THE RESEARCH AND DESIGN OF PEDIATRIC DENTAL HANDPIECES THAT

OFFER REDUCED APPREHENSION FOR PEDIATRIC PATIENTS

AND ENHANCED ERGONOMICS FOR DENTISTS

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# THE RESEARCH AND DESIGN OF PEDIATRIC DENTAL HANDPIECES THAT OFFER REDUCED APPREHENSION FOR PEDIATRIC PATIENTS AND ENHANCED ERGONOMICS FOR DENTISTS

Alexander Garber Reynolds, Jr.

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Alexander Garber Reynolds, Jr.



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Date of Graduation

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In 1982 Alexander Garber Reynolds, Jr., also known as Alex Reynolds, was born in Birmingham, Alabama. This is where the author grew up, raised by his parents Al and Blair Reynolds. Upon graduating John Carroll Catholic High School in 2000, Alex moved to Colorado for college. During his time there, the writer met his future wife Kara Strawbridge. Five years later, Alex and Kara were married on August 4 of 2006. Previously, in May of 2005, Alex graduated Colorado State University with a Bachelors of Science in Marketing. From there Alex moved to Auburn University to attain a BSEV in Environmental design (2006) and a masters in Industrial Design (2008).

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# THESIS ABSTRACT

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Alexander Garber Reynolds, Jr.

Masters of Industrial Design, May 10, 2008
(BSEV, Auburn University, 2006)
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10.7% of 5 to 11-year-olds are afraid of dental visits (*Australian Dental Journal*, 2001). Interviews with five dentists revealed that reasons for this include separation from parents, dental workers' poor bedside manner and dental tools. While many of the fears are difficult to prevent, the fear of dental tools can be minimized through careful design of the dental handpieces (dental drills). Historically, most dental tools have been constructed using materials that tend to have a menacing appearance.

The interviews of dentists revealed many elements of the dental drill that could use improvement. One dentist described the drill as having a knife-like appearance, and

many of the dentists showed interest in a range of color options. Other complaints about the typical dental drills include slippery grips and the cord tugging on the back end of the drill, which throws off the balance of the tool. All of these issues are addressed later through research and design.

After accomplishing preliminary research and identifying problems, further research and design are executed to find ways to solve these problems. The further research and design includes reading related books and articles, conceptualizing, building mock up models and numerous ergonomic models, using those models for ergonomic testing and finally administering surveys to collect opinions of a broad range of dentists and children.

This research revealed new ways to use materials and technologies that are already used in dental equipment. With these materials and technologies it was possible to solve, or improve, the problem conditions mentioned earlier. A silicone rubber grip is used to add color while also improving the grip for dentists. Adding grooves to the grip channels water and saliva away from the gripping surface, which further improves grip for dentists. Implementing a downward bend in back end of the drill reduced the tug of the hose. A swivel ensures that the bend always points downward, no mater how the dentist holds the tool.

This thesis details the redesigning of a dental drill to make the tool easier for the dentist to use and less intimidating to the pediatric patients. The approach used in this thesis is one that can be implemented for the redesign of any pediatric medical equipment.

| | |
|---|---|
| Style manual or journal used: | APA Standard Guide, Fifth Edition |
| Computer software used: | Microsoft Office: mac 2004, Student Teacher Edition |
| | Adobe Photoshop CS2 |
| | Rhinocerous 4.0 |
| | Maxwell Render 1.6 |

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# CHAPTER 1

# INTRODUCTION

A large percentage of adults are afraid of the dentist. The *Australian Dental Journal* administered a telephone survey that acquired 7,312 completed surveys from Australian residents, aged 5 and above. According to the article, "The prevalence of high dental fear in the entire sample was 16.1 percent" (Armfield, Spencer and Stewart, 2006). The *Journal of the American Dental Association* published an article called "The Prevalence of Dental Fear and Avoidance: a Recent Survey Study." This article summed up a survey which used a random dialing procedure to shed light on patients' fear of the dental office. According to the article "results indicated that 11.7% of the respondents reported high dental fear, and another 17.5% reported moderate dental fear. Approximately 15.5% of the respondents surveyed have some degree of dental fear and are dental avoiders" (Gatchel, Ingersoll, Bowman, Robertson and Walker, 1983).

This anxiety has been the subject of several articles. The *Journal of the Canadian Dental Association* published an article called "A Professional Psychologist and Dental Phobic Speaks…" In this article, psychologist John Harvey writes about his experiences working with patients that have anxiety disorders. Dr. Harvey explains that these fears often start during childhood and worsen with age. "An unpleasant day in a child's life can grow into an affliction that can cripple an adult." Many adult fears of the dental office begin as a bad childhood experience in the dental office. A survey of dentists that was administered as research for this thesis reveals that four out of nine dentists cite previous bad experiences at the dental office as the root of patients' fears.

**1.1 Problem Statement**

The fear of the dental office often starts with the dental handpiece that most people know as the dental drill. The dentists that were interviewed for this thesis point out this problem. Also, according to a survey of 329 elementary school students which was administered as research for this thesis, 48 percent of children do not feel comfortable going to the dentist. When the dental drill appears, the number of children feeling comfortable drops by 33 percent, and the number of children feeling very uncomfortable quadruples. The dental handpiece may well be the single most feared component of the dental office experience.

Reducing the anxiety associated with a visit to the dentist also improves the quality of the treatment. According to the survey of dentists administered for this thesis, five out of nine dentists say that patients who bring anxiety to the dentist office hinder treatment. These patients often suffer unnecessary additional anxiety. Many of these fears begin during childhood, as described by Dr. Harvey. Therefore, from a designer's perspective, the best opportunity to reduce anxiety is to make dental visits more pleasant for pediatric patients and to make treatment easier for dentists through the improvement of dental equipment. The goal of the process is to develop new dental equipment that both satisfies the dentists' needs and creates a more neutral experience for pediatric patients. This thesis will focus on the redesign of the dental drill to make it easier for dentists to use and less intimidating to pediatric patients.

### 1.2 Need for Study

When a patient has a cavity, dentists use a handpiece to remove the tooth decay (which is what a cavity consists of) and prepare the tooth for a filling. According to the Center for Disease Control and Prevention (CDC) "More than half of children aged 5-9 have had at least one cavity or filling" and "78 percent of 17-year-olds have experienced tooth decay" (2007). That means that 78 percent of children require the use of a dental drill to remove tooth decay before they reach the adult age of 18.

For those children with improper dental care, life is more challenging. According to the CDC, "the daily reality for children with untreated oral disease is often persistent pain, inability to eat comfortably or chew well, embarrassment at discolored and damaged teeth, and distraction from play and learning" (Center for Disease Control and Prevention, 2004). Tooth decay may even progress to the point that adult teeth need to be removed. According to the CDC, "By age 17, more than 7 percent of children have lost at least one permanent tooth to decay" (Center for Disease Control and Prevention, 2004). These children's teeth could have been saved had the decay been treated sooner.

If the handpiece did not have such an unpleasing presence, fears of the dental office would diminish. If children's fears can be reduced, then many future adult apprehensions will consequentially be reduced. The result would likely be more adults visiting the dental office and receiving proper dental care.

### 1.3 Objectives of Study

This study requires both field research and design conceptualization. The objectives for this study are as follows:

- Develop a handpiece that has a more neutral presence, and can be used without scaring children.
- Develop a handpiece that satisfies dentists' needs by being flexible enough and ergonomic enough to compete with existing drills, and sturdy enough to survive typical cleaning procedures.
- Enhance the ergonomics of the dental handpiece.
- Verify the effectiveness of the new design by collecting children's and dentists' opinions regarding the new design verses existing handpieces.

### 1.4 Scopes & Limits

This research and design project results in the design of a new dental drill that has a more neutral presence in the eyes of children from kindergarten to 5$^{th}$ grade. The new design also offers improved ergonomics for dentists.

This thesis is limited to the construction and fabrication of an appearance model to embody the design. Because it is not a fully functional prototype, the user evaluations are limited to evaluating the appearance and ergonomics of the new design.

### 1.5 Literature Review

#### 1.5.1 Dental Phobia

As mentioned previously, fear of the dental office is a common problem among patients. The Australian Dental Journal administered a telephone survey that acquired 7,312 completed surveys from Australian residents, aged 5 and above. "The prevalence of high dental fear in the entire sample was 16.1 percent" (Armfield, Spencer and Stewart, 2006). This fear is common enough that there are many websites dedicated to dental phobia, ranging from forums for complaining about dentists to sites dedicated to helping people deal with their fears. These websites refer to this fear of dentists as "dental phobia."

According to the Royal College of Psychiatrists phobia is defined as follows:

> If feelings [of fear] become too strong or go for too long, they can stop us from doing the things we want to and can make our lives miserable… A phobia is a fear of particular situations or things that are not dangerous and which most people do not find troublesome… A phobia will lead a sufferer to avoid situations in which they know they will be anxious, but this will actually make the phobia worse as time goes on… Sufferers usually know that there is no real danger, they may feel silly about their fear but they are still unable to control it. (Timms, 2001)

The *Journal of the Canadian Dental Association* published one of these Web sites that discussed dental phobia. This site displayed an article written by a psychologist, Dr. John Harvey. As a professional who works with people suffering from debilitating psychological issues on a daily basis, Dr. Harvey has some viewpoints regarding phobias and bad childhood experiences.

In his article, the doctor states, “For many dental phobics, the anticipatory anxiety is the worst.” This is interesting because the worst part does not involve pain, but rather the anticipation of what is to come.

As mentioned earlier, Dr. Harvey goes on to say that many adult fears come from childhood experiences. “An unpleasant day in a child’s life can grow into an affliction that can cripple an adult.” Many of Dr. Harvey’s patients have afflictions which grew out of an unpleasant childhood experience. (2005)

These fears become a problem when patients become so fearful that they begin to avoid going to the dentist. Also as mentioned earlier, the American Dental Association administered a survey using a random dialing procedure which shed light on patients’ fear of the dental office. The survey is summed up in an article called “The Prevalence of Dental Fear and Avoidance: A Recent Survey Study” published in the *Journal of the American Dental Association*. According to this article “results indicated that 11.7 percent of the respondents reported high dental fear, and another 17.5 percent reported moderate dental fear. Results also disclosed that 36.5 percent of those surveyed had not been to the dentist in over a year.” The importance of this is that some of these people are crippled by this fear and avoid the dentist altogether. “Approximately 15.5 percent of the respondents surveyed had some degree of dental fear and were dental avoiders” (Gatchel, Ingersoll, Bowman, Robertson and Walker, 1983).

Upon further study, certain factors of the survey are found to be consistent across different demographics and geographic areas. This further study of the previous survey is summed up in an article called “Factor Analysis of the Dental Fear Survey with Cross-

Validation," also published in the *Journal of the American Dental Association*. This article states:

> Factor analysis of the Dental Fear Survey disclosed…stable and reliable factors. The first factor related to patterns of dental avoidance and anticipatory anxiety… Cross validation showed [dental avoidance and anticipatory anxiety]… to be consistent across four demographically and geographically diverse groups. (Kleinknecht, Thorndike, McGlynn, and Harkavy, 1984)

**1.5.2 Oral Health In the U.S.A.**

The Center for Disease Control and Prevention (CDC) wrote in an article called "Summary Health Statistics for U.S. Adults: National Health Interview Survey" (2005) that tooth decay is the most common disease amongst children. It is "five times as common as asthma and 7 times as common as hay fever." 28 percent of two to five year olds have experienced tooth decay in their primary teeth. More than 50 percent of children aged five to nine have had a cavity, while cavities affect 78 percent of 17 year olds. In fact, 7 percent of 17 year olds have lost a permanent tooth because of tooth decay. In 2005, 16,310 U.S. adults were missing all of their natural teeth. Children with tooth decay that is not properly treated often suffer "persistent pain, inability to eat comfortably or chew well, embarrassment at discolored and damaged teeth, and distraction from play and learning." Such dental related illnesses account for more then 51 million missed school hours every year.

The CDC suggests that children receive one oral examination between the ages of one and two, and then receive oral examinations every 6 months after that.

The tables provided by the CDC, tables 1 and 2, demonstrate how many U.S. adults have lost all of their permanent teeth and what percentage of children have cavities that do not receive proper dental treatment.

| Age Range | Absence of all natural teeth (U.S. 2005) |
|---|---|
| Total | 16,310 |
| 18-44 years old | 1,993 |
| 45-64 years old | 5,033 |
| 65-74 years old | 3,917 |
| 75 years & older | 5,368 |

Table 1. Absence of teeth among U.S. adults

| | Ages 2-5 | | | Ages 6-17 | | |
|---|---|---|---|---|---|---|
| | 1971-1974 | 1988-1994 | 1999-2002 | 1971-1974 | 1988-1994 | 1999-2002 |
| | Percent of persons with untreated dental cavities | | | | | |
| Total | 25.0% | 19.1% | 19.3% | 54.8% | 23.6% | 21.5% |

Table 2. Untreated dental cavities

To summarize, by the age of 9 more than half of the children in the U.S. have had tooth decay which required the help of a dental handpiece. This means that an improved handpiece could directly improve the dental office experience for over 50% of children.

Another interesting fact is the rise in dental cavities that coincides with the rise of industrialized societies. Cavities have plagued mankind in industrialized cultures more and more over the last four centuries, not including a dip in the trend that correlates with the introduction of fluoride. According to Dr. Jerry Gordon "fossilized remains of men and women from the Iron Age discovered in Warwickshire, England showed a cavity rate of only 8%. When today's Warwickshire inhabitants are compared, a remarkable high cavity rate of 48% was found." This is most likely due to the high contents of processed sugars in the modern diet (Gordon, 2000).

### 1.5.3 Tooth Anatomy

Before describing cavities and how dental drills are used it is important to understand the anatomy of the tooth. The outermost layer of the tooth, just above the gum line, is the enamel. This is the hardest and most mineralized part of the body. Cementum is what covers the roots of the tooth beneath the gum line. Dentin is located beneath enamel and cementum. It is made of the same substance as bone and includes nerve endings. Dental pulp is located beneath the dentin. According to Dr. Gordon, it "is a vascular tissue, composed of capillaries, larger blood vessels, connective tissue, nerve fibers, and cells including odontoblasts, fibroblasts, macrophages, and lymphocytes." During growth and development it is used to nourish the tooth, but as an adult tooth it is only used to indicate problems. It accomplishes this with the feeling of pain (Gordon, 2000).

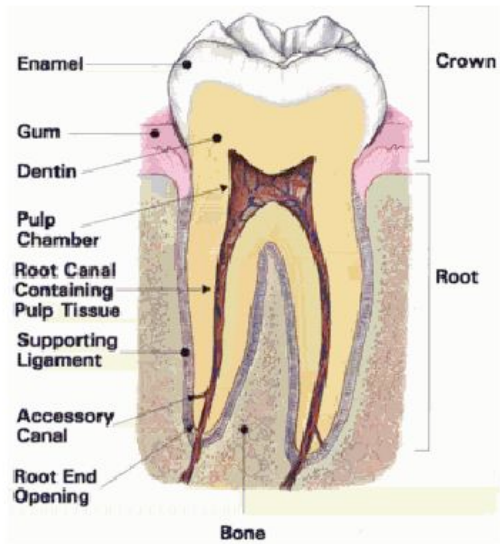



Figure 1. The anatomy of a tooth

**1.5.4 The Cavity**

In order to fully understand the handpiece and why it is used one must first understand cavities. According to Dr. Jerry Gordon (2000), a cavity is a hole in the enamel of a tooth. These holes are created by plaque, which forms a "film of bacteria" on teeth. This bacterium creates acid as a byproduct of its metabolism. This acid is what eats holes in the enamel of teeth. These holes, or cavities, are also known as caries.

If the acid breaks all the way through the enamel it reaches the next layer of the tooth, the dentin. The dentin is much softer then the enamel. Since the dentin is softer, the acid eats through that layer much faster, straight to the core pulp, which is the innermost layer of the tooth. Once the acid reaches the pulp, it creates a tooth infection and the tooth will require a root canal.

When a bacterium that naturally grows in the mouth mixes with carbohydrate-containing foods, the bacteria feed on the carbohydrates and create acid as a byproduct. As the acid changes the pH balance of the mouth, the acid begins to dissolve tooth enamel. The normal pH balance for a human mouth is 6.2 – 7.0, which is a bit more acidic than water. Tooth decay happens at a balance of 5.2 - 5.5. This balance happens after every exposure to carbohydrate-containing foods (Gordon, 2000).

Figure 2. Picture of a cavity

Figure 3. X-ray of a cavity

There are two types of cavity attacks (Gordon, 2000).

1. Some cavities attack through pits and fissures, which are nothing more than the visible grooves in the top surface of the molars and premolars. Food is easily

trapped in these areas and the enamel is thin. These cavities start as small points and spread widely as they hit the dentin.

2. The other type of cavity attacks are attacks to the smooth surfaces of teeth. The fronts, backs and sides of teeth are made up of these smooth surfaces. The enamel is much thicker there. These cavities start wide and tend to converge to a point as they go deeper.

**1.5.4.1 Treating Cavities**

The most common symptom of having a cavity is increased sensitivity to cold and/or sweet foods and drinks. Typically, though, there are no symptoms because enamel has no nerves. Therefore, shallow cavities do not involve nerves and pain. (Gordon, 2000)

Dentists have many ways of finding cavities (Gordon, 2000).

1. Scraping teeth with a hand held instrument called the explorer or scaler is one way of finding cavities. If it catches it is likely the dentist has found a cavity.
2. Visual examinations look for discoloration of teeth. Discoloration is usually brown or black.
3. X-rays help to find cavities that cannot be seen or reached, like cavities between teeth, under the gum or under a filling.
4. If there is a suspicious area and all of the previous methods are inconclusive then a special disclosing solution is used to diagnose the tooth.

Once a cavity is found it will likely be treated. However, this depends on how deep the cavity has gone. Jerry Gordon (2000) states, “Early dental cavities that have not spread to the dentin or undergone cavitation should not be treated, as they can be healed or re-mineralized with fluoride."  More developed cavities require a more in depth treatment.

