An Approach for Designing Dental Tools

by

Jonathan Dunn

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Approved by

Rich Britnell, Chair, Professor of Inustrial Design
Shea Tillman, Associate Professor of Inustrial Design
Tin-Man Lau, Professor of Inustrial Design

Abstract

One study from the University of Iowa found 93% of dental hygienists reported at least one musculoskeletal disorder in the past year, and they have one of the highest incidences of Carpal Tunnel Syndrome (Anton, 2002). To help prevent, or lessen, the number of these problems, better dental tool designs are needed. This study will explore a process for designing dental tools that considers better ergonomics, FDA and ADA guidelines, and the general design process. But first, several areas of dentistry must be studied, including anatomy, microbiology, and ergonomic problems.

To develop a design process for reducing musculoskeletal disorders, one must first understand the need for dental tools. A study of dental microbiology helps with understanding the types of bacteria in the mouth, and the need for removal of the harmful ones. With research showing a direct link between plaque or oral bio-films in the mouth and the plaque that forms in the heart, dental tool design takes on a new importance. Dental anatomy studies will help the designer locate the crucial areas of hidden bacteria in the mouth. It will also show the need for improved dental tools to reach and debride these areas.

After concluding the study of anatomy and microbiology, as well as the ergonomic problems facing dental personnel, this thesis will discuss a new approach to designing dental tools to better the dental industry. These tools will include hand, ultrasonic, handheld, and laser design. This tool design approach will suggest ways to aid the dental professional as well as the patient. This could also lead to improved home care product design.

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Image Reference

All pictures with no reference are not taken from a secondary source, The pictures were taken by Jonathan Dunn.

Chapter 1

Introduction

1.1 Problem Statement

In the dental field, there is no specific development process in making tools needed in the industry. Many of the tools in use now are not ergonomically designed, resulting in many hand injuries to dental professionals. “In 1987, the estimated loss in income due to musculoskeletal pain in dentistry was $41 million” (Valachi, 2008, p.4). Just seventeen years later, “the annual loss income in 2004 was approximately $131 million” (Valachi, 2008, p.5). Workman’s compensation claims and premiums must also be considered. The dental tools need to be redesigned to accommodate difficult to instrumentate areas of dental anatomy. A solution to this problem would be developing a design process or check list to provide information to designers for developing better dental tools. With the development of better dental tools, this design process could also lead to improved home dental care tools. Repetitive Stress Injury repots, “Dental tool design can also play a factor in the avoidance of repetitive injuries and cumulative trauma disorders in dental care” (Williams, 2013). Patients with certain disabilities like cerebral palsey and multiple sclerosis, represent one group that presently do not have tools with designs that accommodate their disability, and therefore leaves them without a method to remove harmful bacteria. These problems involving ergonomics and better tool design can be achieved with a design process for dental tool development.

1.2 Need for Study

In a study done by the University of Iowa, “dental hygienists have some of the highest occupational incidences of carpal tunnel syndrome…In a survey of 95 dental hygienists, 93%

reported at least one musculoskeletal disorder, particularly in the region of the wrist and hand, the neck, and the upper back" (Anton, 2002). Also noted in research, "a high reporting of Carpal Tunnel Syndrome or CTS symptoms among dental hygienists is due to the fact that the occupation often requires repeated and forceful gripping of small instruments when cleaning teeth" (Anton, 2002). Therefore, logically new ergonomically designed tools will help reduce the incidence of Carpal Tunnel Syndrome. Developing new ergonomic dental tools involves a study of dental anatomy and microbiology, anthropometry and ergonomics, and will provide the user with tool design that will improve oral health care, provide better overall health, and reduce musculoskeletal disorders for dental professionals.

