and 5 first place rankings, respectively. This shows that 52.2 % of subjects preferred Tool A over B and C. The absolute rating also shows that Tools B and C had very similar ranking schemes by the subjects. The overall distribution of tool rankings can be seen in Table 5.

Table 5. Absolute Rankings

Place	Tool A	Tool B	Tool C
1	12	6	5
2	4	9	10
1	7	8	8

Next, each subject was also asked by how much they preferred one tool over another. The scale of 1 to 10 was used with 9-10 absolutely better, 7-8 significantly better, 5-6, much better, 3-4 somewhat better, and 1-2 equal to. The two values collected were preference and amount in order to determine the subject's relative ratings. The data was then reduced to an eigenvector, which was then normalized by preference. Next, an eigenvector (w) was calculated for the entire population. The w was 0.8615, 0.1279, and 0.0106 for Tool A, B, and C, respectively. This shows by how much Tool A is preferred over Tool B and C.

An ANOVA test was completed to look at the effect of the factors and covariates on the response of tool preference based on each individual's eigenvector. Again, the factors tested were gender, BMI, exercise, and tool, and the covariates included had breadth, hand length, and wrist width. The ANOVA test showed that tool and the interaction of gender and tool were significant ($p<0.10$). An interaction plot between gender and tool was generated and can be seen in Figure 3. It shows that tool preference is dependent on gender. The plot shows that females (0) prefer Tool A the most, then C based on the preference mean. On the other hand, males (1) were indifferent in tool preference.

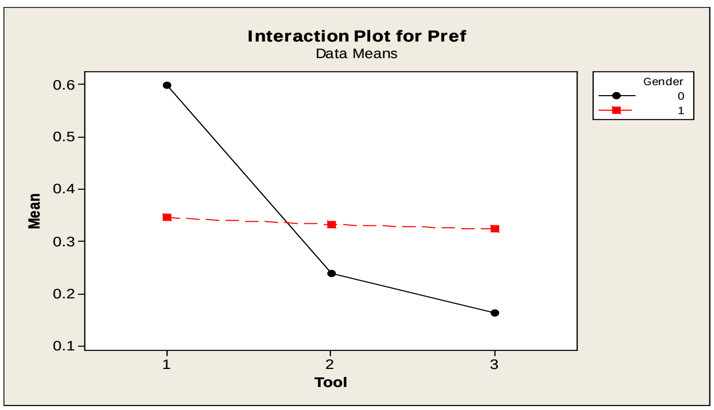

Figure 3. Interaction Plot for Tool Preference

4. Conclusions

Based on the literature review findings, a survey was designed and distributed to dentists in Kansas, Missouri, and Texas to help identify one tool to redesign based on ergonomic principles. There were 24 total responses (18 males and 6 females). Survey results were then compared to a similar study from the University of Kentucky involving dental hygienists. The most frequent sources of pain in both surveys were in the neck, lower back, and wrist/hand regions. The tool most commonly associated with this pain from the survey results was identified as the hand scaler. Since dental scaling is estimated to represent 50% of dental hygienists daily tasks (Bramson et al.,1998), a new dental scaling tool was designed. The plan was to apply ergonomic principles of handtool design to redesign a scaler. The goal of the scaler design would be to help decrease the weight of standard stainless steel tools while increasing the compressibility in the grip region of the handle. The key constraint was that the tool had to be designed to be usable in the current dental work environment (the patient's mouth). This also means that the patient's maximum mouth opening and precision required must be factored into design characteristics.

A new dental scaler (Tool A) was made out of a titanium tube with added compressibility in the handle design with the addition of two rubber grips. This tool was designed to be the same length as the two control tools (6.5 inches) yet weighed less than the stainless steel alternative (Tool B). The metal was in contrast with the material utilized for the second control (Tool C), which was made out of a medical grade resin.

An experiment was designed to test the new dental tool versus two control tools varying in weight and material composition. Grip strength, pinch strength, and hand steadiness before and after were tested and utilized as the responses for the experiment. In addition, each subject (n=23) was required to rank the tools in terms of preference based on absolute and relative rating scales. The results of the experiment found that the eigenvector associated with subject preference was significant (p-value > 0.10). Also, the interaction between tool type and gender was significant. This interaction term showed that more females preferred Tool A to B and C while males' responses were consistent across all three tools tested. The remaining responses, change in grip strength and pinch strength, had no clear trend in statistically significant results.

5. Improvements

There are many improvements that could be made to the experiment. First, the scaling task should have been longer than 10 minutes with a 5 minute fatigue period. This could possibly explain the non-statistically significant differences in the change in grip strength and pinch strength. Second, artificial calculus could have been administered to the scaling area utilizing a paint mask and syringe to further standardize the scaling task instead of utilizing a nail polish.

Another area of improvement could have been in the workstation design and subjects selected for the experiment. An improvement would have been to use dental hygiene students or those currently practicing as experimental subjects in order to reduce variability and decrease the likelihood of a learning curve effect that could have been experienced by the Industrial Ergonomics student subjects.

Another important design feature to be researched further is a scaler similar to Tool A in weight, length, and grip type with a tapered shank from the handle towards the working end. An example of what this would potentially look like can be seen in Figure 4 drawn in SolidWorks. By increasing the area of the tool shank, fatigue, pinch strength, and force required should be tested.

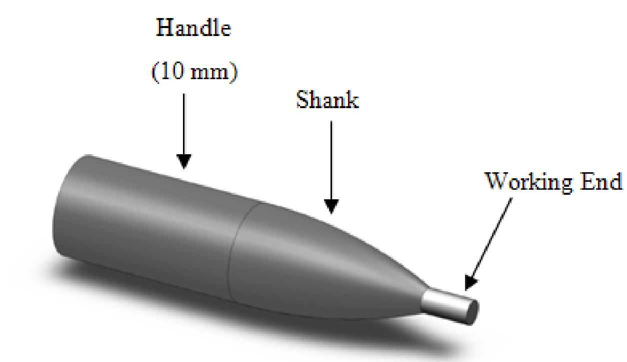

Figure 4. Redesign of Tool A Handle

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This is an extended version of a conference paper presented at the 16th International Conference on Industrial Engineering - Theory, Applications, and Practice, 2011, Stuttgart, Germany.