When treating one of these more developed cavities there are two basic goals (Gordon, 2000):

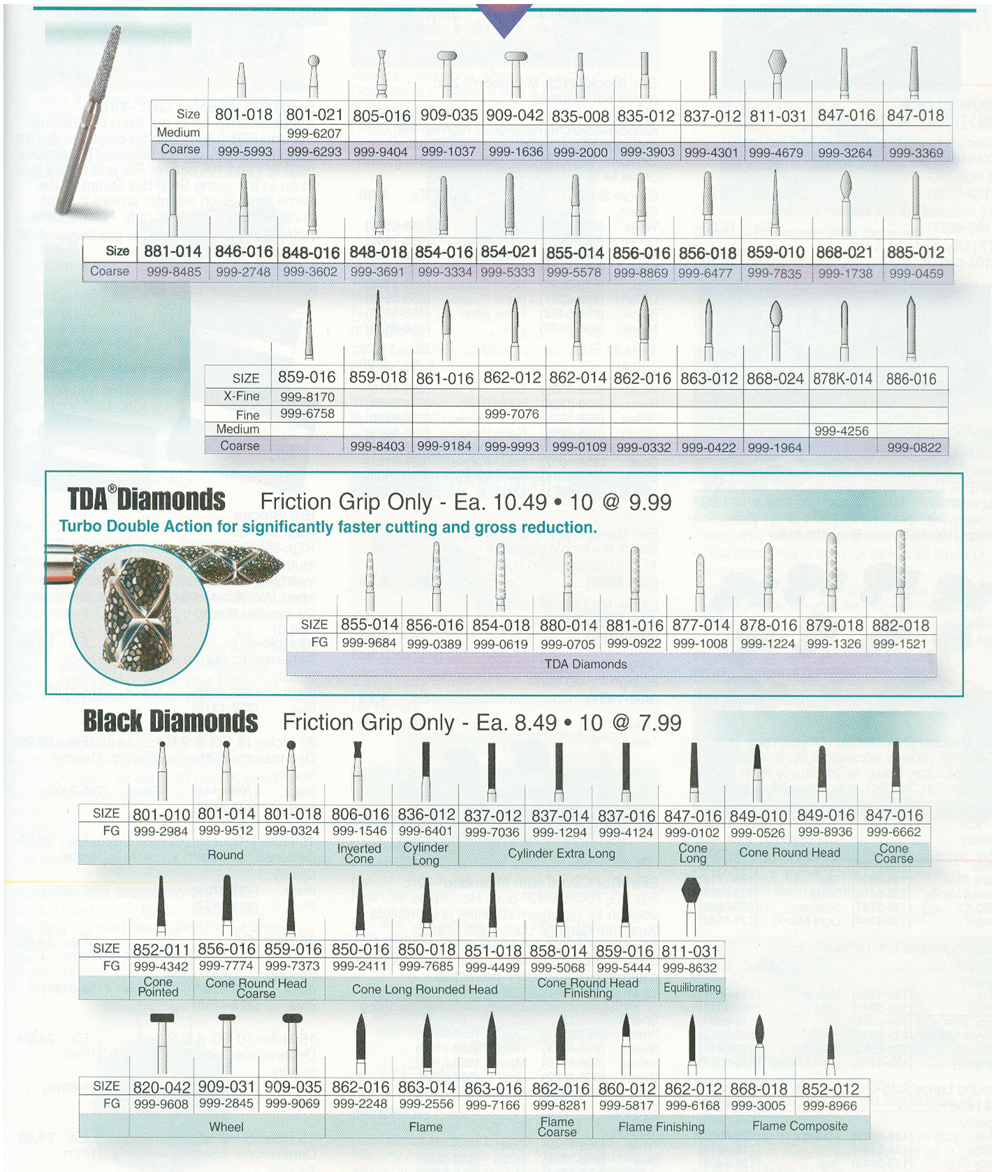
1. Remove the decayed material of the tooth using the dental handpiece, otherwise known as the dental drill.
2. Use a fill material to rebuild the removed tooth material.  This is usually done with a filling, but in worse cases a crown is required to fill the missing tooth material.

### 1.5.5 The Dental Handpiece

According to the five dentists interviewed for this thesis, the dental drill is used to treat dental cavities by removing decayed tooth material and preparing the tooth for the insertion of a dental filling or crown.


Figure 4.  A dental handpiece (dental drill)

The part of the handpiece that comes into contact with the tooth and does the cutting and drilling is a hard metal alloy bit, which is called the "bur."  These burs are available in many different shapes for a variety of specific applications.  Figure 5 illustrates just a few examples of the many different shapes of burs.  Usually these are constructed of steel with a tungsten carbide coating, or are made completely of tungsten carbide.  Sometimes burs are also diamond coated (Sullivan-Schein, 2005).



| Size | 801-018 | 801-021 | 805-016 | 909-035 | 909-042 | 835-008 | 835-012 | 837-012 | 811-031 | 847-016 | 847-018 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Medium | | 999-6207 | | | | | | | | | |
| Coarse | 999-5993 | 999-6293 | 999-9404 | 999-1037 | 999-1636 | 999-2000 | 999-3903 | 999-4301 | 999-4679 | 999-3264 | 999-3369 |

| Size | 881-014 | 846-016 | 848-016 | 848-018 | 854-016 | 854-021 | 855-014 | 856-016 | 856-018 | 859-010 | 868-021 | 885-012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coarse | 999-8485 | 999-2748 | 999-3602 | 999-3691 | 999-3334 | 999-5333 | 999-5578 | 999-8869 | 999-6477 | 999-7835 | 999-1738 | 999-0459 |

| SIZE | 859-016 | 859-018 | 861-016 | 862-012 | 862-014 | 862-016 | 863-012 | 868-024 | 878K-014 | 886-016 |
|---|---|---|---|---|---|---|---|---|---|---|
| X-Fine | 999-8170 | | | | | | | | | |
| Fine | 999-6758 | | | 999-7076 | | | | | | |
| Medium | | | | | | | | | 999-4256 | |
| Coarse | | 999-8403 | 999-9184 | 999-9993 | 999-0109 | 999-0332 | 999-0422 | 999-1964 | | 999-0822 |

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| SIZE | 855-014 | 856-016 | 854-018 | 880-014 | 881-016 | 877-014 | 878-016 | 879-018 | 882-018 |
|---|---|---|---|---|---|---|---|---|---|
| FG | 999-9684 | 999-0389 | 999-0619 | 999-0705 | 999-0922 | 999-1008 | 999-1224 | 999-1326 | 999-1521 |
| | TDA Diamonds | | | | | | | | |

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| SIZE | 801-010 | 801-014 | 801-018 | 806-016 | 836-012 | 837-012 | 837-014 | 837-016 | 847-016 | 849-010 | 849-016 | 847-016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FG | 999-2984 | 999-9512 | 999-0324 | 999-1546 | 999-6401 | 999-7036 | 999-1294 | 999-4124 | 999-0102 | 999-0526 | 999-8936 | 999-6662 |
| | Round | | | Inverted Cone | Cylinder Long | Cylinder Extra Long | | | Cone Long | Cone Round Head | | Cone Coarse |

| SIZE | 852-011 | 856-016 | 859-016 | 850-016 | 850-018 | 851-018 | 858-014 | 859-016 | 811-031 |
|---|---|---|---|---|---|---|---|---|---|
| FG | 999-4342 | 999-7774 | 999-7373 | 999-2411 | 999-7685 | 999-4499 | 999-5068 | 999-5444 | 999-8632 |
| | Cone Pointed | Cone Round Head Coarse | | Cone Long Rounded Head | | | Cone Round Head Finishing | | Equilibrating |

| SIZE | 820-042 | 909-031 | 909-035 | 862-016 | 863-014 | 863-016 | 862-016 | 860-012 | 862-012 | 868-018 | 852-012 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FG | 999-9608 | 999-2845 | 999-9069 | 999-2248 | 999-2556 | 999-7166 | 999-8281 | 999-5817 | 999-6168 | 999-3005 | 999-8966 |
| | Wheel | | | Flame | | | Flame Coarse | Flame Finishing | | Flame Composite | |

Figure 5. Bur profile examples

### 1.5.5.1 New Types of Handpieces

A number of alternative dental drills have been developed. These less traditional models do not use a bur like most handpieces. Each of these different handpieces has very promising features, but also have drawbacks which have kept them from becoming widely accepted.

The plasma needle handpiece, rather than using a bur, uses a plasma tip and a flame to remove decay. Zeeya Merali describes the drill as follows:

> Sticking a needle with a flaming plasma tip into your mouth may not at first strike you as much of an improvement on conventional dentistry. However, the plasma needle, which is cold and painless to the touch, could be just the panacea we have been waiting for. (2006)

The advantage of the plasma needle is that it is a painless method of removing decay. The problem is that the flame on the tip, which is inserted into the patient's mouth, can cause as much apprehension as a traditional dental drill. This open flame keeps it from being widely accepted as a handpiece that will give patients a more pleasant experience in the dental chair.

Another promising alternative to the traditional handpiece is the particle beam drill. James Schultz, author of the article "New Type of Dental Drill Takes Fear Out of Fillings," claims, "A new generation of 'particle beam' dental drills could take the fear - and pain - out of semi-annual checkups." The article described the process as follows:

> The drill, powered by compressed air just like conventional drills, uses ultra-fine abrasive powder to cleanse teeth [and] to pinpoint cavities and other trouble spots. A narrowly focused stream of miniscule aluminum oxide particles, each no more than a tenth the diameter of a

single human hair, essentially sandblasts away decay in preparation for repair. (1996)

It is a process that keeps the tooth cool and performs without any pain, sound or smells.

Dr. James Baker, whose Chesapeake practice is one of a handful to offer the device, claims that patients love the new drill. Dr. Baker goes on to say, "There's no sound or smell of the drill." Only 5 percent of Baker's patients need anesthesia.

The high cost is the most likely reason this drill has not yet been widely adopted. According to the above-mentioned article, a particle beam drill costs $9,500. According to a catalogue called Everything Dental (Sullivan-Schein, 2005), traditional handpieces cost anywhere from $184.99 to $924.99.

The last and most common alternative handpiece is the laser-based handpiece. There are many articles on this style drill, but the most informative of them is "How Cavities and Fillings Work" by Dr. Jerry Gordon (2000). According to Dr. Gordon, lasers were approved for soft tissue (gum) dental work in the early 1990's. "In 1997, the Food and Drug Administration approved laser use in dental hard tissues (teeth) for the treatment of cavities." This is a promising treatment because it can be done in a virtually painless manner versus the painful treatments with typical dental drills, which usually require anesthetics. These lasers can be used to treat small to medium-sized cavities in adults and children. The most common type of laser used for this is the erbium: yttrium-aluminum-garnet (Er:YAG).

There are reasons that laser dental treatments have not taken off and become widely popular. First, the tools are prohibitively expensive. Some companies that produce the laser tools lease them to dentists on a price per treatment basis. Secondly, the laser is not useful in approximately 90-95% of dental treatments. They cannot remove old, broken and worn-out fillings and they have difficulty removing soft dental decay (present in deep cavities). Nor can these lasers prepare a tooth for crowns (caps), inlays, onlays, or porcelain veneers. They are also ineffective for performing a root canal.

Finally some researchers still worry that the laser may create excessive heat that can damage the dental pulp. Laser-based dental drills are not yet practical and may not be safe for the tooth (Gordon, 2000).

### 1.5.6 Ergonomics of Hand Tools

When designing a hand tool that will be used repetitively on a daily basis, such as the dental handpiece, it is important to consider the ergonomics of that tool. By implementing good ergonomics in the tool's design, one can ensure improved user comfort throughout daily work, thus decreasing the possibility of injury.

#### 1.5.6.1 The Wrist

There are two key wrist movements that apply to this study: pronation and supination. Stephen Pheasant, author of *Body Space: Anthropometry, Ergonomics and the Design of Work*, describes these movements as such. Pronation is an inward rotation of the forearm. When the palm is turned down it is in the prone position. Supination is an outward rotation of the forearm. When the palm is turned upward it is in the supine position. It is important to note that these movements are not movements of the wrist. They are actually movements created by rotation of the radius and ulna bones that run parallel with the radial and ulnar arteries in the forearm (1996).

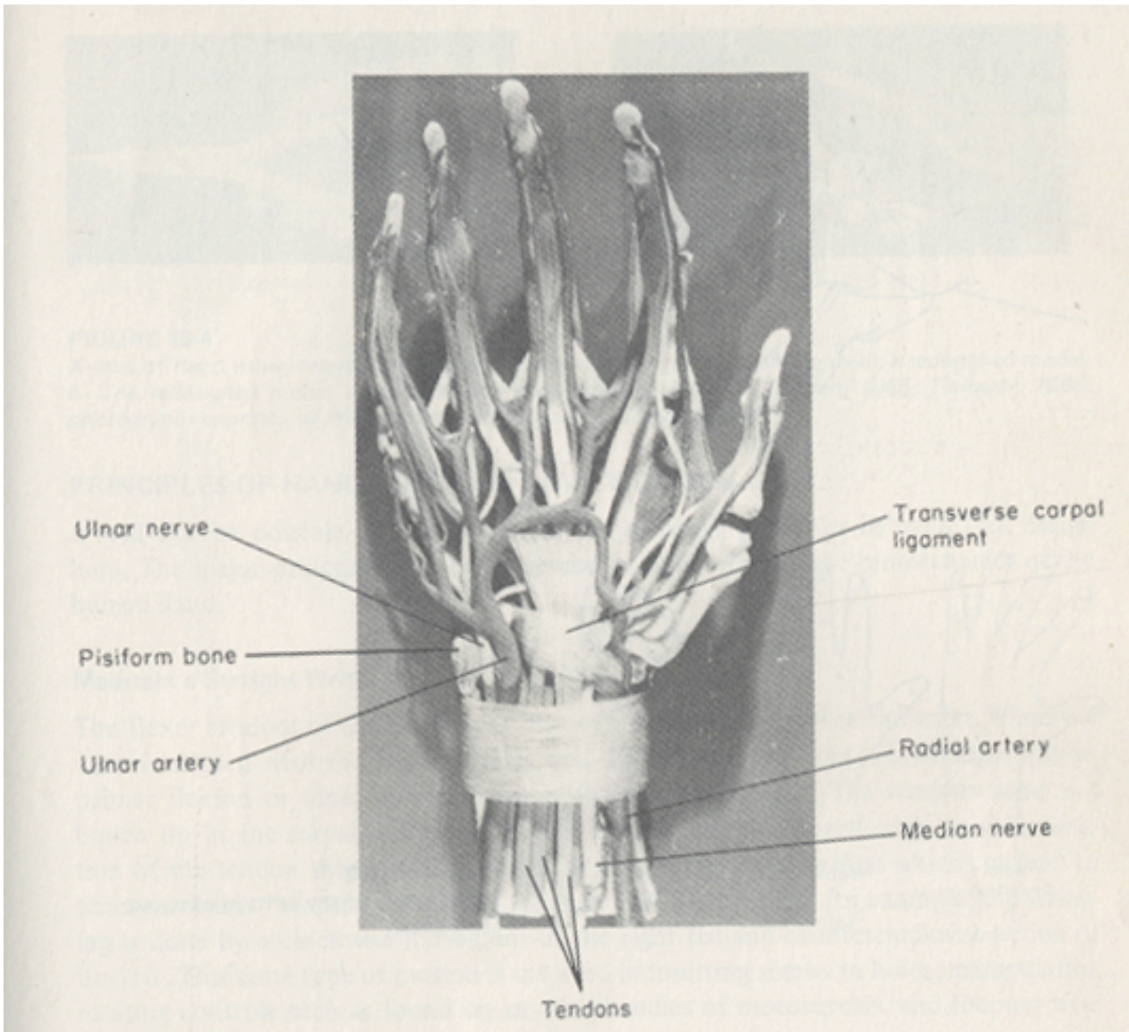


Figure 6. Anatomy of the wrist

### 1.5.6.2 Injuries Induced by Tools

A key consideration in developing hand tools is designing them to reduce both major and minor injuries. McCormick and Sanders, authors of *Human Factors in*

*Engineering and Design* (1982, p.283), reference the findings of Ayoub, Purswell, and Hicks (1977) that state, “Injuries resulting from hand tool use accounted for 5 to 10 percent of all compensable injuries.” Interestingly, power tools caused only 21-29 percent of those compensable injuries.

McCormick and Sanders go on to say that most of the injuries cited in these reports are single incident traumatic injuries. These injuries usually involve a knife, a wrench, or a hammer. Not mentioned in the reports are cumulative-effect traumas. This type of injury typically leads to “reduced work output, poorer-quality work, increased absenteeism, and single-incident traumatic injuries.” (p. 284) Thus, there is a need to design tools with improved ergonomics, with the intent to reduce both single incident traumas and cumulative-effect traumas.

#### 1.5.6.3 Principles of Hand Tool & Device Design

McCormick and Sanders also discuss what they call the “Principles of Hand Tool and Device Design”. These principles include:

“Maintain a Straight Wrist

“Avoid Tissue Compression Stress

“Avoid Repetitive Finger Action

“Design for Safe Operation

“Remember Women and Left-Handers

“Vibration-Induced White Finger”

### 1.5.6.3.1 Maintain a Straight Wrist

When the wrist is not kept straight during use of a hand tool, there are two general problems that arise. The first is that grip strength is compromised. McCormick and Sanders cite Terrell and Purswell (1976) as reporting "that grip strength is reduced if the wrist is bent in any direction." This creates fatigue and increases likelihood that the tool will be dropped, causing injury, or damage to the tool.

The second problem is that "radial deviation, particularly if combined with pronation and dorsiflexion, increases pressure between the head of the radius and the capitulum of the humerus in the elbow" (McCormick & Sanders, 1982, p. 289). This is also what causes epicondylitis, which is more commonly known as tennis elbow.

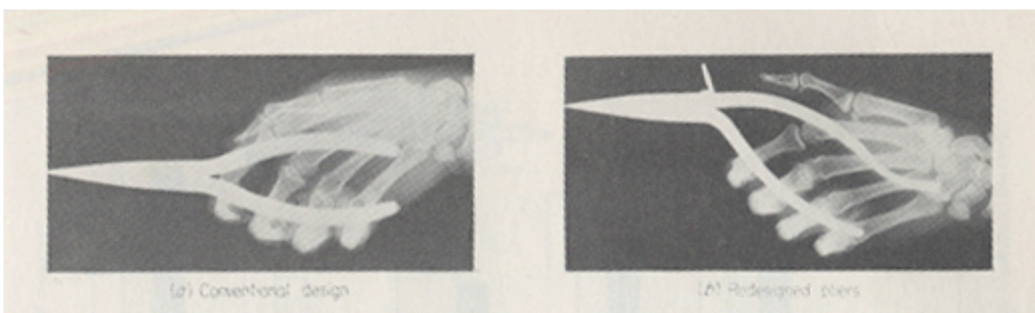


Figure 7. Conventional pliers vs. ergonomically designed pliers

### 1.5.6.3.2 Avoid Tissue Compression Stress

Many tools place considerable pressure on the palm of the hand. The ulnar and radial arteries pass through the palm, as do nerves. Thus, placing excessive pressure on the palm is frowned upon and can be painful. Ideally, the tool should spread the pressure over more area and focus pressure on less sensitive areas like the "tough tissue between the thumb and index finger." Using the palm of the hand as a hammer is unacceptable.

This can cause artery, nerve and tendon damage as well as send shock waves up the arm to other parts of the body (McCormick & Sanders, 1982, p. 290-291).

In addition, another consideration is the ever-popular finger grooves. "Tichauer (1978) recommends not using deep finger grooves or recesses in tool handles if repetitive high finger forces are required." The higher points between the grooves become pressure points for users with thicker fingers. Users with smaller hands tend to place two fingers into one groove, which creates discomfort by pressing those fingers together. (McCormick & Sanders, 1982, p. 291)

**1.5.6.3.3 Avoid Repetitive Finger Action**

Repetitive finger actions can cause injuries, particularly when they involve the index finger. McCormick & Sanders describe this problem and its solutions as such:

> If the index finger is used excessively for operating triggers, a condition known as trigger finger develops. The afflicted person typically can flex but cannot extend the finger actively. It must be passively straightened, and when it is, an audible click may be heard.