1.3 Objective of Study

- To study dental anatomy
- To study dental microbiology
- To study dental procedures
- To study dental ergonomics
- To study the design process specifically as it pertains to dental design
- To develop a process/checklist for dental tool design
- To research current tools in the dental field
- To investigate the FDA/ADA/ISO/ANSI guidelines for dental tool development
- To develop a product based on the process/checklist produced in this thesis

1.4 Scopes and Limit

The scope of this study will cover dental anatomy, the different types of dental bacteria that cause gum disease, ergonomics in hand tool design, and the design process applied to the dental field. Also, the FDA and ADA guidelines and regulations in design of dental tools will be discussed. The study will also look at some of the diseases and their relation to plaque. Understanding the above is crucial to a better design approach for dental tools. An example of this is developing a tool especially for the furcations of molar teeth, and the curves on the sides of other teeth. The instruments used now are too big for these spots, and cause discomfort to patients when used in these areas.

One of the major limitations of this study is the inability to test the design approach. Other limitations are that most of the research will be from books and online sources. There will be little dental personnel interactions. These limitations are due to time constraints preventing a reliable survey of dental personnel and adequate testing on patients of this approach. The study will limit certain diseases for study. Only one dental tool prototype will be produced during this research.

1.5 Definition of Terms

Abduction: "To draw away from the midline of the body" (Merriam-Webster's Medocal Dictionary, n.d.).

ADA: "American Dental Association" (Daniel & Kimmelman, 2008).

Alveolar Mucosa: “The covering on the alveolar process loosely attached to bone that extends from the muco-gingival junction to the vestibular epithelium and from the lower jaw to the sublingual sulcus” (Merriam-Webster’s Medical Dictionary, n.d.).

Anthropometry: “The scientific study of the measurements and proportions of the human body” (Merriam-Webster’s Medical Dictionary, n.d.).

Antibiotic Prophylaxis: “Pre-medication provided to patients with certain health problems to eliminate harmful bacteria in the blood stream prior to dental procedures” (Merriam-Webster’s Medical Dictionary, n.d.).

Anaerobic Bacteria: “Bacteria that lives below the gum line in the absence of oxygen. Autoclavable: The ability to sterilize instruments at a certain temperature with steam under pressure” (Merriam-Webster’s Medical Dictionary, n.d.).

Antinfective Agent: “Chemotherapeutic agent that reduces the number of bacteria present” (Merriam-Webster’s Medical Dictionary, n.d.).

Attached Gingiva: “The portion of the oral mucosal membrane bound to the tooth and to the alveolar arches of the jaw” (Merriam-Webster’s Medical Dictionary, n.d.).

Bacteria: "Simplest (single-celled) organisms that can be found in virtually all environments" (Merriam-Webster's Medical Dictionary, n.d.).

Bacterial Flora: "All the bacteria inside, or on the surface of an organism" (Merriam-Webster's Medical Dictionary, n.d.).

Calculus: "Densely packed, colonized and colonizing microorganisms which grow on and attach to the tooth" (Merriam-Webster's Medical Dictionary, n.d.).

Carious Lesions: "Cavities in the teeth" (Merriam-Webster's Medical Dictionary, n.d.).

Cementum: "Calcified structure that covers the anatomic roots of teeth" (Merriam-Webster's Medical Dictionary, n.d.).

Chemotherapeutic Agents: "An antibiotic agent that acts by reducing the number of bacteria present" (Merriam-Webster's Medical Dictionary, n.d.).

Crown: "The top part of the tooth covered by enamel" (Merriam-Webster's Medical Dictionary, n.d.).

Cuspids: "Name of the teeth located in the corners of the mouth. Located in both upper and lower jaws; also called canine or eye teeth" (Merriam-Webster's Medical Dictionary, n.d.).

Dental Biofilms: “Living film having a well-organized community of bacteria, it also contains many species of bacteria, other organisms, and debris such as food. It forms rapidly on any wet surface” (Merriam-Webster’s Medical Dictionary, n.d.).

Dental Microbiology: “The study of bacteria found in the mouth” (Merriam-Webster’s Medical Dictionary, n.d.).

Dentin: “Calcified tissue found under the enamel making up the largest part of a tooth” (Merriam-Webster’s Medical Dictionary, n.d.).