If a repetitive finger action is unavoidable, it is best to use the thumb for those actions. According to McCormick & Sanders:

> Frequent use of the index finger should be avoided, and the thumb-operated controls should be used. The thumb is the only finger that is

flexed, abducted, and opposed by strong, short muscles located entirely within the palm of the hand.

Avoid hyper extending the thumb. Finger strip controls are preferable over thumb controls because the load is spread across many fingers and the thumb is allowed to grip and guide. (1982, p. 291)

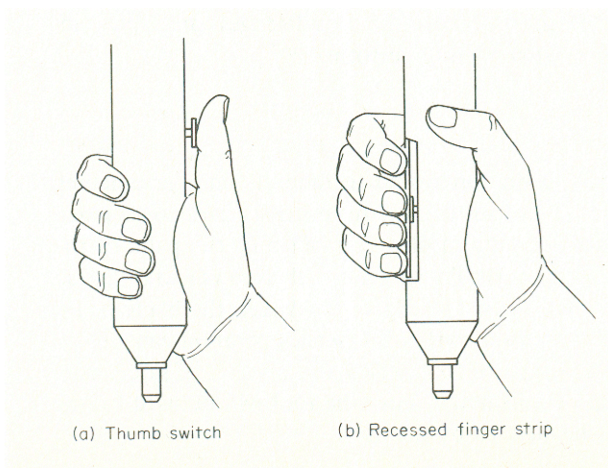


Figure 8. Using a finger strip to spread the load

**1.5.6.3.4 Design for Safe Operation**

McCormick and Sanders recommend what should be considered when designing a hand tool in order to ensure safe operation. First, McCormick & Sanders say that "designing tools and devices for safe operation would include eliminating pinching hazards and sharp corners and edges." This also reduces the chance of the operator quickly reacting to a pinch or sharp edge, reducing the chance the operator will flinch and cause an indirect injury. The second point is that "proper placement of the power switch for quick operation can also reduce accidents with power tools." This creates more opportunity for operators to switch power tools off before someone gets hurt in the event of an emergency. The final point on this topic is that "the designer must consider, in detail, how the tool will be used by the operator, and also how it is likely to be *misused* by the user." Most tools are misused at some time. It is important to make sure tools are as safe as possible, even when being misused. (1982, p. 292)

#### 1.5.6.3.5 Remember Women & Left-Handers

McCormick and Sanders cite Barsley (1970) for saying that women make up 50 percent of the population and, on average, have two-thirds the grip strength that men have. Left-handers make up about 8 to 10 percent of the population (McCormick & Sanders, 1982, p. 292-293). Tool design must accommodate both right and left-handed users, as well as male and female users. Designing to accommodate these users will give the tool a more universal design.

#### 1.5.6.3.6 Vibration-Induced White Finger

Many powered hand tools create noticeable vibration. Constant use of vibrating hand tools over an extended period of time (months/years) can cause vibration-induced white finger (VWF), neuritis, decalcification and cysts of the radial and ulnar bones (McCormick & Sanders, 1982, p. 295). When designing tools that vibrate, efforts must be made to reduce handle vibration.

### 1.5.6.4 Fundamentals of Handle Design

Just as McCormick and Sanders offer what they call the principles of hand tool and device design, Stephen Pheasent, author of *Bodyspace; Anthropometry, Ergonomics and the Design of Work,* offers what he calls the "fundamentals of handle design." Pheasent describes these fundamentals as follows:

I. Force is exerted most effectively when hand and handle interact in compression rather than shear. Hence, it is better to exert a thrust perpendicular to the axis of a cylindrical handle than along the axis [Fb in Figure 9 rather than Fa]. If the latter is necessary a knob on the end will give extra purchase.

II. All sharp edges or other surface features, which cause pressure hot spots when gripped, should be eliminated. These include:

   i. "Finger shaping" (unless designed with anthropometric factors in mind) [should be eliminated.]

   ii. The ends of tools such as pliers, which may dig into the palm (if the handle is short) [should be redesigned.]

   iii. The edges of flat or raised surfaces, e.g. for the application of labels, logos, etc. [should be removed from designs.]

   iv. Pinch points' between moving parts such as triggers, etc. [should also be avoided in any well-designed tool.]

III. Handles of circular cross-section (and appropriate diameter, e.g. 30-50 mm) will be most comfortable to grip since there will be no possibility of hot spots – but they may not provide adequate purchase. Rectangular or polyhedral sections will give greater purchase but will be less comfortable. In general, wherever two planes meet (within the area that engages the hand) the edges should be rounded; there are no exact figures but a minimum radius of curvature of about 25 mm seems reasonable.

IV. Surface quality should neither be so smooth as to be slippery nor be so rough as to be abrasive. The Frictional properties of the "hand/handle interface" are complex since the skin is both visco-elastically deformable and lubricated. Heavily varnished wooden handles give a better purchase than metal or plastic of similar smoothness. The explanation is possibly in [metal or plastic's] resilience (elastic compliance). Rubber is similar [to metal or plastic] but becomes "tacky." The subject is worthy of more extensive investigation.

V. If part of the hand is to pass through an aperture (as in a suitcase or teacup) adequate clearance must be given. It is remarkable how often this perfectly obvious design principle is violated. The following spaces will accommodate virtually all users with a slight leeway:

   i. For the palm, as far as the web of the thumb (as in the handle of a suitcase), allow a rectangle 115 mm x 50 mm.

   ii. For a finger or thumb, a circle 35 mm in diameter will allow insertion, rotation and extraction. (1996, p. 86-87)

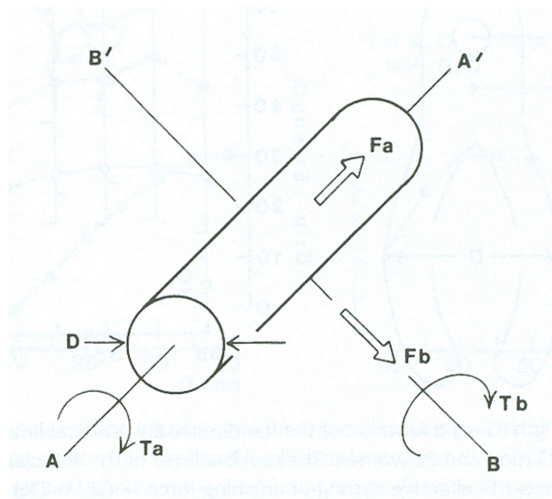


Figure 9. Hand & handle interaction demonstration

### 1.5.6.5 Buttons, Switches, Etc.

There are many different ways to control precision hand tools. Some tools are more complex than others in that they require buttons, switches or other such devices to give the operator more control. When designing these complex tools, deciding which of these devices is used can be an important decision. The following is a listing of details about these devices and what distinguishes them, as described by Tilley and Henry Dreyfuss Associates:

> Push Buttons
>
> Buttons should give the operator positive feedback to show activation of the control. This can be provided by incorporating a sensory or audible click when the motion is carried out. Push-on-push-off types are not as good, because they cancel out the expected movements for "on."

Rocker & Toggle Switches

Rocker switches carry important messages on the front face in addition to the titles that must appear on the panel face. Rocker switches must be oriented the same way as the toggle switch: “off” is always down or to the left. The simplest toggle switches are accurate if they follow this rule. If triple-position switches are used, their position may not be immediately apparent.

Thumbwheels

Thumbwheels, which are difficult to read, must also be ‘off’ when down or to the left. They are convenient and widely used on small audio receivers and players.

Triggers & Tool Grips

Provide a full finger grip for the trigger of at least 1.1 in (27 mm) in diameter for use with gloves. Other dimensions of the hand grip can vary depending on the force to be exerted as long as the minimums are preserved. (2002, p. 77)

### 1.5.6.6 Handles & Grips

Another aspect of hand tools is the most fundamental of parts, the handle. Stephen Pheasant describes a handle in a way that gives it new meaning through its function:

> The purpose of a handle is to facilitate the transmission of force from the musculoskeletal system of the user; to the tool or object he is using; in the performance of the task or purpose for which he is using it. As a general rule we can say that to optimize force transmission is to optimize handle design. (1996, p. 86)

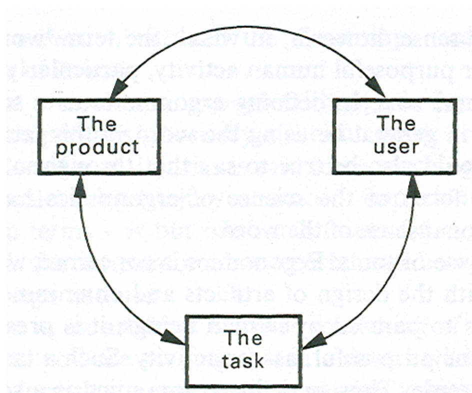


Figure 10. Stephen Pheasant's user-centered design

One cannot transmit force through a handle without gripping it. An important part of handle design is considering what type of grip should be used with the handle and accommodating the handle to that grip style. Pheasant talks about two different types of grips that are involved with handles:

In a classic and widely quoted paper on the subject (gripping actions vs. non-gripping actions), Napier (1956, p. 86) divided gripping into two main categories.

I. Power Grips, in which the fingers (and sometimes the thumb) are used to clamp the object against the palm;

II. Precision Grips, in which the object is manipulated between the tips (pads or sides) of the fingers and thumb.

Note that both entail a closed kinetic chain.

In the basic power grip…the thumb wraps around the back of the fingers to provide extra stability and gripping force. As the need for precision increases, however, the thumb moves along the shaft of the tool handle–providing extra control and the possibility of both power gripping and precision manipulation as the situation may demand (1996, p.86).

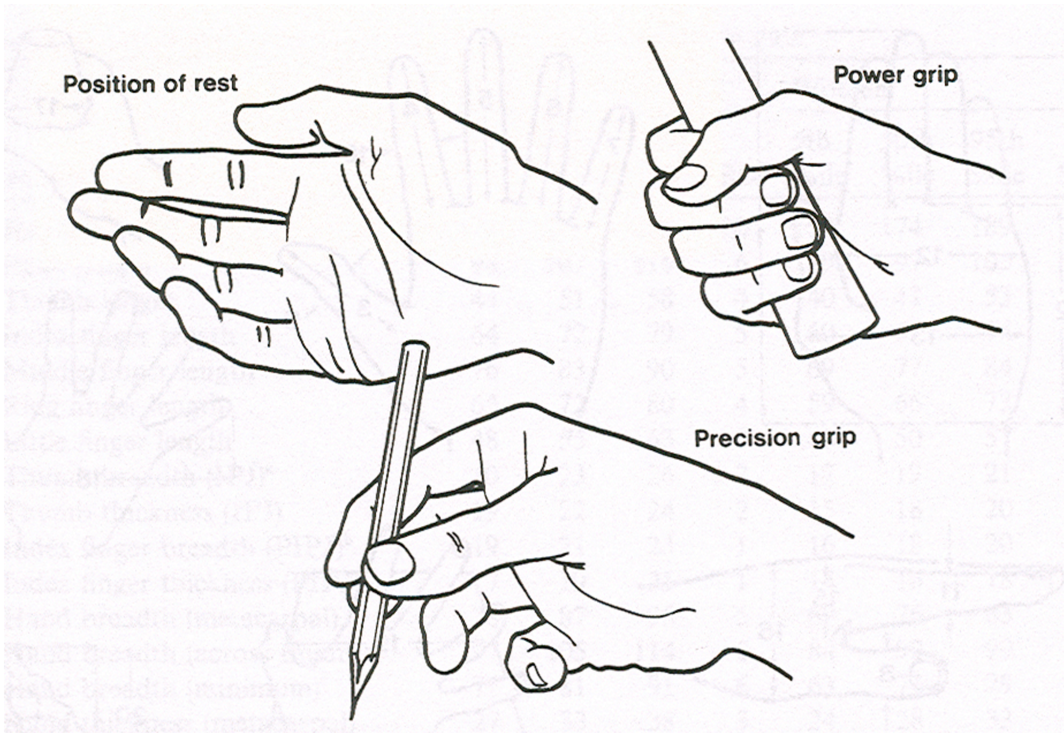


Figure 11. Grip types

### 1.5.7 Silicone Rubber

Part of the problem with dental handpieces is hypothesized to be the cold, hard and metallic look. During our search for ways to give dental drills a softer, warmer and more comforting appearance, an interesting trend emerged. Many of today's scalers use silicone rubber grips. Scalers are dental instruments characterized by their sharp tipped hook and used for removing tartar from teeth. These scalers go through the same daily use and cleaning process as the dental drills.

It is common to find scalers with silicone grips. Silicone is softer, more comfortable, and more ergonomic than a metal grip, plus it can withstand the extreme environment of an autoclave as well as withstand cleaning chemicals. Even better, silicone rubber is also resistive to less extreme, yet more typical, wear and tear. Another benefit is that silicone is inexpensive. *Dental Catalog (155th ed.)* offers products from a company called Dentsply Professional which carries many lines of scalers with silicone grips. For example, one line, called Flexichange, sells silicone grips at the cost of $9.29 (*Dental Catalog*, 2005).

The same catalogue lists dental handpieces from $184.99 to $924.99. When silicone rubber grip is added, even the least expensive of handpieces would only see about a five percent increase in price. The average handpiece's price would only increase approximately three percent, which makes silicone rubber a realistically cost viable option. (2005)

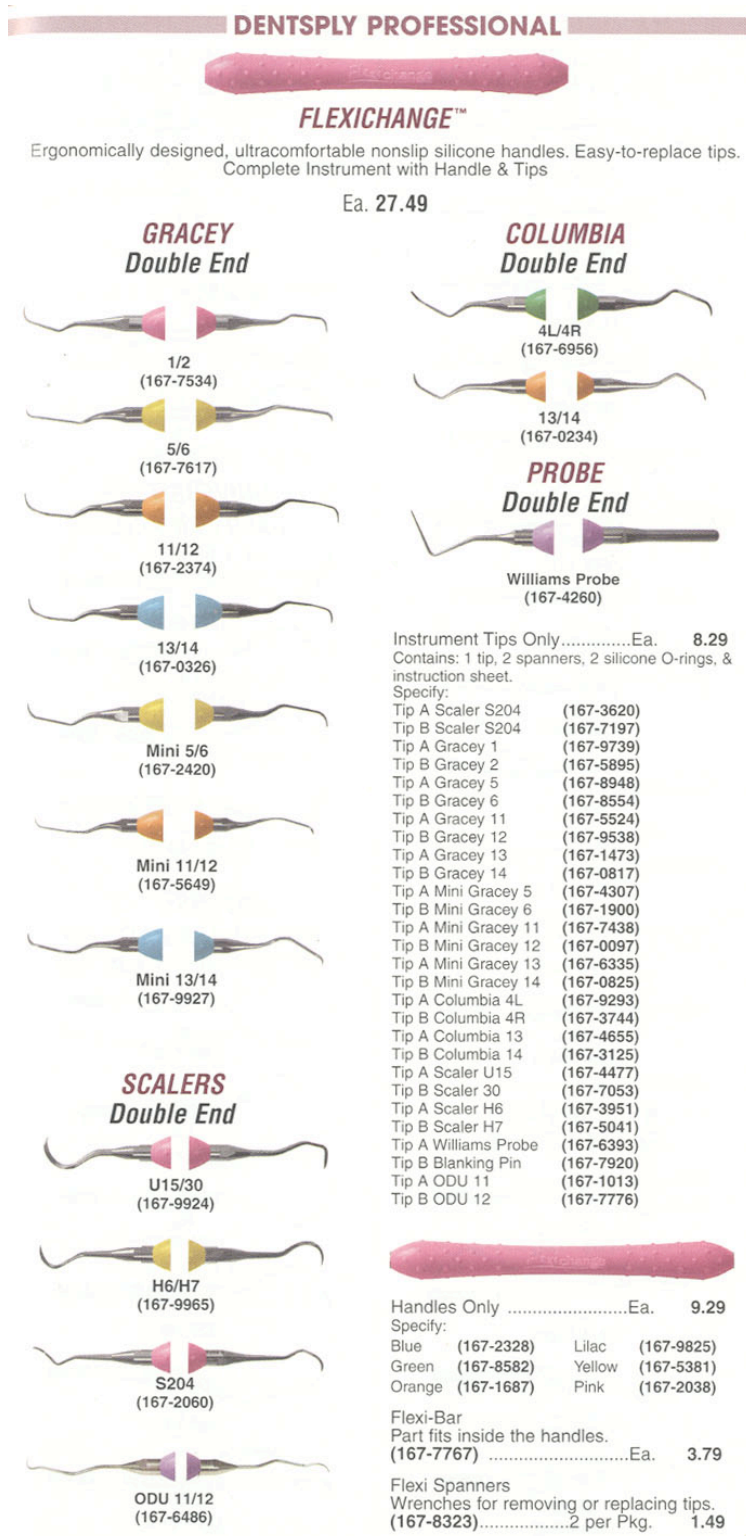


Figure 12. Low cost silicone grips

### 1.5.8 Fiber Optics & Swivels

During the research process it became clear that designing a new, revolutionary dental handpiece should include some of the latest technology available. It would be helpful to include a fiber optics lighting feature to give dentists a well-lit workspace. In addition, adding a swivel to the cable will aid dentists by reducing the resistance from the dental drill's hose. This often hinders dentist's work, as was mentioned by almost every dentist interviewed. This raises the question: for air powered dental drills, is it possible to produce a swivel connection which accommodates fiber optic lighting and does not suffer significant loss of air pressure and/or water pressure? According to *Dental Catalog (155th ed.)*, this can be achieved. The Sullivan Schein Catalog lists several fiber optic swivels which are already in production and available to dentists for the cost of $134.99 to $250.99 (2005).

STARFLEX® HANDPIECES

High-speed handpiece with steel autochuck turbine. Small head size improves visibility and accessibility to the oral cavity. Lightweight, electropolished, stainless steel surface is resistant to damage caused by handling. Scalloped handle design eliminates grooves where debris and bacteria are often harbored, provides nonslip gripping. 1-year warranty.

**Starflex® SWL Fiber-Optic Handpiece**
Handpiece Less Swivel #62945
(808-8586)....................Ea. **579.99**
3 @ **564.99**

**HiFlo™ Swivels**
Redesigned for increased air flow and easier disconnection. 360° air distribution eliminates performance fluctuation as handpiece is rotated.

**4-Hole Fiber Optic Swivel**
For connecting Star Dental high-speed fiber-optic handpieces to 4-hole fiber-optic tubing.
(808-7501)....................Ea. **194.99**

**6-Pin Fiber Optic Swivel**
For connecting Star Dental high-speed fiber-optic handpieces to ISO-C (6-pin) fiber-optic tubing. Built-in lamp withstands the rigors of autoclaving and chemiclaving. No need to remove lamp prior to sterilization.
(808-0205)....................Ea. **250.99**

**Starflex® SW Handpiece**
Nonfiber-Optic Handpiece Less Swivel #62696
(808-4845)....................Ea. **356.99**
3 @ **346.99**

Note: **Attaches to 2/3 Line or 4-Line Star 360° Swivel.**

**360° Quick-Connect Swivel**
Swivel Assembly....................Ea. **134.99**
Specify:
2/3 Line **(808-0243)** 4 Line **(808-1380)**

**Starflex® K Handpiece with Autochuck**
4-Hole Handpiece #62943. Fixed back end.
(808-7430)....................Ea. **376.99**
3 @ **366.99**

Figure 13. Fiber optic swivels for dental drills

### 1.5.9 Sound

After interviewing 5 dentists and their registered dental hygienists, it became clear that one of the most glaring problems with the experience surrounding the dental drill is the noise level. Each individual interviewed cited the noise of the dental drill as a problem, whether it scared patients or caused hearing loss for people involved with the sound on a daily basis.

According to John Foreman, author of *Sound Analysis and Noise Control*, noise is "unwanted sound." This unwanted sound can keep people from performing at maximum ability and efficiency. Foreman says it can increase nervous tension associated with psychological effects. Noise is a form of air pollution (1990, p.1); therefore it is important to study sound and soundproofing to better understand how to improve the experience surrounding the use of the dental handpiece.

**1.5.9.1 Generation of Sound**

Foreman also describes the generation of sound as follows:

> Sound requires a source, a medium for transmission, and a receiver. The source is simply an object, which is caused to vibrate by some external energy source. The medium is the substance which carries the sound energy from one place to another. (1990, p.1)

As the source vibrates it is moving at a very high frequency. However, to better understand what is occurring, consider a vibration as one movement at a time. Imagine the source as it moves to the right as part of a vibration. As it moves to the right, the source compresses molecules of the medium that are to the right of it. Eventually that source moves back to the left and decompresses the molecules, creating a rarefaction (refer to figure 14). As the source continues to do this again and again, it creates a series of these compressions and rarefactions that travel through the medium away from the source. The ear and microphone receive these changes in pressure, and translates the pressure changes as sound. (Foreman, 1990, p.1)

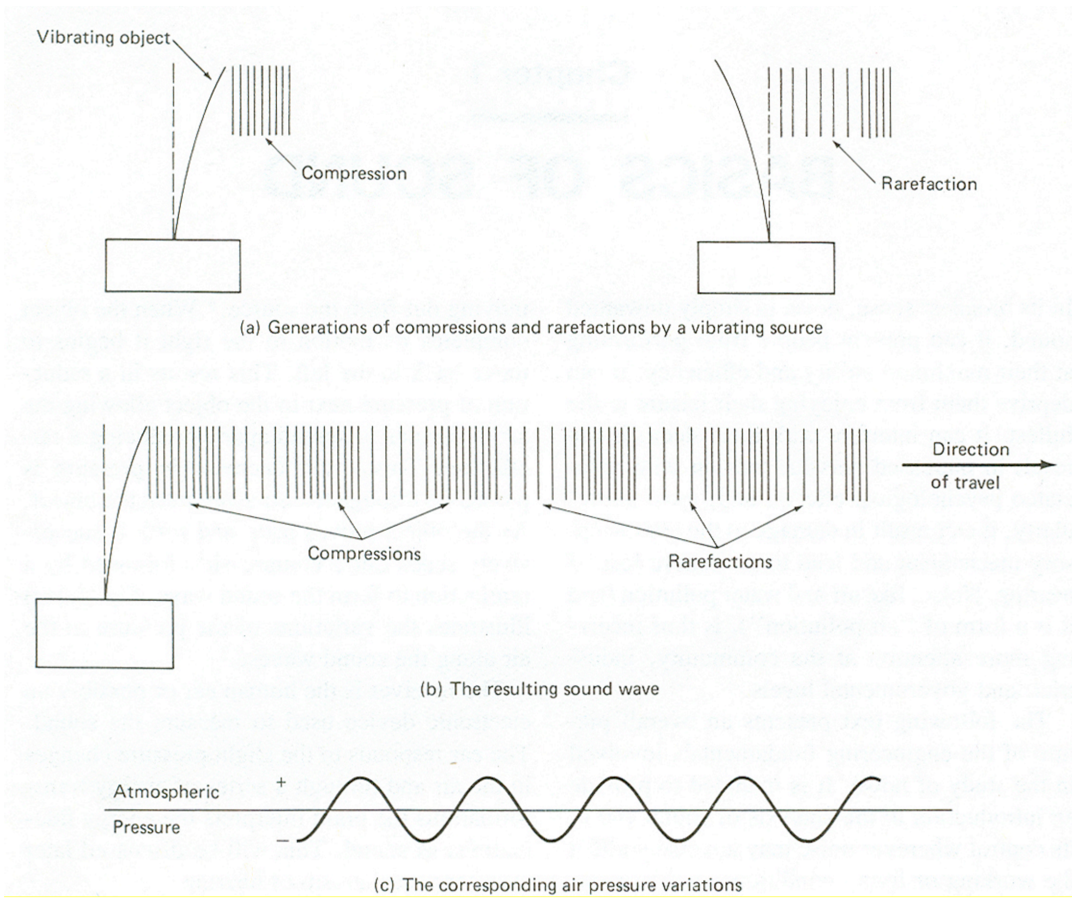


Figure 14. The generation of sound waves

### 1.5.9.2 Soundproofing

John Foreman explains three different mechanisms for absorbing sound. These methods for soundproofing are viscous flow, internal friction and panel vibration. Foreman explains them as the following:

**Viscous Flow**. An effective absorber consists of a series of interconnected pores and voids through which sound waves propagate. During propagation, the particle velocity associated with the sound wave causes relative motion between the air molecules and the surrounding material. As a result, friction generates heat, which is dissipated into the atmosphere as lost energy from the sound wave.

**Internal friction**. Some absorptive materials have resilient fibrous or porous structures; dissipation of energy occurs not only from the viscous flow losses, but also from the internal friction of the material itself.

**Panel vibration**. Some increase in low-frequency absorption can often be obtained by mounting the absorption material at a suitable distance from the walls of a room. This is because the energy in the low-frequency incident sound causes the material to vibrate like a panel, and in so doing some energy is removed from the incident sound wave. (For example, drapes should be hung away from a wall, not touching it, if it is desired to increase the low frequency absorption of the drape).

The absorptive characteristics of an acoustical material are determined to a large extent by the pore or void size, interconnections between pores and voids, and material thickness. (1990, p. 110)

John Foreman continues by explaining sound absorbing materials and the three different types:

> The types of porous materials in common use are fibrous materials (such as rock wool, mineral wool, and fiberglass), perforated loose-texture board, foam rubber (in particular, reticulated poly urethane foam-where there is a common air path between cells in the foam), fabrics, carpets, drapes, upholstery, etc. Commercial porous materials can be divided into three categories: (1) prefabricated acoustical units, (2) acoustical plasters and sprayed-on material, and (3) acoustical (isolation) blankets. (1990, p. 112)

One method of sound absorption is NASA's sound suppression water system. The John F. Kennedy Space Center uses a sound suppression water system to protect the orbiter and its payloads from damage created by acoustical energy and rocket exhaust reflected from the flame trench. This system uses a 300,000 gallon elevated water tank, which fills in about 20 seconds just before ignition. As the space shuttle reaches an elevation of 300 feet above the platform acoustical levels reach their peak, and drift off until they are no longer a problem at an altitude of 1,000 feet.

There are two primary components to this sound suppression system, a water spray system, and a series of water baths. Together these water barriers block the path of the reflected pressure wave from the rocket boosters, which decreases the intensity of the pressure and sound (Morgan, JoAnn H., 2000).

### 1.5.10 Child Psychology

Since the focus of this thesis is creating a neutral appearance for the dental handpiece in the eyes of children, it is important to get children's opinions on the subject. This can be a difficult task for a number of reasons. This section explores literature that discusses the topic of collecting children's opinions, the difficulties involved, and what helpful hints are available.

#### 1.5.10.1 Minimal Interference

One of the first things to keep in mind when conducting observations or surveys is to minimize interference. It is difficult to collect the opinions of others without influencing those opinions, but for the sake of research, that interference must be minimized. Pellegrini and Bjorklund describe the importance of this problem in some detail:

> The notion of minimal interference should be stressed to the extent that observers typically have an effect on those that are being observed albeit an unintentional influence. It is crucial that observers recognize the effects they have on those being observed and try to minimize them. In the final analyses, observers must also account for these effects on the behavior of those being observed. (1998, p.73)

#### 1.5.10.2 Questionnaires

Since observation is not as effective in collecting opinions from large quantities of children and dentists, questionnaires were used to accomplish this goal. Touliatos and Compton, authors of *Approaches to Child Study,* describe questionnaires in detail. Questionnaires usually require little explanation. The respondents are typically given as much time as they need to think about their answers without pressure to respond. Questionnaires also have the advantage that there is typically less desire on the respondents' part than an interviewee to try to impress the investigator. Plus, the questionnaire is inexpensive and requires little skill on the part of the administrator when compared to interviews. Also, it can be administered to a large group simultaneously while providing anonymity for the respondents. (1983, p. 188)

Touliatos and Compton also describe the limitations of questionnaires in detail:

> Among the limitations of questionnaires are the diversity of meaning that may be attributed to a question by various respondents, the amount of education that may be required of a person in order to understand the questions and procedures, the difficulty of securing valid personal or confidential information, and the uncertainty of whether an adequate number of responses will be received to represent the population. (1983, p. 188)

These are challenges that are taken into account while writing the questionnaires and while analyzing the data collected from the questionnaires. Some of these problems are compounded when working with children.

This is why Touliatos and Compton (1983, p. 188) claim that, “Obviously, self-administered questionnaires cannot be used with young children.” This is an interesting point because it is one that this thesis intends to disprove. Theoretically, if the questionnaire is graphically based and created with the explicit intent of being understood by a targeted age group of children, these difficulties can be overcome enough to collect relevant data.

Michael P. Riccards also has some things to say about the difficulty of surveying children. Riccards breaks it down into three main problems:

- First, some children (especially teenagers) may not take the questionnaire seriously.
- Second, boys and girls often tend to regard the questionnaire as a “test” and they are more likely to choose the answer they feel is correct rather than the one that most closely coincides with their feelings.
- Third, the questionnaire by its very phraseology may be eliciting a specific response. (1973, p. 115)

Michael P. Riccards (1973, p. 116) also warns that, “researchers would still have to be careful to use terms which have the same meaning for all children.” Riccards explains an example of research conducted which "examined the child's differing views of the good citizen." They found that citizenship is used as synonym for conduct in elementary schools. "Thus a well-behaved pupil is termed a good citizen." Therefore, instead of revealing what children felt made a good citizen, they found that children "associated citizenship with obeying the school's rules and regulations."

Another thing to consider when asking questions of children is how far they are in the developmental process. Older children tend to be more capable of answering more complicated questions because they are further developed and further educated. Ross Vasta, author of *Strategies and Techniques of Child Study,* describes this issue using mathematics as an example:

> As children develop they may employ strategies or processes that either were simply not available earlier or were used inappropriately. For example, most 3- and 4-year-olds cannot answer questions like '5 + 3 = ?', where as 7- and 8-year olds do so readily. The nature of developmental change here is that older children have acquired a set of rules for addition…that younger children simply do not have… Older children might solve such problems more effectively than younger children, because they are able to hold and manipulate more information at one time than younger children… The speed of specific processes may increase with age in a way that enhances performance. (Vasta, 1982, p. 212-213)

### 1.5.11 Design Process

The main point of this thesis is to outline a design process, which can guide other designers in designing medical tools that offer improvements over earlier tools. To develop such an outline, it is important to study the design process.

Mike Baxter, author of *Product Design: Practical Methods for the Systematic Development of New Products*, describes three key concepts for a successful design process:

1. Establish aims and scope for concept design

   Different design projects will have very different objectives and constraints determining how radical or incremental the concepts need to be. These must be clearly established with guidance from the opportunity specification.

2. Generate lots of concepts

   Concept design is usually considered to be the creative heart of the design process. As a result, creative idea generation techniques are used most often at this stage. Several techniques exist for the force-generation of new product concepts. These are likely to increase the number of ideas generated from a few to many tens or even hundreds of concepts.

3. Select the best

   Concept selection techniques select the best concepts against criteria derived from the opportunity specification. Probably more importantly,

> they provide a framework for hybridizing and expanding the range of concepts generated initially. Concept selection can, therefore, comprise a highly creative and invaluable conclusion to the concept design process. (Baxter, 1995)

These points are used in the design process of this thesis in ways that are discussed later.

Tim Brown, CEO and president of IDEO, one of the world's leading product-design firms, wrote an article called "Strategy by Design" for the magazine *Fast Company*. Brown has two specific tips that are very relevant to this research. The first is called "Hit the Streets":

> Any real-world strategy starts with having fresh, original insights about your market and your customers. Those insights come only when you observe directly what's happening in your market. As Jane Fulton Suri, who directs our human-factors group, notes in her book *Thoughtless Acts?* (Chronicle Books, 2005), "Directly witnessing and experiencing aspects of behavior in the real world is a proven way of inspiring and informing [new] ideas. The insights that emerge from careful observation of people's behavior… uncover all kinds of opportunities that were not previously evident."

Tim Brown also goes on to explain a strategy called "Build to Think":

> Design thinking is inherently a prototyping process. Once you spot a promising idea, you build it. The prototype is typically a drawing, model or film that describes a product, system or service. We build these models very quickly; they're rough, ready, and not at all elegant, but they work. The goal isn't to create a close approximation of the finished product or process; the goal is to elicit feedback that helps us work through the problem we're trying to solve. In a sense, we build to think… It's a process of enlightened trial and error: Observe the world, identify patterns of behavior, generate ideas, get feedback, repeat the process, and keep refining until you're ready to bring the thing to market. (2007)

As mentioned earlier, this thesis' design process is also based on the design process used by Apple, the company that designs Macintosh computers and iPods. Apple is known for continually churning out innovative designs. Helen Walters (2008) says that many companies try to understand design in the way that Apple does, but fall short. Business Week highlighted her blog on their innovation web site. In this blog Walters details a presentation at South by Southwest (SXSW), by Michael Lopp, senior engineering manager at Apple. Walters quotes Michael Lopp's answer to the question, "How the f*ck do you do that?"

Lopp answered that question with elements of Apple's design process. There are two elements that are particularly relevant to this research. The first is called "10 to 3 to 1":

Apple designers come up with 10 entirely different mock ups of any new feature. "Not," Lopp said, "seven in order to make three look good," which seems to be fairly standard practice elsewhere. They'll take ten, and give themselves room to design without restriction. Later they whittle that number to three, spend more months on those three and then finally end up with one strong decision. (Walters, 2008)

The other element is called the "Pony Meeting". Walters says:

This refers to a story Lopp told earlier in the session, which described the process of a senior manager outlining what they wanted from any new application: "I want WYSIWYG…I want it to support major browsers…I want it to reflect the spirit of the company." Or, as Lopp put it: "I want a pony!" He added: "Who doesn't? A pony is gorgeous!" The problem, he said, is that these people are describing what they think they want. And even if they're misguided, they, as the ones signing the checks, really cannot be ignored.

The solution, he described, is to take the best ideas from the paired design meetings and present those to leadership, who might just decide that some of those ideas are, in fact their longed-for ponies. In this way, the ponies morph into deliverables. (Walters, 2008)

### 1.5.12 Concluding the Literature Review

With the detailed information collected from these knowledgeable writers and researchers, one is better equipped to redesign the dental handpiece with improved ergonomics for the dentists and a focus on eliminating fear that children associate with this dental tool. One must understand considerations for the tool, the user, the recipient, and the ergonomics involved to create an improved design. This review details these considerations, except for the user, who will be explored further with interviews that are discussed later in this thesis.

The research that has already been discussed revealed what could and could not be done with this redesigned handpiece. For instance, in interviews with dentists that will be discussed later, the sound of the drill is often cited as a significant factor that contributes to pediatric patients' fear of the dental office. The research of sound proofing and reduction discussed earlier revealed that reducing the sound of the drill would require an addition of weight and spatial volume, which would make the drill more difficult for dentists to work with.

What the research revealed that could be accomplished with this redesign included these things. First of all, silicone grips can be used in order to improve three problems. The silicone will add color to the drill, making it more appealing and less intimidating to children. Silicone grips are also soft, which creates a more ergonomic grip. The silicone rubber also gives dentists a better grip on the tool. The interviews mentioned later revealed that during use, the dental drill becomes covered in saliva and is very difficult to get a firm grip on. By using a silicone rubber grip with grooves to channel the saliva away from where dentists grip the tool, dentists can have the firm grip that they desire.

### 1.6 Definition of Terms

**Capitulum** is "a rounded protuberance of an anatomical part as (a) the knob at the end of a bone or cartilage (b) the beak of a tick composed of the mouthparts and palpi" (Merriam-Webster's Medical Dictionary, 2008).

A **cavity** (also known as a **cary**) "is a hole in the enamel (the outer very hard part of a tooth). These holes are created by plaque, which forms a 'film of bacteria' on teeth. This bacterium creates acid as a byproduct of its metabolism. This acid is what eats holes in the enamel of teeth" (Gordon, Jerry, 2000).

**Cementum** "covers the roots of the tooth beneath the gum line" (Gordon, Jerry, 2000).

**Dorsiflexion** is "flexion in a dorsal direction, especially flexion of the foot in an upward direction" (Merriam-Webster's Medical Dictionary, 2008).

**Dental Pulp** is located beneath the dentin. It is "a vascular tissue, composed of capillaries, larger blood vessels, connective tissue, nerve fibers, and cells including odontoblasts, fibroblasts, macrophages, and lymphocytes." During growth and development it is used to nourish the tooth, but as an adult tooth it is only used to indicate problems. This is accomplished through pain (Gordon, Jerry, 2000).

**Dentin** is located beneath enamel and cementum. It is made of the same substance as bone and includes nerve endings (Gordon, Jerry, 2000).

**Enamel** is the outermost layer of the tooth just above the gum line. This is the hardest and most mineralized part of the body (Gordon, Jerry, 2000).

**Epicondylitis** is also known as Tennis Elbow. This is an injury caused by persistent rotation of the wrist during use of a hand tool (McCormick & Sanders, 1982).

An **explorer** is a tool that dentist use by scraping along teeth to find cavities (Gordon, Jerry, 2000).

The **handpiece**, also known as the dental drill, is "a small, high-speed drill used in dentistry to remove decayed tooth material prior to the insertion of a dental filling." It is used to treat dental caries (cavities) (Wikipedia, 2007).

The **humerus** is "the longest bone of the upper arm or forelimb extending from the shoulder to the elbow, articulating above by a rounded head with the glenoid fossa, having below a broad articular surface divided by a ridge into a medial pulley-shaped portion and a lateral rounded eminence that articulates with the ulna and radius respectively, and providing various processes and modified surfaces for the attachment of muscles" (Merriam-Webster's Medical Dictionary, 2008).