Distal: “The side of the tooth located away from the middle of the mouth” (Merriam-Webster’s Medical Dictionary, n.d.).

Enamel: “The outer, hard coating of teeth that is seen in the mouth” (Merriam-Webster’s Medical Dictionary, n.d.).

Ergonomics: “The applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort. Also called biotechnology, human engineering, human factors engineering” (Merriam-Webster’s Medical Dictionary, n.d.).

Facial: “The side of the tooth facing the outside of the mouth” (Merriam-Webster’s Medical Dictionary, n.d.).

FDA: “Food and Drug Administration” (Daniel & Kimmelman, 2008).

Free Marginal Gingiva: “The portion of the gum surrounding the neck of the tooth, not directly attached to the tooth” (Merriam-Webster’s Medical Dictionary, n.d.).

Front-End Design: “The visual side of the design process” (Merriam-Webster’s Medical Dictionary, n.d.).

Fulcrum: “A finger rest placed on an adjacent tooth. Always used by the operator to ensure control of the instrument being used” (Merriam-Webster’s Medical Dictionary, n.d.).

Furcations: “Areas or region lying between and at the base of two or more normal anatomically divided roots” (Merriam-Webster’s Medical Dictionary, n.d.).

Gingiva: “Gum tissue” (Merriam-Webster’s Medical Dictionary, n.d.).

Instrumentate: “The act of using dental instruments to remove diseased dental tissue” (Merriam-Webster’s Medical Dictionary, n.d.).

Incisors: “Name of the front four teeth in both and maxillary and mandibular jaws” (Merriam-Webster’s Medical Dictionary, n.d.).

Invasive: “Tending to spread prolifically and undesirably or harmfully” (Merriam-Webster’s Medical Dictionary, n.d.).

Ischemia: “A decrease in the blood supply to a body part caused by constriction of the blood vessels” (Merriam-Webster’s Medical Dictionary, n.d.).

Iteration: “The repetition of a process or utterance” (Merriam-Webster’s Medical Dictionary, n.d.).

Lingual: “The side of the tooth facing toward the inside of the mouth” (Merriam-Webster’s Medical Dictionary, n.d.).

Mandibular: “Referring to the lower structures of the teeth and bone” (Merriam-Webster’s Medical Dictionary, n.d.).

Mastication: “The act of chewing” (Merriam-Webster’s Medical Dictionary, n.d.).

Materia Alba: “Soft accumulations of bacteria, food matter, and tissue cells that lack organized structure” (Merriam-Webster’s Medical Dictionary, n.d.).

Maxillary: "Referring to upper structures of the teeth and bone" (Merriam-Webster's Medical Dictionary, n.d.).

Mesial: "The side of the tooth located toward the middle of the mouth" (Merriam-Webster's Medical Dictionary, n.d.).

Molars: "Teeth located in back of jaw. Used for chewing and found in both the upper and lower jaws" (Merriam-Webster's Medical Dictionary, n.d.).

Mucogingival Junction: "The scalloped linear area denoting the approximation or separation of the gingivae and alveolar mucosa" (Merriam-Webster's Medical Dictionary, n.d.).

Musculoskeletal: "Pertaining to or comprising the skeleton and muscles" (Merriam-Webster's Medical Dictionary, n.d.).

Non-Invasive: "Procedures do not involve tools that break the skin or physically enter the body" (Merriam-Webster's Medical Dictionary, n.d.).

Periodontium: "Refers to the specialized tissues that both surround and support the teeth, maintaining them in the maxillary and mandibular bones" (Merriam-Webster's Medical Dictionary, n.d.).

Periodontal Disease: “A type of disease that affects one or more of the periodontal tissues” (Merriam-Webster’s Medical Dictionary, n.d.).

Permanent Teeth: “Adult teeth that are kept for a lifetime” (Merriam-Webster’s Medical Dictionary, n.d.).

Plaque: “Grouping of bacteria that can be densely packed or free floating” (Merriam-Webster’s Medical Dictionary, n.d.).

Plaque Control: “Regular removal of microbial plaque and the prevention of its accumulation on the teeth and adjacent gingival surfaces” (Merriam-Webster’s Medical Dictionary, n.d.).

Premolars: “Name of teeth located behind cuspids. Found in both upper and lower jaws” (Merriam-Webster’s Medical Dictionary, n.d.).

Prevent Model: “A plan that helps establish a sequence of clinical services with the patient’s input to reduce the risk of disease, and promote oral and bodily health” (Merriam-Webster’s Medical Dictionary, n.d.).

Pulp: “Soft, connective tissue organ containing arteries, veins, and nerves” (Merriam-Webster’s Medical Dictionary, n.d.).

Root: "The lower portion of the tooth covered by cementum" (Merriam-Webster's Medical Dictionary, n.d.).

Sonic Scalers: "Instruments that work at a frequency of 2,000 to 6500 cycles per second and use a high or low speed air source from a dental unit" (Merriam-Webster's Medical Dictionary, n.d.).

Supragingibal Calculus: "Hard deposits found above the gum tissue" (Merriam-Webster's Medical Dictionary, n.d.).

Subgingival Calculus: "Hard deposits found under the gum tissue" (Merriam-Webster's Medical Dictionary, n.d.).

Sulcus: "A deep, narrow furrow or groove around a tooth" (Merriam-Webster's Medical Dictionary, n.d.).

Ultrasonic Scalers: "Instruments with metal stacks that change dimensions when vibrating at a frequency range of 18,000 to 50,000 cycles per second" (Merriam-Webster's Medical Dictionary, n.d.).

Chapter 2

Literature Review

2.1 Introduction

To be able to propose a design check list for designing dental tools for the dental industry, one must first understand the need for such tools. The bacteria involved in the oral cavity, its relation to the development of plaque, bacterial flora, and calculus is the first consideration. Next, a designer must consider the anatomy of the dentition. Grooves, furcations or divisions in the root of the tooth, and the overall root anatomy of each tooth creates problems in creating the right length and curvature of the cutting surfaces of dental instruments. In addition, the types of dental tools, hand, sonic/ultrasonics, lasers, and home care tools all have different aspects for the designer to consider.

Dental procedures involved in plaque control, as well as the chemotherapeutic agents needed to control bacteria, must be considered by the designer. Ergonomics is another important aspect in instrument design. Many problems associated with dental professionals are related to poor techniques, sometimes related to the design of their dental tools. "According to researchers from the University of Iowa, dental hygienists may have some of the highest occupational incidences of carpal tunnel syndrome (CTS)" (Michael, 2002). When considering financial losses, a grim picture appears. "Financial losses can be significant for dental hygienists whose wages range from $25 to $50 dollars per hour.

Many hygienists must reduce the days they work to avoid surgery because this course of action can reduce grip strength, causing the hygienist to retire altogether" (Valachi, 2008, p.5). Poor musculoskeletal health in the dentist or hygienist can "adversely impact loss of productivity, reducing the restorative treatment that comes out of the hygiene department, reducing goodwill by having to reschedule patients or put them with a different hygienist, and use of temporary hygienists reducing quality of care since the new hygienist is not familiar with the patient's needs" (Valachi, 2008, p.6-7). Lastly, FDA and ADA guidelines must be considered when designing tools. Materials used must be safe for the patients and must be able to be sterilized with extreme heat under pressure. All of these will be discussed in detail in this thesis.

2.2 Dental Microbiology

Dental Microbiology is the study of the bacteria and its relation to oral health and disease, and understanding of the periodontium begins with this study. "The main functions of the periodontium are to attach teeth to the bone of the jaws, and is important in maintaining the functional barrier against physical and microbial challenges, and to maintain good facial esthetics" (Vernino, Gray, & Hughes, 2008, p. 1). An understanding of the relation of the bacteria to dental disease and to the overall health of the patient, as well as understanding the challenges of bacteria, plaque, calculus, and bacterial flora, will help designers to construct better tools to eliminate these challenges.