**Internal friction** occurs when "some absorptive materials have resilient fibrous or porous structures, which create a dissipation of energy, not only from the viscous flow losses, but also from the internal friction of the material itself" (Forman, 1990).

**Panel vibration** is an "increase in low-frequency absorption that is obtained by mounting the absorption material at a suitable distance from the walls of a room. This is because the energy in the low-frequency incident sound causes the material to vibrate like a panel. When that happens some energy is removed from the incident sound wave. (For example, drapes should be hung away from a wall, not touching it, if it is desired to increase the low frequency absorption of the drape)" (Forman, 1990).

**Pronation** is an inward rotation of the forearm (turning the palm downwards) (Pheasant, 1996).

The **radius**: "the bone on the thumb side of the human forearm, (or on the corresponding part of the forelimb of vertebrates, which are above fishes in the evolutionary scale) in humans is movably articulated with the ulna at both ends so as to permit partial rotation about that bone. The radius bears on its inner aspect, a prominence, somewhat distal to the head, for the insertion of the biceps tendon. The distal end of the radius has a broadened area for articulation with the proximal bones of the carpus, so that rotation of the radius involves the hand" (Merriam-Webster's Medical Dictionary, 2008).

**Scaler** is a "dental instrument for removing tartar from teeth" (Merriam-Webster's Medical Dictionary, 2008). Its sharp tipped hook is the scaler's defining characteristic.

"**Soundproofing** is any means of reducing the intensity of sound with respect to a specified source and receptor" (Wikipedia, 2007).

**Supination** is an outward rotation of the forearm (turning the palm upwards) (Pheasant, 1996).

**Viscous Flow** is a sound absorber which "consists of a series of interconnected pores and voids through which sound waves propagate. During propagation, the particle velocity associated with the sound wave causes relative motion between the air molecules and the surrounding material. As a result, friction generates heat, which is dissipated into the atmosphere as lost energy from the sound wave" (Forman, 1990).

# CHAPTER 2

# DEVELOPMENT PROCESS

Every well-designed product goes through a thorough design process. Michael Lopp, senior engineering manager for Apple, describes how Apple produces one successful design after another. What he describes as their factor for success is Apple's design process.

Though the process used in this thesis is not identical, it is based on Apple's 10 to 3 to 1 design process. According to Michael Lopp, Apple requires their designers to come up with 10 completely different concept mock-ups of each new feature or concept. From that 10, three are selected to continue development. The designers spend a few months working on those three, which are later narrowed down to one concept which will be further developed (2008). As mentioned before, the 10 to 3 to 1 process is the basis for the process written about and exemplified in this thesis through the redesign of the dental drill.

The design process of this thesis is also based on Mike Baxter's three key concepts of design process, which were discussed earlier: Establish aims and scope for concept design, Generate lots of concepts and Select the best (1995).

## 2.1 Observation

Once a product has been chosen for redesign it is important that the designer become as familiar with the product and user as possible. In the article written by Tim Brown, CEO and President of IDEO, he quotes IDEO's director of human-factors group, Jane Fulton Suri. Suri said, "Directly witnessing and experiencing aspects of behavior in the real world is a proven way of inspiring and informing [new] ideas. The insights that emerge from careful observation of people's behavior…uncover all kinds of opportunities that were not previously evident." This is typically best achieved by user interviews and product usage observation (2007).

### 2.1.1 User Interviews

To understand a product one must understanding the users, how the users perceive the product, what the users like about the product and what the users dislike about the product. It is also important to listen to what the users claim they want and distill that information down to the benefits that they really want. This is described in Michael Lopp's speech that was mentioned earlier (2008). This senior engineering manager for Apple described meetings with leadership figures above him in the company. These leadership figures would describe what they want from the designers. Michael summed up these great, yet unrealistic, ideas that they ask for as "I want a pony!" ideas. Lopp mentions, "Who doesn't? A pony is gorgeous!" Helen Walters, who wrote the article about Lopp's speech, describes Lopp as saying, "The problem…is that these people are describing what they think they want." Lopp's solution is to take the ideas that the designers have, and the ideas that the upper management has, then fit these ideas together in a way that allows him to give upper management realistic deliverables. These deliverables may be very different than the "pony" ideas, but they offer the same benefits. This way upper management may not get the exact ponies that they asked for, but they get the benefits they are looking for in a more realistic package that can be manufactured (Walters, 2008). Interviewing users should be approached in much the same way. Listen to what users claim they want, and then use that to figure out the benefits that they are really looking for. The next task is to find realistic ways to deliver those benefits.

This thesis began with interviews of four dentists offices and one orthodontist's office. 6 dentists were interviewed, Dr. Arthur Carroll, Dr. Laura Durham, Dr. Jan Ellington, Dr. Bennie Evans, Dr. Chuck Lindsey and Dr. Brian Roehl, along with two registered dental hygienists Daye Blackmon and Fran Shaddix.


Figure 15. The different dental offices being visited

The interviews provided a list of concerns involved with the dental drill. That list is as follows:

- The sound is very intimidating
- The drill's appearance resembles a knife
- The handle is too thin
- Multiple color choices would offer better variety in the office
- Needs better grip
  - Slips under ideal conditions
  - Very slippery with use of gloves
  - Even worse when wet (dental drills are typically wet with saliva when in use)
- Cleaned by high pressure, high temperature steam
    - According to cleaning device manual (autoclave manual), handpieces must, for 12 minutes, withstand 134 degrees C steam that has been pressurized to 216 kPa.
- Cords can hinder work
  - Cords tangle
  - Curly Cords exhibit even more tangling problems
  - A cordless dental drill would be great
  - Long hand pieces weigh down the back end throwing off the balance of the tool
- Smaller and lighter is always better (less fatigue)

All of these things are considered during the design process to guide this new handpiece in the right direction.

### 2.1.2 Product Usage Observation

User interviews are not enough. Often users do things that they are not conscious of. These unconscious acts are often revealed through field studies.

In order to fully understand the handpiece and the entire process that surrounds its use, dentists were observed using the drills to prepare teeth for fillings and crowns. During this time, pictures are taken as documentation for further study later. Three dental offices mentioned earlier are visited and five patients are observed.

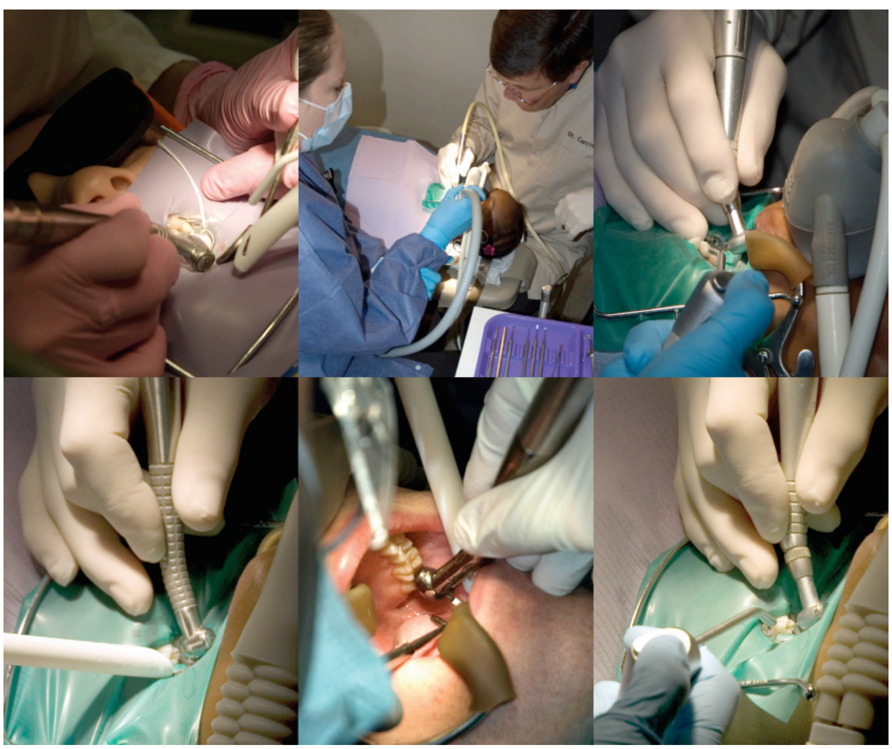

Figure 16. Usage observations

An in depth study of the pictures taken reveals the many different ways that dentists hold dental drills. This study reveals that dentists use not only the precision grip, but sometimes use a combination of both the precision grip and the power grip mentioned earlier. Dentists use the tip of their pointer finger and thumb for the precision grip, and sometimes use other fingers to brace or to apply force. This study also reveals that dentists tend to hold the dental drill in two different locations on the handle. They either hold it close to the head and in front of the bend in the handle, or further back, just behind the bend in the handle. Plus, when working on the upper teeth, dentists tend to sit behind the patient's head and use the dental drill upside down. Also, the dental drill is often rotated with the fingertips to get the perfect angle for the job.

After analyzing the information collected from interviews and observations it is time to implement Mike Baxter's first key concept, "Establish aims and scope for concept design" (1995). The problems need to be clearly defined at this stage. Once that is done, it is important to decide which problems reveal realistic opportunities for innovation. Finally, that information should be used to define the aims and scope for the new concept design.

### 2.2 Product Conceptualization

Once the aims and scopes are clearly defined it is time to implement Mike Baxter's second key concept of design process, "Generate lots of concepts" (1995). The field data mentioned earlier is used to create numerous concepts.

Mock up models are also an essential part of the design process. As mentioned earlier, Tim Brown, CEO and President of IDEO, describes the importance of mock-ups in an article called "Strategy by Design" which was published by *Fast Company*:

> "The prototype is typically a drawing, model, or film that describes a product, system or service. We build these models very quickly; they're rough, ready, and not at all elegant, but they work. The goal isn't to create a close approximation of the finished product or process; the goal is to elicit feedback that helps us work through the problem we're trying to solve. In a sense, we build to think. [This is] a process of enlightened trial and error: Observe the world, identify patterns of behavior, generate ideas, get feedback, repeat the process, and keep refining until you're ready to bring the thing to market." (2007)

At this stage sketching is useful because sketching has few limitations. The idea is that a designer can sketch whatever can be conceived in the mind. Some designers go straight to computer modeling, but this is a problem because the tools used for computer modeling are more restrictive than a writing utensil and paper. It is also slower than sketching. These two factors restrict the conceptualization process. The designer needs sketches to quickly record and visualize ideas. The idea here is to create as many concepts as possible without restriction. Thumbnail sketches are used to provide a quick "snapshot" of form or detail ideas.

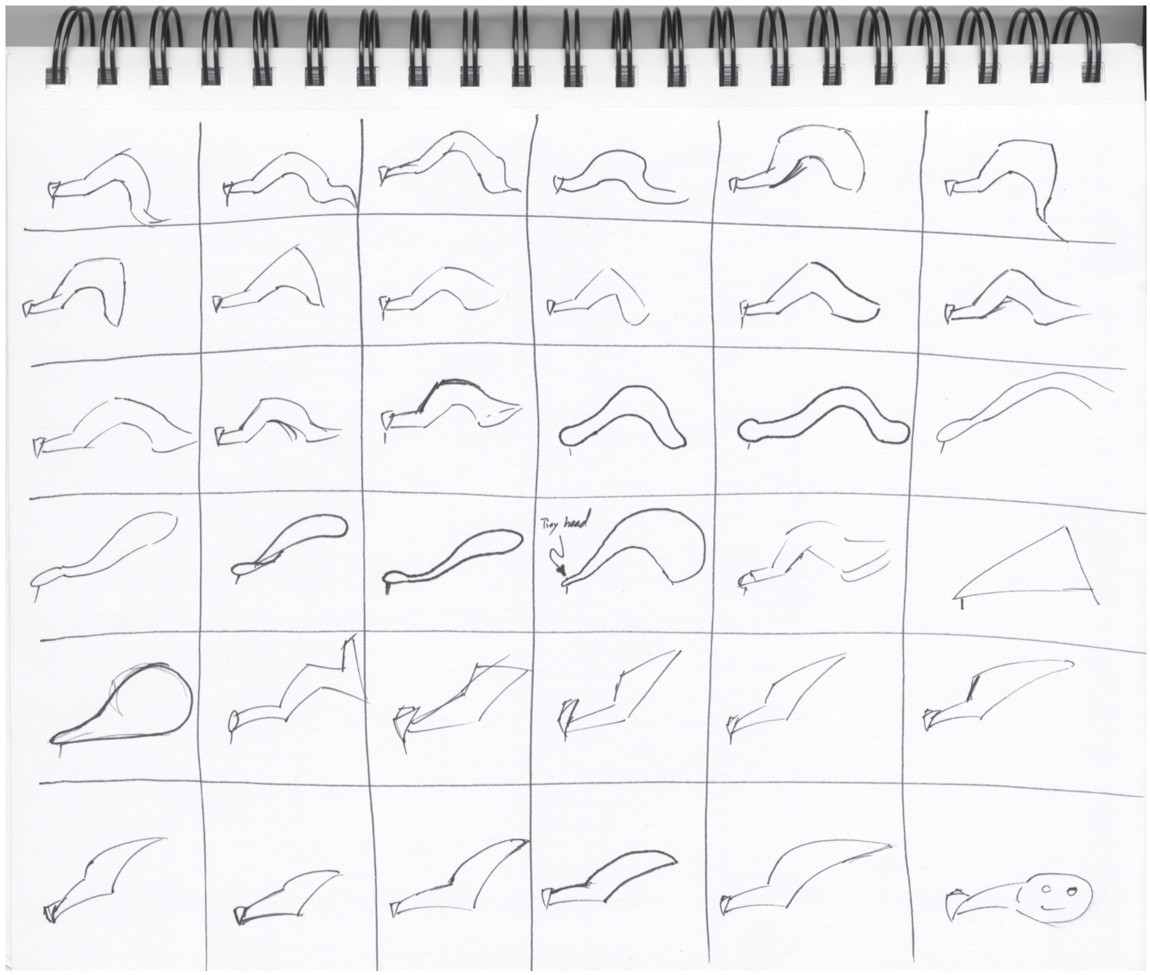


Figure 17. Thumbnail sketches

Preliminary sketches are often drawn based on thumbnail sketches. They are typically larger and provide more detailed information.

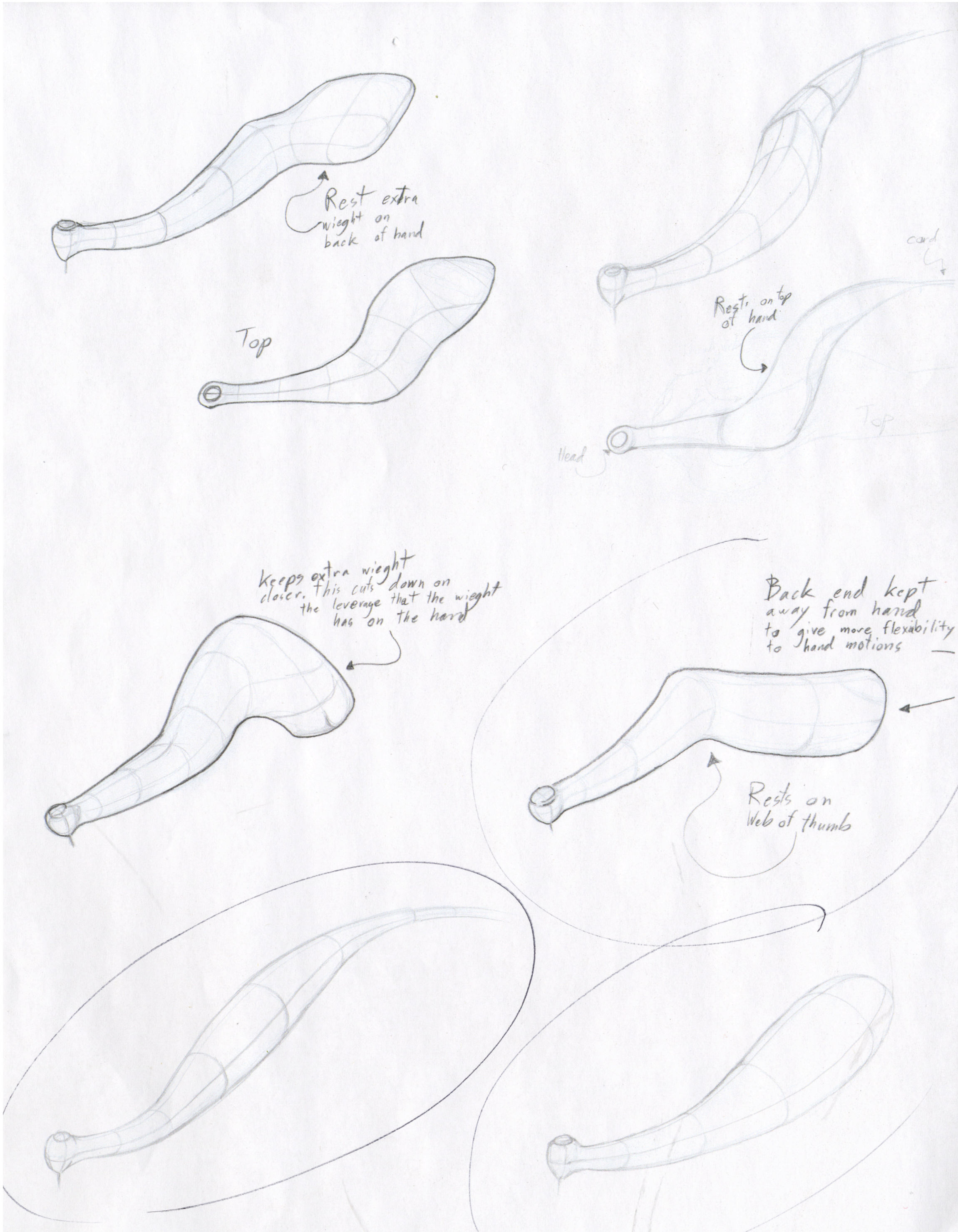


Figure 18. Refined preliminary sketches

## 2.3 Preliminary Ergonomic Models

Since the dental drill is a hand tool, it is important to study its ergonomics during the design process. It is very important that the new model has ergonomics that are equal to, if not better than, the ergonomics of existing handpieces.

This is when Mike Baxter's third key concept of design process, "Select the best" is used for the first time (1995). Initially the top 8 sketches are chosen and built as rough clay models. These models are not intended to be finished appearance models. They are models used to determine which designs are generally more ergonomic. The ergonomics that are examined include comfort and maneuverability. They are much like rough 3-D sketches. This is done to weed out some of the less practical ideas before user testing.