The study of the bacteria will shed light on the diseases affecting the dental tissue. "Periodontal disease may be defined as any pathologic process that affects the periodontium. The vast majority of inflammatory diseases of the periodontium result from bacterial infection" (Vernino, Gray, & Hughes, 2008, p. 15). The pathologic process involves microorganisms that colonize on the tooth surfaces. This plaque must be removed with dental tools. To understand bacterial plaque and its relationship to periodontal disease, it is necessary to define the various materials that accumulate on the surface. Bacteria and the bacterial biofilms, plaque, and calculus are the tooth surface deposits that must be defined. The bacteria of the mouth includes many and various strains which group together to from bacterial plaque. Nield-Gehrig‘s (2011) research states:

> Bacteria are the simplest organisms, a group of microscopic, single-celled organisms that inhabit virtually all environments, including soil, water, organic matter, and the bodies of multicellular animals including humans. They can be gram positive, or gram negative. These gram-negative bacteria are the concern of the dental professional…they can be innocuous or not harmful to humans or they can be pathogenic and capable of causing disease…and since they can replicate quickly, they can adapt to changes in their environments rapidly (p. 97).

Bacterial plaque involves many types, but the ones related to periodontal disease can be divided into two major types. “One consists of densely packed, colonized and colonizing microorganisms, which grow on and attach to the tooth. This is referred to as calcified plaque or calculus. It may be supragingial(above the gum) or subgingival(below the gum)” (Vernino, Gray, & Hughes, 2008, p. 15). This first type of bacterial plaque cannot be brushed off; it must be removed with dental tools used by dental professionals. “The other type is subgingival plaque that is “free floating”, or loosely attached between the soft tissue and the tooth” (Vernino, Gray, & Hughes, 2008, p. 15). This second type may be removed with dental tools used by the patient. “Material alba refers to soft accumulations of bacteria, food matter, and tissue cells that lack the organized structure of dental plaque” (Newman, Takei, Klokkevold, & Carranza, 2012, p.241). This plaque further develops what dental professionals refer to as dental biofilms.

Dental biofilms are a form of plaque. "A biofilm is a living film having a well-organized community of bacteria…it contains many species of bacteria, other organisms, and debris such as food and it forms rapidly on any wet surface" (Nield-Gehrig, Willmann, 2011, p. 99). These biofilms adhere to all areas of the mouth including teeth, the oral mucosa including the tongue and gums, and all dental restorations. The lifecycle of biofilm is important to understand, and is a crucial reason for designing tools that can affectively remove it. The lifecycle of bioflim has three stages.

> "The first stage is the actually attachment of the bacteria to a surface…the second is the growth of that bacteria…in this growth, the attached bacteria releases substances that attract free-floating bacteria to join the biofilm community…this bacteria then secretes a slime layer which helps the bacteria to stay attached to the surface and acts as a protective shield…The third part of the life cycle involves in detachment…Clumps of the main biofilm break off and carried away by the fluid surrounding the biofilm including the blood stream which when detached the bacteria can attach to other areas and form new bacterial colonies" (Nield-Gehrig, Willmann, 2011, p. 100).

This last fact has is directly related to recent research linking dental plaque to the plaque found in the heart. This new information makes designing dental tools to eliminate and control the dental plaque in the mouth more important.

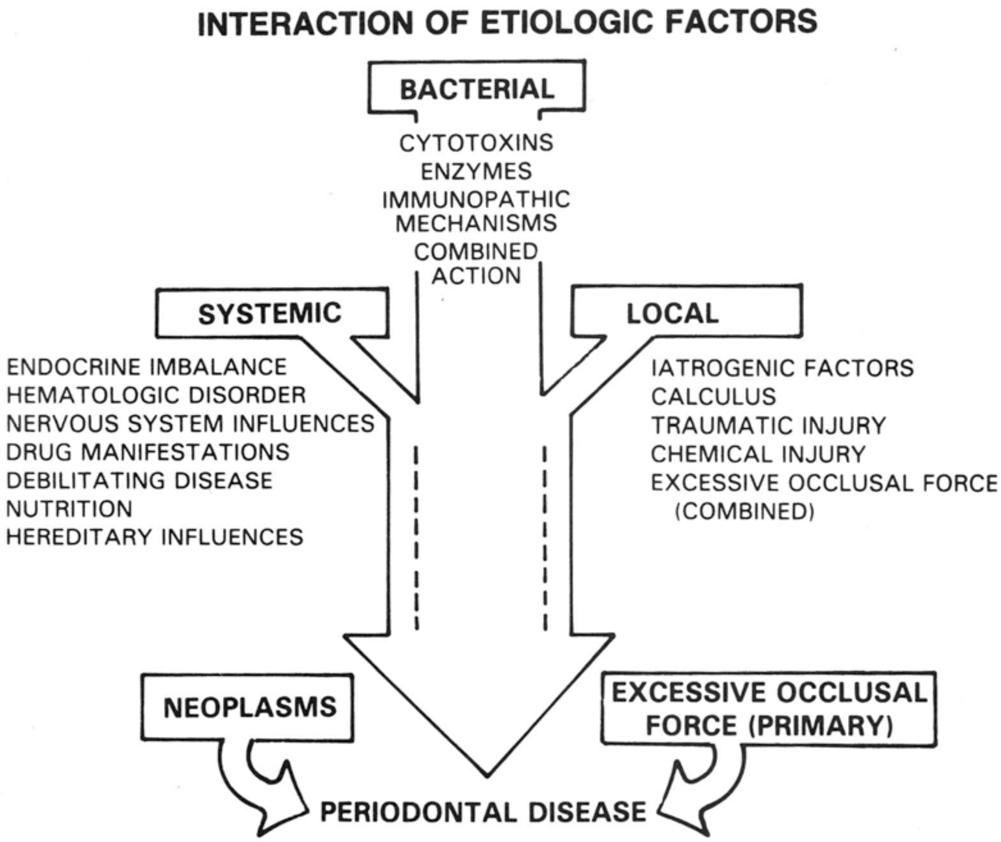


Figure 1. "Periodontal syllabus" (Vernino, Gray, & Hughes, 2008, p.16).

Understanding the bacteria will help in the understanding of pathogenesis. "The pathogenesis of a disease refers to the biologic and histological events that occur in the tissues during the process of conversion from a healthy state to a diseased state. This will allow the clinician to make rational decisions regarding the most predictable methods to prevent or treat this widespread disease" (Vernino, Gray, & Hughes, 2008, p. 20). To understand the relation of the bacteria to dental disease and health and to the overall health of the whole body, we must understand the inflammation process. "Plaque-related periodontal disease is characterized by inflammation. The inflammation process is activated to limit the spread of the disease process.

However, in addition to its beneficial effects, the inflammatory process also has a destructive component. The objective of treatment is to enhance the beneficial aspects of inflammation and to limit or control the destructive potential" (Vernino, Gray, & Hughes, 2008, p.22). Certain diseases, like diabetes, and medical procedures, such as hip and knee replacements, can be affected by or affect this inflammation process. In the presence of inflammation, bacteria enters the blood stream and can attack knee and hip replacements causing them to fail. This bacteria in the blood can also cause a life threatning condition when circulating through the heart. New research also shows a direct link of dental plaque in the mouth to the plaque associated with heart disease. Understanding this inflammation process will help designers better understand how to develop tools that can reduce or eliminate the bacteria involved with this inflammation process.

> "Antibiotic Prophylaxis is usually provided for patients at risk for bacterial endocarditis and after joint replacement surgery. Premedication must be provided for the first five systemic conditions listed... Patients with mitrial valve prolapse, prosthetic heart valves, joint prostheses, subaortic stenosis, and compromised immune systems must be premedicated for dental procedures that involve bleeding and bacteria" (ADA, & AHA. (n.d.).