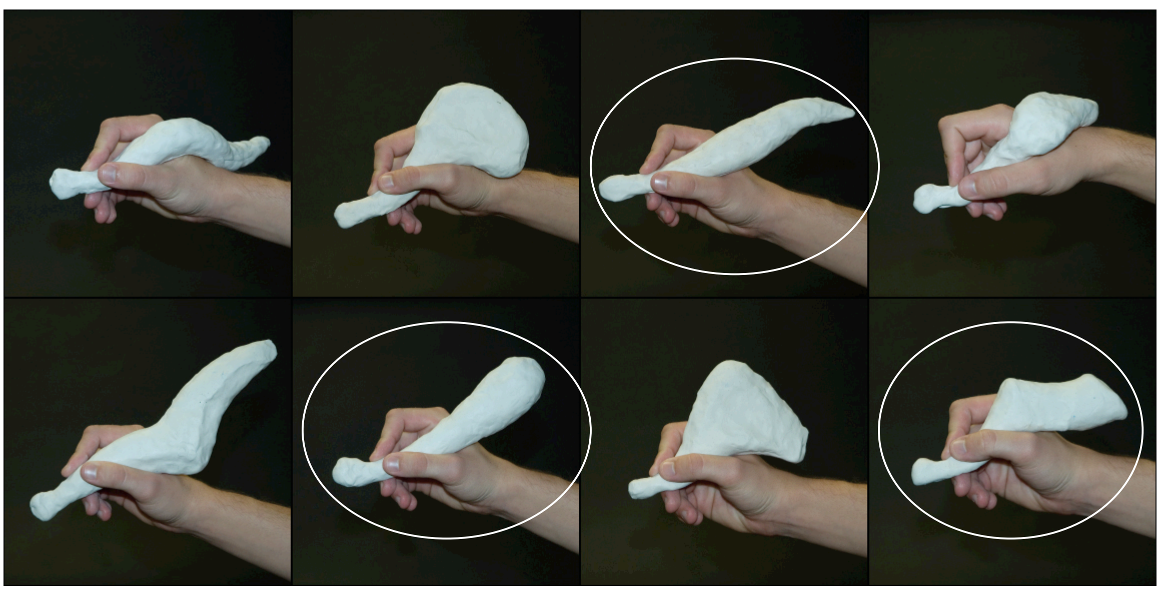

Figure 19. Clay ergonomic models

In the case of the existing dental drill there are three pronounced ergonomic problems. These problems include grip control, visual feedback and balance. The grip is typically slippery because it is a smooth metal grip covered in back spray and saliva. Visual feedback is hindered by the large size of the drill's head. The balance is thrown off by the hose which puts excess pull on the back end of the tool, creating more fatigue on the user's hand and wrist during operation.

After holding and simulating using the clay models it is determined that the two models with a large rear mass (shown in Figure 19) had very poor balance. The two models that wrap over the top of the hand proved to hinder maneuverability. They also were not universal enough to be used by both right handed and left handed people. The model in the bottom left corner of Figure 19 exhibited poor balance.

The three models circled in Figure 19 all exhibited reasonable balance and maneuverability. They also proved to be good universal solutions for both left handed and right handed users. With that in mind, Mike Baxter's concept "Select the best" (1995) is implemented once again, narrowing the 8 concepts down to three top concepts.

### 2.4 Secondary Ergonomic Models

After creating rough clay models it is time to create more refined ergonomic models to put into the hands of the users, in the case of this study, dentists. Clay is great for the preliminary ergonomic models, but a more solid material is necessary for the secondary models and user testing. Though the ability to change the models shape quickly and easily was great for the previous stage, it is important that the shape does not shift during the user testing of this stage. If the models inadvertently change shape in the users' hands during testing, it will be difficult to attain accurate feedback from users. That is why this stage requires a model material that is more solid than clay.

MDF (medium density fiberboard) is chosen as the secondary ergonomic model material.  It is hard enough to hold the same shape through the user testing of 5 dentists, yet soft enough that the shape can be carved out with a dremel.  It is also an inexpensive material that is easy to come by.  The best material for the job will change with the job and situation.

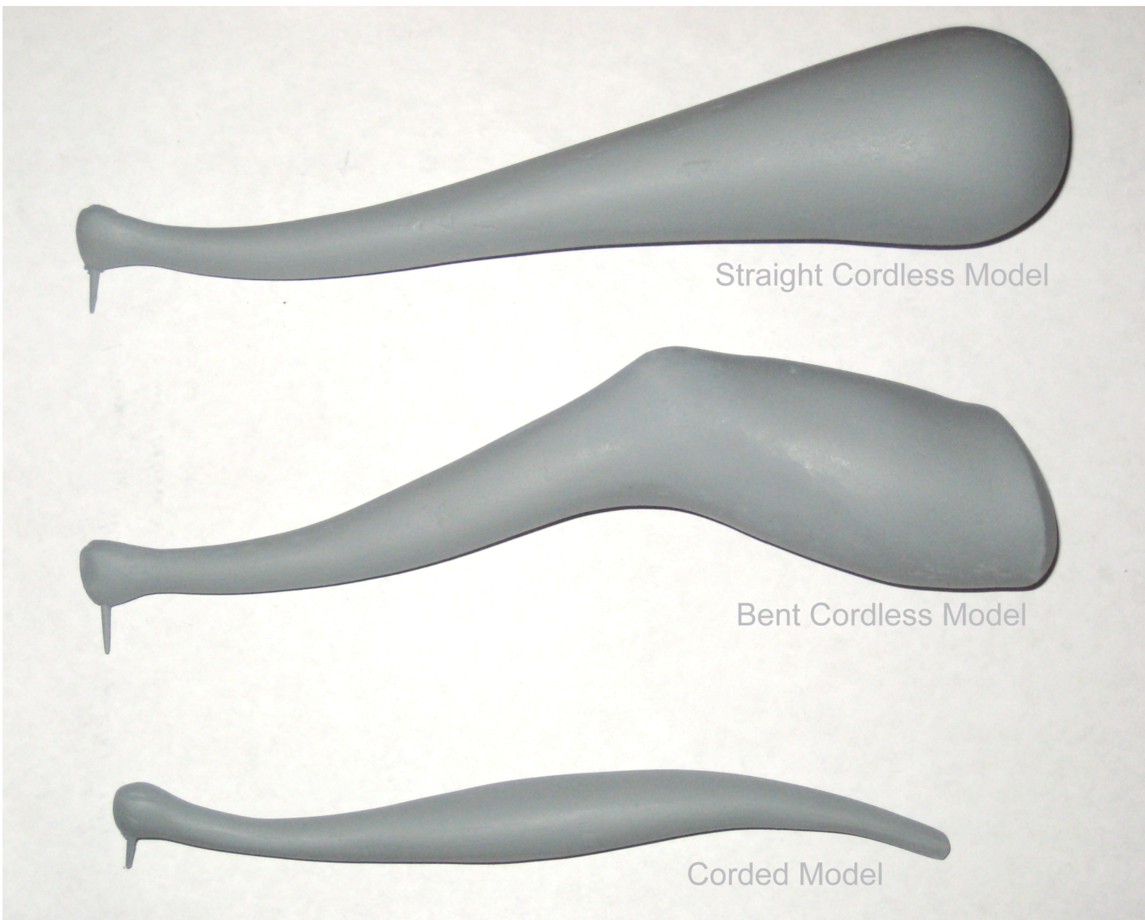


Figure 20. Secondary ergonomic models

It is now time for the first testing method, user testing.  After the models are produced, they are taken to 5 dentists, Dr. Arthur Carroll, Dr. Laura Durham, Dr. Jan

Ellington, Dr. Bennie Evans and Dr. Brian Roehl. The doctors are asked to hold the models, play with them, simulate using them and then talk about their thoughts on the models. What do they like? What do they dislike? Is it comfortable? What can be improved? Which model is their favorite? Which model do they dislike the most?

Two of the three models are intended to be cordless (see Figure 20). Those two models have larger, heavier back ends to allow space and weight for extra components that are required to go cordless. The first thing learned about those two models is that the heavy weighted back end is too heavy and would interfere with work. They would also wear down dentists' wrist muscles more than present dental drills. They also suffered balance issues. The bent cordless model had poor rotational balance. The straight cordless model puts more leverage on the dentists' hands because the weight on the back end was so high.

Moreover, it is discovered that there are already low speed cordless handpieces for sale and in use, though not widely used. This may be due to the heavy weight of the battery. Cordless high-speed handpieces have been tried too. As mentioned before, drills that operate at high-speeds require pressurized water to cool the tooth while drilling. This prevents nerve damage. As for cordless high-speed drills, there is no technology that can deliver pressurized water from such a small tool without the use of a cord.

Dentists overwhelmingly preferred the corded concept (see Figure 20) because of the small size, lightweight and sleek shape. The main complaint is that the diameter of the handle is too small, an easy adjustment for the next model. With this input, it is time to use Baxter's third concept, "Select the best," (1995) one last time and narrow down to the better of the three concepts, then move on to the next stage.

## 2.5 Third Generation Ergonomic Model

It is now time to build an exact ergonomic model of the corded concept. User suggestions should also be considered and analyzed in order to find adjustments that should be made to the concept. This new model needs to go through user testing, just like its three predecessors, for final suggestions from the users.

Before building the model it is necessary to draw a few more sketches to refine the concept, which is a good demonstration of how some steps should be repeated throughout the process as needed.

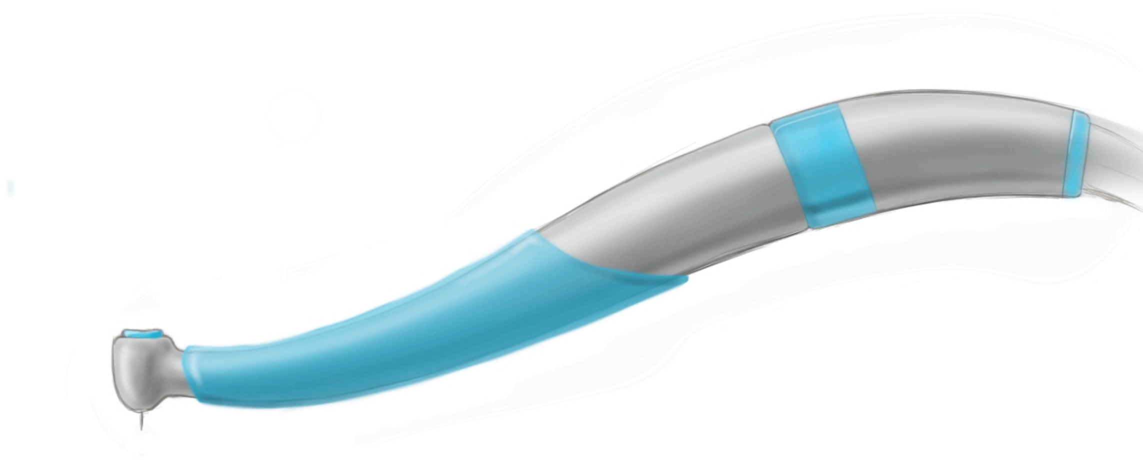

Figure 21. Refining sketch

The precise ergonomic model is drawn in Rhino (a 3-D computer aided designing software), then transferred to a computer-controlled milling machine. The model was milled from HDPE plastic. The model is given the appropriate weight by adding metal pellets to the interior.

Once the model is properly weighted and finished, it is time for user testing. The same dentist offices are visited again and the exact same user testing method is used again for the last ergonomic model.

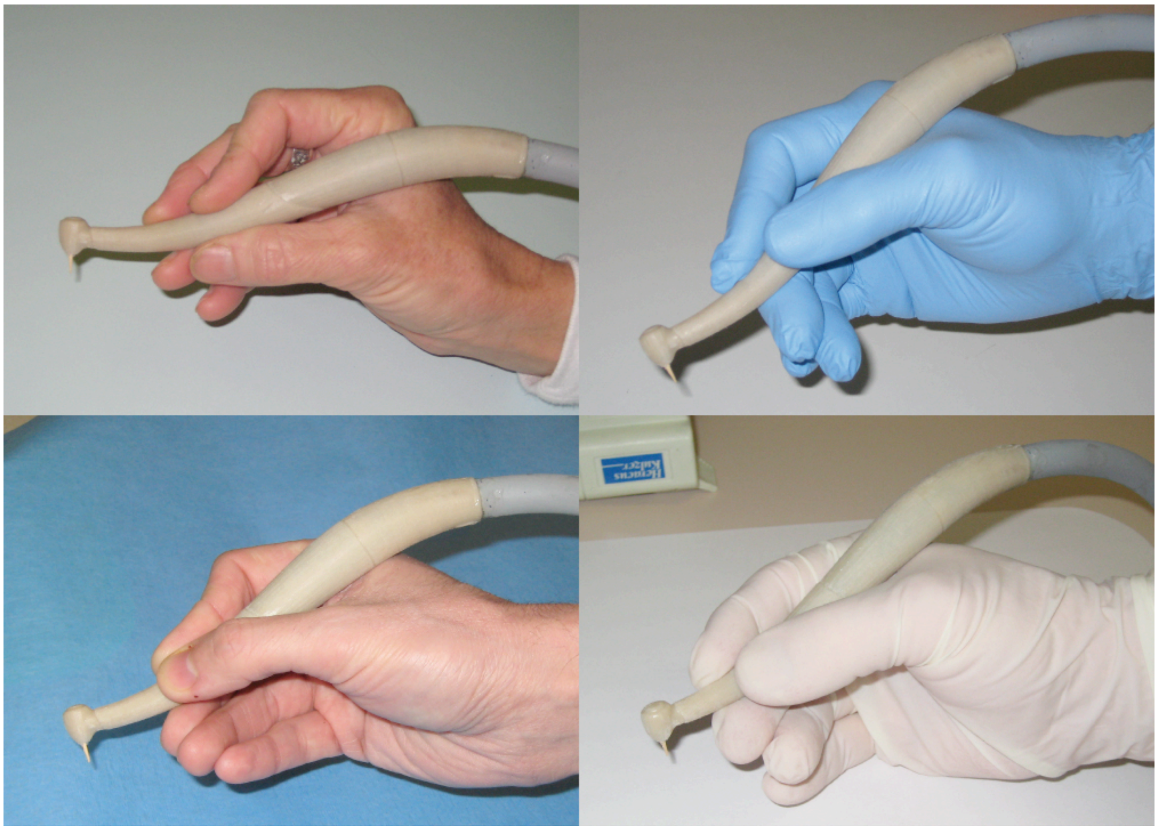

Figure 22. Third generation ergonomic model testing

The user testing proves that the refinements are paying off. The dentists love the latest model with only two complaints. The first complaint is that the handle diameter is still a bit too small and the second complaint is that the weight balance is too far back. The handle thickness is, again, easily adjusted. The balance is due to a model building restriction. Due to the small form factor and lightweight building materials, it was not possible to properly balance the model, which leaves less accurate feedback, though the feedback is accurate enough for the purposes of this study.

### 2.6 Questionnaires

Though it is important to work closely with a few dentists in order to get detailed feedback, at some point it is important to get more general feedback from a larger number of dentists. This helps to make sure that the design is not just designed specifically for a few dentists, but it is designed for a broad range of dentists. It is also important to survey a broad number of children for the same reasons. The target is 300 hundred responses for each group, the dentists and the children, to make sure that substantial feedback is collected.

#### 2.6.1 Surveying Users

First the users are surveyed, which for this study, are the dentists. These surveys are a bit less challenging than the children's survey. Communication with adults who have professional dental education is much easier. The survey can ask questions very directly and precisely. The only challenges in surveying dentists is making sure that the language of the questions and answers is short, clear, to the point and unbiased. Surveying children has these same challenges and many others that are discussed later.

##### 2.6.1.1 Anticipated Outcome

Before administering the survey, certain results are anticipated. First, it is anticipated that a vast majority of dentists will point to children as the patients that are most fearful of the dental office. As for asking, "What was the most significant contributing factor to patients fear?" it is anticipated that about 30% of dentists will indicate the dental drill, while the most common answer will be bad experiences with a dentist. When asking dentists, "Do fearful patients hinder work?" 90% or more are anticipated to agree. Fewer are expected to attribute a significant amount of this fear to the dental drill, though a majority of dentists are still expected to agree with the drill being a significant factor. When asked if a drill with a friendlier appearance would help, the percentage of dentists expected to agree drops out of the majority, but is still expected to be a significantly large percentage of agreeing dentists. It is also anticipated that the majority of dentists will select that 21-40% of their patients are afraid of the dental drill. As for the new design, it is expected that about 80% of dentists will like the rubberized grip and about 20-30% to like the idea of a lighter, colorized plastic handle.

#### 2.6.1.2 Statistical Findings

Before talking about how dentists responded to the survey, it is important to mention how many dentists responded to the survey. The target is to collect 300 dentist responses. Unfortunately, after much hard work, only 9 responses are collected. It is suggested that designers still strive for 300 user responses. With that in mind, even though the target has not been reached, 9 responses are enough to give some indication of how dentists feel. Here are the results of how those dentists responded to the questionnaire.

66% of dentists said that the patients most fearful of the dentist office are under the age of 10. This is certainly a majority, yet a bit smaller percentage than was expected. When dentists are asked what they think is the main contributing factor to patients' fear, the anticipated results are close. The responses to this question are broader than anticipated, though. The most common response is bad experiences with previous dentists, which is mentioned by three of the nine dentists. Only one dentist mentions the drill, while two indicate the fear of pain. On the other hand, when they are directly asked if they feel the dental drill is a significant contributing factor to patients' fears, 77% of dentists agreed that it is. This indicates that the drill may not be patients' main fear, but it is certainly a significant contributing factor to their fear. After fearful patients were watched during part of the observation stage, it is anticipated that the vast majority of dentists will agree that fearful patients hinder their work. 55% of dentists feel this way, according to the survey results. It was expected that there would be more agreement on this topic, but 55% is still a substantial number of dentists. It is also surprising to see that the same number of dentists that feel the dental drill is a significant contributing factor, also feel that a drill with a friendlier appearance would help calm fearful patients. This included 7 out of 9 dentists. When asked what percent of their patients fear the handpiece, four of the dentists say less than 21% while 5 of the dentist claim over 20%. Two of those dentists even go as far as to say over 40% of their patients fear the dental drill.

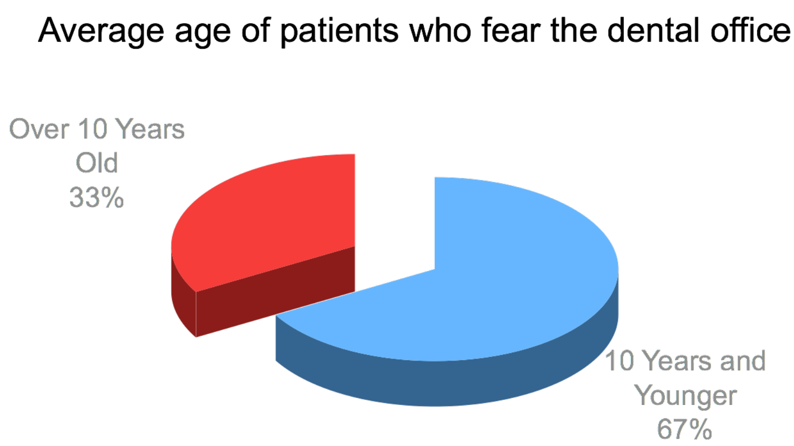


Figure 23. Average age of fearful patients

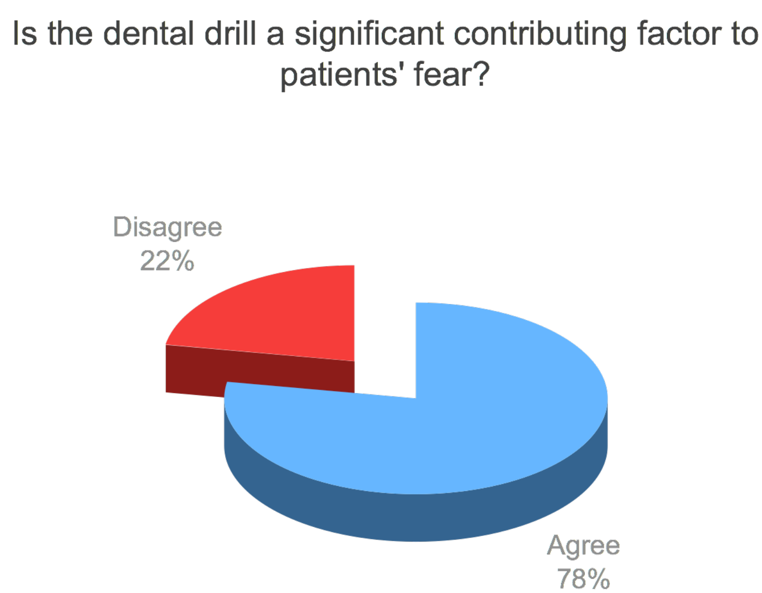


Figure 24. Dental drill's contribution to fear

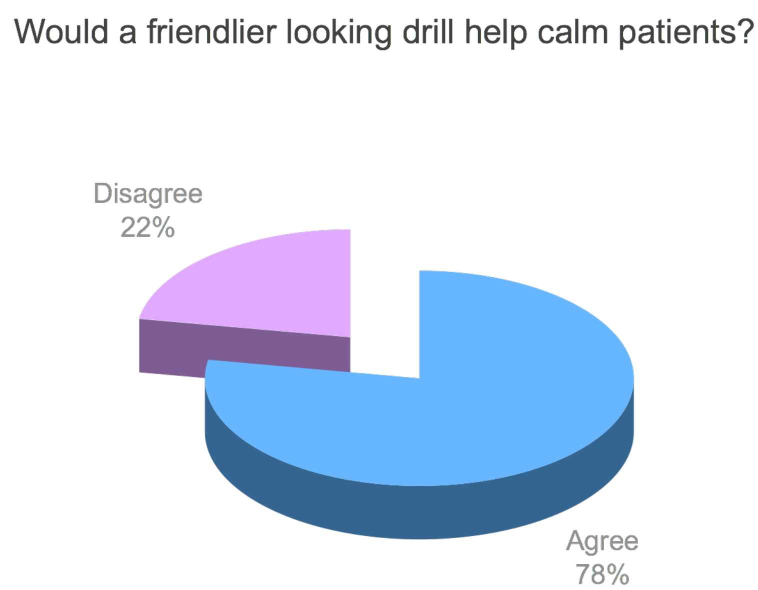


Figure 25. Friendlier drills could calm patients

When asked about concepts involving the new design, a surprisingly high number of responses in favor of the new ideas are received. Not a single dentist is against a rubber grip, while only one dentist out of the nine is against using a plastic dental drill. Five of the dentists are in favor of the rubber grip and surprisingly; six dentists are in favor of trying a plastic dental drill if it means more color options and less weight.

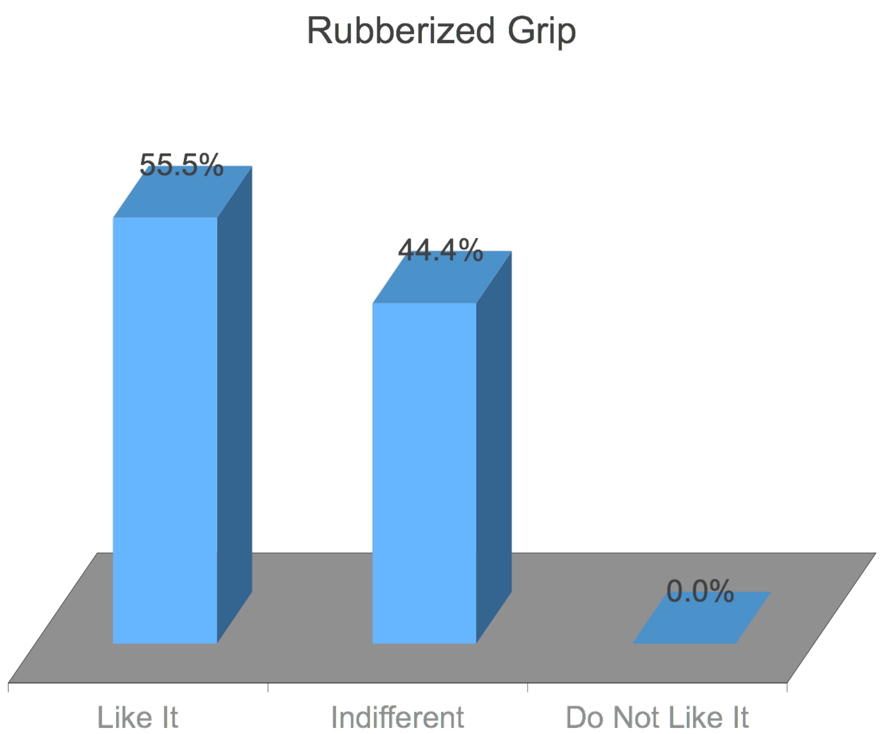


Figure 26. Acceptance of the silicone grip

### 2.6.2 Surveying Patients

The tool is ergonomically correct and has the approval of several users (dentists). Now it is time to see what the patients think about it and see what adjustments can be made in order to please them. This step is a bit more challenging since the idea here is to work specifically with pediatric patients, otherwise known as children. Soliciting adult opinions takes some skill, but soliciting information from children is even more challenging for many reasons. John Touliatos and Norma H. Compton, authors of *Approaches to Child Study,* describe some of the difficulties of surveying adults:

> Among the limitations of questionnaires are the diversity of meaning that may be attributed to a question by various respondents, the amount of education that may be required of a person in order to understand the questions and procedures, the difficulty of securing valid personal or confidential information, and the uncertainty of whether an adequate number of responses will be received to represent the population. (1983)

The most prominent problem with gathering children's opinions is that children's reading, writing and comprehension skills are not as far developed as adults'. This makes communicating questions to them, as well as figuring out the best way for children to communicate their answers, more challenging. Ross Vasta (1982), the author of *Strategies and Techniques of Child Study* uses math as an example to explain this problem:

> As children develop they may employ strategies or processes that either were simply not available earlier or were used inappropriately. For example, most 3 and 4 year-olds cannot answer questions like '5 + 3 = ?', where as 7 and 8 year olds do so readily. The nature of developmental change here is that older children have acquired a set of rules for addition…that younger children simply do not have. (Vasta, 1982)

Touliatos and Compton go as far as to say, "Obviously, self-administered questionnaires cannot be used with young children." Though this statement certainly holds some truth, this thesis sets forth to prove that it is not entirely true. It is certainly more difficult to collect useful data from self-administered questionnaires for children, but not impossible. With the use of graphics and the minimal use of text, helped along with reading questions out loud, children can be surveyed with such questionnaires, as is exemplified a bit further along in this thesis.

Michael P. Riccards, author of *The Making of the American Citizenry: An Introduction to Political Socialization,* explains other difficulties in gathering children's opinions. He describes difficulties that were encountered when trying to gather children's opinions on politics. He wrote:

> First, some children (especially teenagers) may not take the questionnaire seriously. Second, boys and girls often tend to regard the questionnaire as a "test" and they are more likely to choose the answer they feel is correct rather than the one that most closely coincides with their feelings. Third, the questionnaire by its very phraseology may be eliciting a specific response. (1973)

Though the task is challenging, it is important that children's opinions are collected in order to design medical equipment that reduces apprehension in younger patients. This study does not involve surveying children one by one, though if a designer does have the time and resources for that, it is suggested. For those that do not, mass surveying can be effective.

The problems of surveying children can be worked around by using more graphical pictures and less text. A picture is worth a million words, and everyone knows how to read a picture, though a surveyor must be weary when using pictures. Pictures, much like words, can mean different things to different people. And as is the case with words on a survey, the only thing a survey writer can do about it is to make the pictures as simple, straightforward and clear as possible. Here is one of the surveys being used for this study, which exemplifies these principles.


Figure 27. Survey administered to younger children

Some text is still used because it is impossible to make a survey that is purely graphical, while clearly stating the important points that this study needs to get across. It is more effective to make purely graphical answers than questions. In order to make the text easier for younger children, who could not read to understand, text is supplemented with related pictures and teachers read the questions to the children. The supplemental pictures help the children to follow along and better understand what the teacher is reading to them.

It is also important to note that questions number four and five on the first questionnaire are circle the answers, while they are fill in the blank for the second survey (shown in Figure 28.) Fill in the blank is a much more accurate way to acquire the information for this study, but with the understanding that there is no way for some of the younger children to fill in the blank with meaningful answers, younger children are given a simpler answering format. Therefore, fill in the blank questions are given to the older children who have no problem answering them, and simplified questions with circle the best answer are given to the younger children. Circle-shaped pictures are used to give a more intuitive indication that the answers are to be circled.


Have you ever gone to the dentist?
Mark 1 answer.
Yes
No
How does
going to the dentist make you feel?
Cirlcle 1 answer.
How does this dentist tool
make you feel?
Circle 1 answer.
What did you like the most at
the dental office?
Fill in the blank.
What did you dislike the most
at the dental office?
Fill in the blank.
Circle the dentist tool you
like best.
Circle the dentist tool you
like best.
Circle the dentist tool you
like best.
Circle the dentist tool you
like best.
Circle the dentist tool you
like best.

Figure 28. Survey administered to older children

After a great deal of time is spent developing and rewriting these surveys (much like any other design process), plenty of copies are made and taken to Shades Cahaba Elementary School in Homewood, Alabama. There, 329 students are surveyed.

### 2.6.2.1 Anticipated Outcome

Before the surveys are administered, there are some anticipated outcomes, as follows. At least 90% of the students will have seen the dentist, and about 30% will not be comfortable at the dental office. It is anticipated that a majority will dislike the dental drill, and that about 30% will say the dental drill is what they like least at the dental office. As for the new design, it is anticipated that children will be drawn to the new shape, softer textures and the introduction of color.

### 2.6.2.2 Statistical Findings

After the surveys are administered, collected, and tabulated, there are 329 responses in total. 107 of those responses are kindergartners to 3$^{rd}$ graders who took the survey without fill in the blank answers. 222 of the responses are 4$^{th}$ and 5$^{th}$ graders who took the survey with the fill in the blank answers. Out of those children, 97.6% have visited the dentist. The surveys also show that 48% of children are not comfortable at the dentist office. When the handpiece is introduced to the situation the percentage of children that feel comfortable drops by 33% and the number of children that feel uncomfortable quadruples.

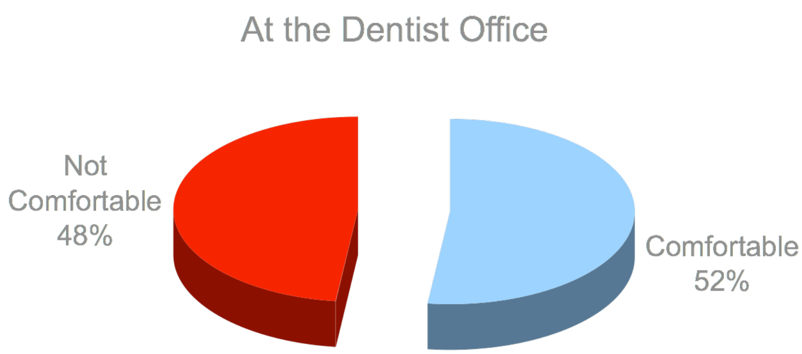


Figure 29. Comfort at the dental office

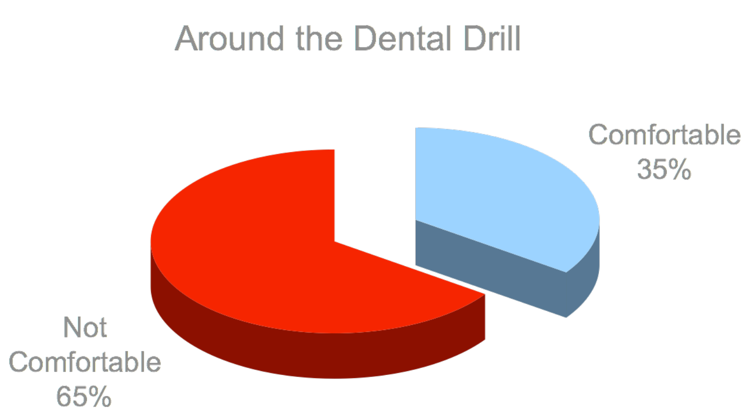


Figure 30. Comfort around the dental drill

The last part of the survey, which addresses the new design shows that the children prefer the new design to existing drills by 88.6%.  The survey also reveals that 61.9% of students are drawn in by the color, and 66% of students like the look of a lugged grip.

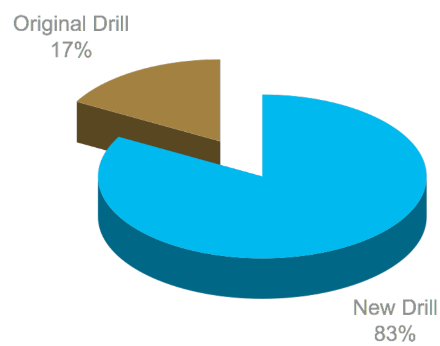


Figure 31. Children prefer the new design

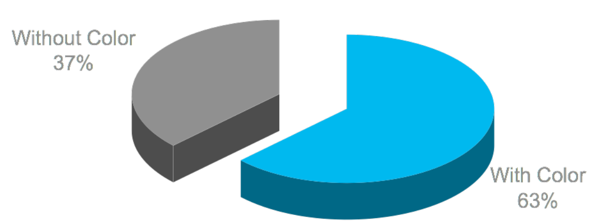


Figure 32. Children prefer color

There is no clear indication that the children are drawn to the shape or texture of the new drill, though there is also no indication that they dislike these attributes either. This may be due to the use of small pictures that do not clearly communicate these differences.

## 2.7 Final Model

Once thorough research has been done, and thorough development has been accomplished, it is time for the final model. This model should represent the final concept as realistically as possible. The model should look, feel and operate as much as possible like the concept tool would if it were in production.

Building a working prototype is not in the scope of this project and therefore the final model for this study is a detailed appearance model. This is because it is unrealistic to build a working dental drill with the resources that are available, and because the final concept uses existing technology, there is little need to prove that the concept would work.

To build the final model a computer is used to ensure precision. There are final adjustments made to the last computer model, and then it is transferred to the computer controlled milling machine to be cut out of ren shape. Ren shape is used because it is a dense material that is more durable and has the ability to show fine detail.

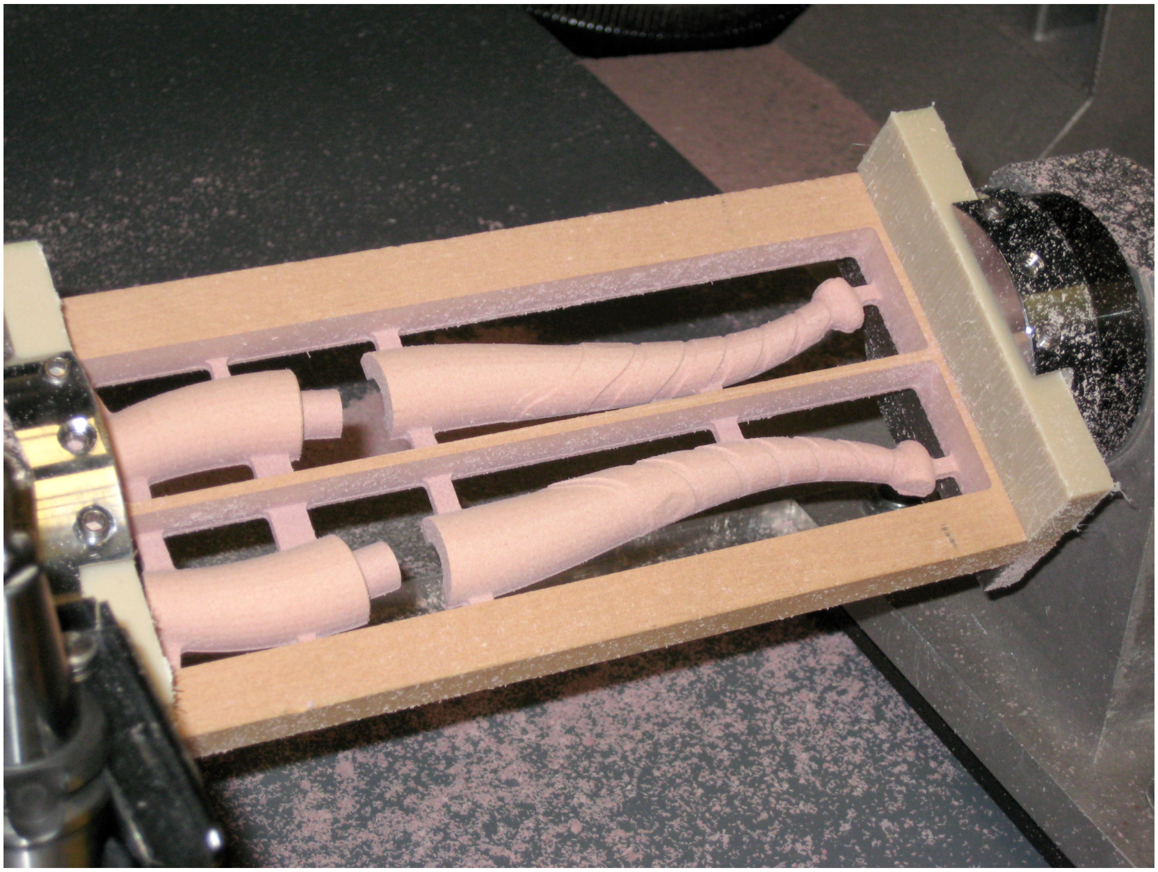

Figure 33. Model parts fresh off of the CNC machine

After the CNC machine is done the parts are sanded and painted to simulate what the concept would look like if it were in production. The metal parts are painted to appear as metal, and the grip is painted to appear as a soft silicone rubber. A rubber tube is used on the back end to simulate the look and feel of having the drill connected to the compressor hose that dentists use to power such drills. The inside of the model is bored out to make room for weights. The weights are put into the model to simulate the weight and feel of a production model. For the final touch, a needle is used to simulate the appearance of the bur (drill bit) of the dental drill. With all of this work done, the model is a highly refined and a nearly exact representation of what a manufactured handpiece based on this new concept would look like and feel like. This model gives an accurate representation of many of the new concepts features that are explained in the next chapter.

Figure 34. Final model

## CHAPTER 3

## CONCLUSION

### 3.1 Results from Studies of Process

First of all, Apple's 10 to 3 to 1 design process gives a good foundation for building a design process: build 10 mockup concepts, narrow that to three concepts, develop those further, then narrow it down to the one best concept and develop that (Walters, 2008). It is not necessary that these numbers be followed exactly but they are a good guideline. A modified process that might be described as a 100 to 8 to 3 to 1 process is used for this thesis. Apple's process is a very good one, but Lopp does not mention anything about the sketching that comes before mock up models, which is a very important element to the design process. There are no constraints on what can be drawn on paper, so there are no constraints on the designer's ability to imagine new concepts. As for the number 100, it is a general number that is meant to exemplify Mike Baxter's key design process concept "Generate lots of concepts" and encourage designers to develop as many sketch concepts as possible before narrowing them down to about 10 concepts for mock up (1995).

The research of this project also shows that user and patient feedback is invaluable as Tim Brown, CEO and president of IDEO, mentions when he cites their director of human factors group, Jane Julton Suri, as saying, "The insights that emerge from careful observation of people's behavior…uncover all kinds of opportunities that were not previously evident." (Brown, 2007) It would have been impossible to come up with useful concepts without feedback from the five dentists that were interviewed and observed for this study. This project would not be able to satisfy the needs of dentists and improve the ergonomics without their feedback. The dentists are an important key to finding what areas of existing dental drills work well and what areas need improvement. Patient feedback is also very useful in understanding what children like, but at the end of this study, it is clear that the children should have been interviewed earlier in the process. About the time interviews with dentists began would have been about the time to start interviewing children. Their input is just as important as the dentists input for a design process that is meant to increase ergonomics for dentists and reduce apprehension for young patients. Children should be interviewed early enough that their input, along with the doctors' input, could be used in the preliminary sketching and conception phase.

### 3.2 Results from Studies of Design

As for results pertaining to the new design, what is learned is that the dentists who were interviewed are drawn to the sleek shape. On top of that, dentists are bothered by the tug of the hose attached to their handpieces. The tug interferes with their work and wears on their hand and wrist muscles. This is why the new design incorporates a bend to alleviate some of that tug. The swivel that rotates with the hose on the new drill ensures that the bend will continue to bend down and operate, as it should, no matter what position the dentist uses the drill in. Studies revealed that this swivel could be made with existing technology for a reasonable price as well. The *Everything Dental* catalogue offers swivels for dental handpieces that deliver the necessary pressurized air and water, as well as fiber optic lighting, for prices as low as $139.99. The same catalogue lists dental handpieces from$184.99 to $924.99. With the technology used in this design it could easily incorporate a fiber optic swivel and still maintain a reasonably low priced handpiece. Studies also show that a silicone rubber grip could be added while holding this price point. *Everything Dental* lists silicone rubber scaler grips for $9.29 (Everything Dental, 2005). Theoretically, this new dental drill could be built and sold for a price below $250. At the price of $250, this new drill offers a silicone rubber grip that gives the tool a softer, more ergonomic handle for dentists, increases grip, and offers more color options in order to better appeal to children. The dentists interviewed for this study complained that the grip of existing handpieces is one feature that could use improvement, and the survey of children revealed that children are clearly attracted to dental tools with color.

**3.3 The Final Concept**

The final model and final concept incorporates a number of new features that solve problems that were cited by dentists during the initial interviews mentioned earlier. The intimidating appearance, which one dentist described as knife-like, is alleviated with a softer shape and form.

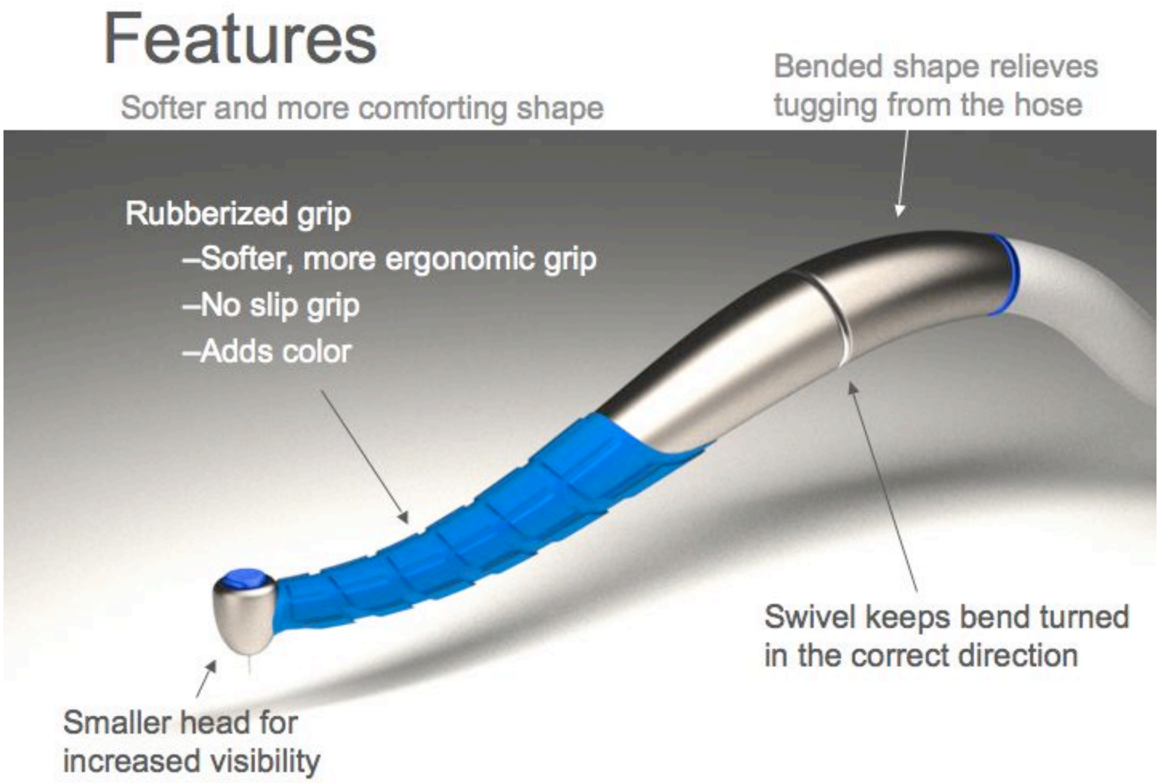


Figure 35. Features

The silicone grip gives dentists the thicker handle they desire as well as a softer grip. This gives the new dental drill enhanced ergonomics. The silicone rubber grip also gives dentists the improved grip that they desire. The tacky grip of the rubber helps to improve the grip, as do the grooves in the rubber, which channel saliva and water away from the dentists' fingertips. The silicone rubber grip also allows color to be incorporated into the tool, which is a desired feature mentioned by dentists during the interviews. These colors are desired because they are more appealing to pediatric patients. The survey of children administered for this study showed that 63% of children preferred dental tools with color. To top it all off, silicone is a very durable rubber that is rated to withstand the extreme high temperatures that dental drills withstand every time they are cleaned.

Figure 36. Color options

Color can be added to more than just the rubber grip though. If the drill's body is made of aluminum, which is a typical material for these tools, then the metal can be anodized to create more color choices as shown in Figure 37.

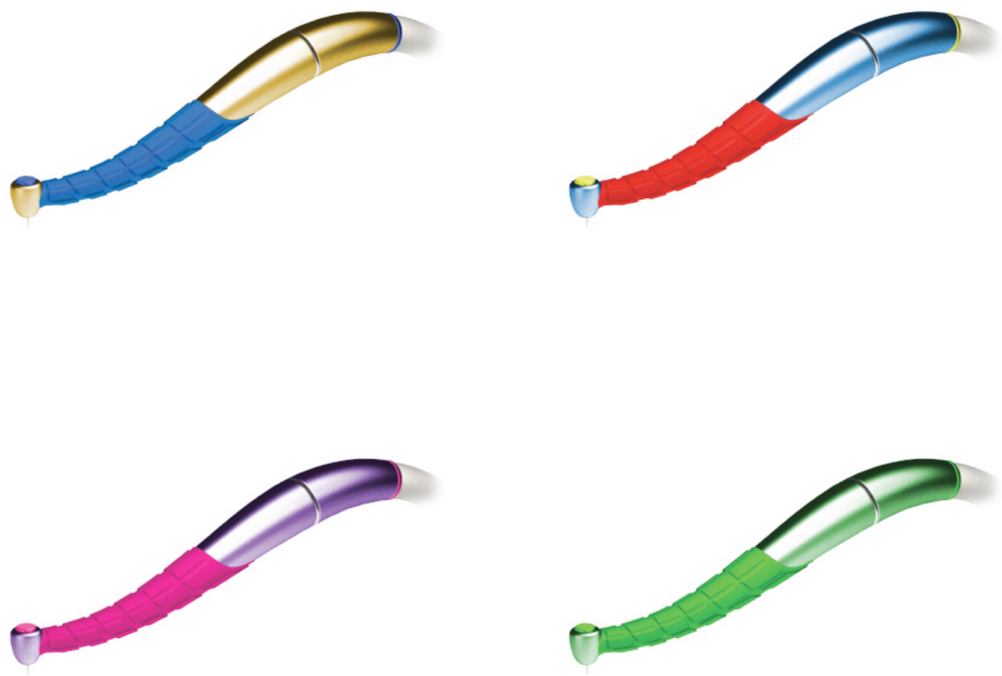

Figure 37. Anodized color options

One other problem that this concept addresses is the tug of the hose on the back end of the dental drill. Dentists mentioned that this throws off the balance of the tool during use. The research mentioned earlier shows that creating a cordless drill is impractical, but there are other ways of alleviating this problem. This concept incorporates a downward bend on the back end of the drill where the hose attaches. This bend adjusts the angle of departure for the hose to be closer to the angle of the part of the hose that is free hanging. With this improved angle the tug on the back of the dental drill is reduced.

Since the dental drill is held at many different angles during use, as demonstrated by the pictures of user observations (figure 16) shown earlier, it is important that this downward bend has some way to adjust itself.  This adjustability should allow the bend to always bend downward, no matter how the dentist holds the drill.  A swivel is incorporated into this design to do just that, as is demonstrated in Figure 38.

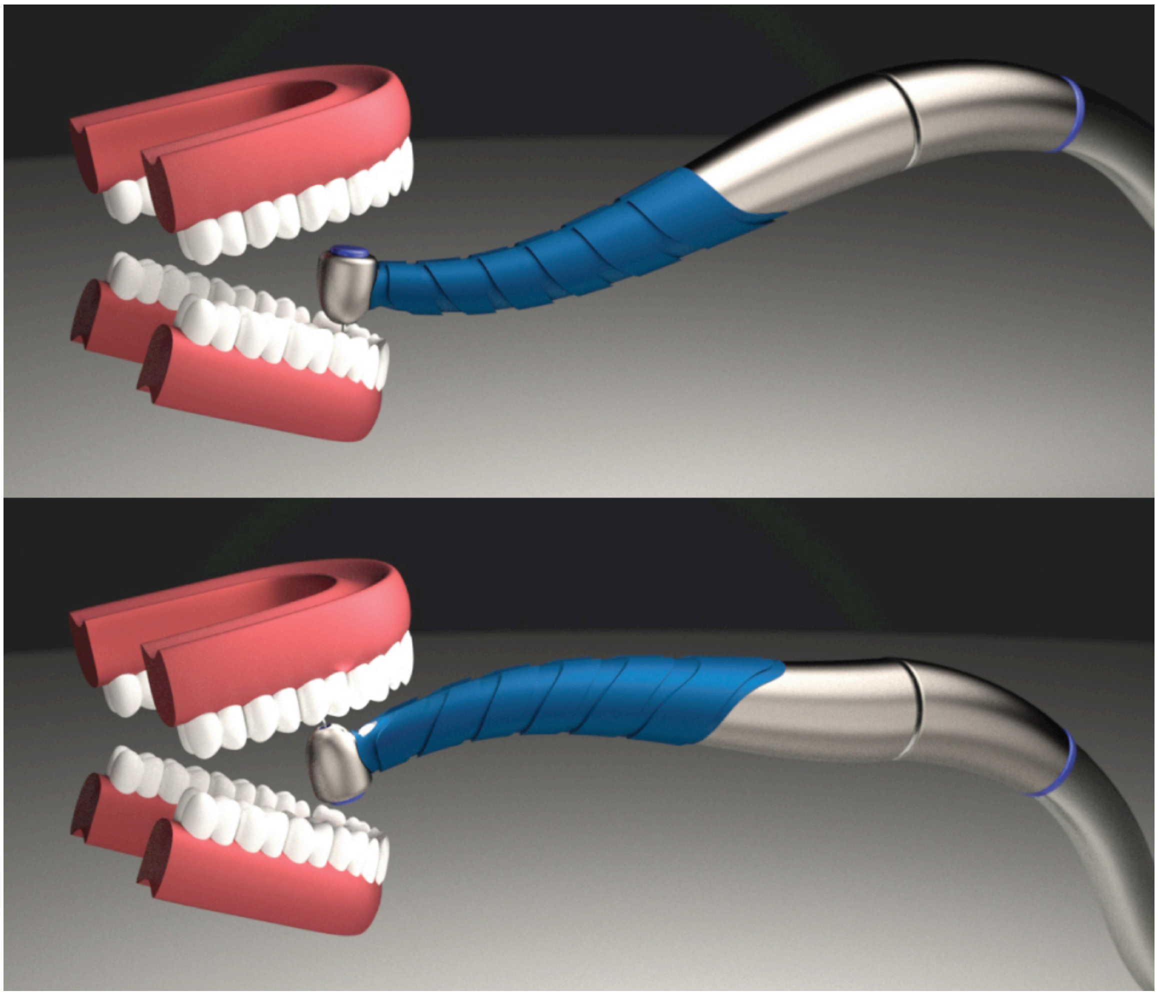

Figure 38. Demonstration of swivel feature

### 3.4 Study Accomplishments

This study outlines a guideline for designing new medical equipment that will be more ergonomic and more appealing for the doctors that use it, while also reducing the apprehension of the young patients that the tools are used for.  This thesis streamlines the process into a set of steps which are easy to understand and practice, and can be adapted to the redesign of any medical tool for doctors who work with pediatric patients.

### 3.5 Areas for Further Study

The scope of this study does not include developing a working prototype. One way to further this study would be to create a working prototype and create a comparison study that allows dentists to use the prototype and the leading existing dental drills. Such a study would reveal more details about the ergonomics and usability of the new design. Also, further study of how children feel about the final model, maybe with the use of larger pictures or by showing the model in physical form, may allow more feedback to be collected from young patients.

Medical tools designed to reduce adult apprehension would also be another good subject to study. There may be a higher percentage of children that are afraid of any given medical tool, but children are not alone. Many adults also suffer fear of medical tools they come in contact with.

With that said, the processes and principles discussed in this thesis are a good guideline for the development of better medical tools that will be more ergonomic for dentists or doctors, and also less intimidating for children or adults.

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**Image Reference**

Figure 1. The anatomy of a tooth is an image from online source, retrieved March 11, 2007, from http://health.howstuffworks.com/cavity.htm

Figure 2. Picture of a cavity is an image from online source, retrieved March 11, 2007, from http://health.howstuffworks.com/cavity.htm

Figure 3. X-ray of a cavity is an image from online source, retrieved March 11, 2007, from http://health.howstuffworks.com/cavity.htm

Figure 4. A dental handpiece (dental drill) has a file name of Dentalhandpiece0111-26-05.jpg. Image from online source, retrieved March 11, 2007, from http://en.wikipedia.org/wiki/Dental_handpiece

Figure 5. Bur profile examples is a picture of page 109 from *Dental Catalog* (155th ed.) by Everything Dental.

Figure 6. Anatomy of the wrist is a picture taken from page 285 of the book *Human Factors in Engineering and Design Fifth Edition*. Authored by McCormick, Ernest J., and Mark S. Sanders.

Figure 7. Conventional pliers vs. ergonomically designed pliers is a picture taken from page 287 of the book *Human Factors in Engineering and Design Fifth Edition*. Authored by McCormick, Ernest J., and Mark S. Sanders.

Figure 8. Using a finger strip to spread the load is a picture taken from page 291 of the book *Human Factors in Engineering and Design Fifth Edition* authored by McCormick, Ernest J., and Mark S. Sanders.

Figure 9. Hand and handle interaction demonstration is a diagram from page 87 of *Bodyspace; Anthropometry, Ergonomics and the Design of Work Second Edition* authored by Pheasant, Stephen.

Figure 10. Stephen Pheasant's user-centered design is a diagram from page 6 of *Bodyspace; Anthropometry, Ergonomics and the Design of Work Second Edition* authored by Pheasant, Stephen.

Figure 11. Grip types is a diagram from page 86 of *Bodyspace; Anthropometry, Ergonomics and the Design of Work Second Edition* authored by Pheasant, Stephen.

Figure 12. Low cost silicone grips is a picture of page 473 from *Dental Catalog* (155th ed.) by Everything Dental.

Figure 13. Fiber optic swivels for dental drills is a picture of page 319 from *Dental Catalog* (155th ed.) by Everything Dental.

Figure 14. The generation of sound waves is a diagram from *Sound Analysis and Noise Control* by Foreman, John E. K.

Figure 15. The different dental offices being visited is a photo montage by Alex Reynolds.

Figure 16. Usage observations is a photo montage by Alex Reynolds.

Figure 17. Thumbnail sketches are sketches by Alex Reynolds.

Figure 18. Refined preliminary sketches are sketches by Alex Reynolds.

Figure 19. Clay ergonomic models is a montage by Alex Reynolds.

Figure 20. Secondary ergonomic models is a photo taken by Alex Reynolds.

Figure 21. Refining sketch is a sketch by Alex Reynolds.

Figure 22. Third generation ergonomic model testing is a montage by Alex Reynolds.

Figure 23. Average age of fearful patients is a graph created by Alex Reynolds to represent findings of a survey administered for the purposes of this thesis.

Figure 32. Children prefer color is a graph created by Alex Reynolds to represent findings of a survey administered for the purposes of this thesis.

Figure 33. Model parts fresh off of the CNC machine is a photo by Alex Reynolds.

Figure 34. Final model is a photo by Alex Reynolds.

Figure 35. Features is a diagram by Alex Reynolds.

Figure 36. Color options is a montage by Alex Reynolds.

Figure 37. Anadized color options is a montage by Alex Reynolds.

Figure 38. Demonstration of swivel feature is a montage by Alex Reynolds.

Table 1. Absence of teeth among U.S. adults is a table from *Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2005* By Center for Disease Control and Prevention.

Table 2. Untreated dental cavities is a table from *Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2005* By Center for Disease Control and Prevention.