Dental cleanings, extractions, and surgery fall into these categories. Pre-medication in these cases is made necessary due to the link between plaque in the mouth and plaque in the bloodstream that can cause overall health problems; the medications helps prevent acute medical reactions after dental procedures due to inflammation. Understanding the causes of, and the inflammation process itself, is just the beginning; designers must also understand dental anatomy.

2.3 Dental Anatomy

Dental anatomy must also be understood before designing dental instruments. The permanent teeth have both a crown and root. “They are comprised of enamel, cementum, dentin, and pulp…the first three are hard tissues, the last is a soft tissue that furnishes the blood and nerve supply to the tooth” (Wheeler, 1974, p. 5-6). The hard tissues are a primary concern to dental designers. Other concerns involve the sides of the roots (the mesial, side toward the midline or nose, and distal, side toward the back of the mouth), as well as the furcations or divisions of the roots of the molars. “The mesial and distal aspects of all teeth have concave areas ...While certain premolars and all molars contain root furcations (areas that spilt from each other)” (Wheeler, 1974, p135-298). These areas are of most concern to the dental designer. Biofilms collect in these hard-to-reach grooves and percussions. New designs are needed that include lengthening the shaft, reducing the size of the tip, and curving the tip slightly to instrumentate the grooves to lessen pain to the patient.

After studying the microbiology and dental anatomy related to the mouth, the designer will now realize the importance of removing the biofilms, and the problems the dental anatomy present in achieving this removal. A plan of action is needed, and is the next step in the design process.

2.4 Dental Procedures

In developing a plan of action to remove and eliminate the bacterial plaque, The Prevent Model is used. This model helps establish a sequence of clinical services with the patient's input to reduce the risk of disease, and promote oral and bodily health.

BOX 16-2

THE PREVENT MODEL

The goal of the model is to establish a sequence of educational and clinical services decided on in collaboration with the patient that will reduce the risk for disease and promote oral health.

Provide complete information.
Inform the patient of the findings of the clinical examination, present oral health status, causes of periodontal disease, and personal risk factors.

Realistic goals identified.
Work with the patient to set realistic short- and long-term goals for improving oral health and changing oral health behaviors.

Explain professional care options.
Discuss the professional services available to solve current problems, maintain oral health, and reduce risk for disease.

Variety of choices offered.
Offer the patient a choice of plaque control devices, oral care products, and self-care methods.

Encourage the patient.
Increase the patient's self-confidence in changing oral self-care behaviors through encouragement, reinforcement, skill building, and other methods.

Negotiate frequency of self-care.
Support the patient in assuming responsibility for personal health and negotiate a schedule for the self-care regimen.

Time reevaluation appropriately.
Sequence appointments to reinforce new skills and evaluate progress toward achieving short-term goals.

Figure 2. "The Prevent Model" (Takei, 2012, p. 448).

When using the Prevent Model, instruments needed include a double-sided mirror, and a periodontal probe with a large color-coded tip for more accurate readings. This measurement is taken from the top of the gingiva to the bone level to determine the depth of the periodontal pocket. According to these measurements, the tools are chosen to best take care of the individual patient. Scaling instruments of different angles, ultrasonic tips with different angles, and lasers with different tips are chosen, depending on the severity of each case. After the initial debridement or removal of deposits, home care tools are chosen to best help the patient reach areas that brushing and flossing alone cannot reach. Designers need to heed these difficult areas, and make tools for both patients and dental professionals that will help in better debridement and home care. While various dental tools are available, hygienists tell of frustration in accessing certain areas with their instruments, and the need for different tools for better home care for their patients.

By understanding this model, the dental professional can evaluate patient’s needs choose the appropriate and the tools needed to achieve the goal of oral health. In order to support these goals, the dental tool designer must work with the dental professional in designing tools to be used by the professional as well as the patient. “After careful analysis and diagnosis of the specific periodontal condition present, the dentist must develop a treatment plan that includes all required procedures, and estimates the number of appointments necessary to complete phase I or pre surgery therapy. Sequence of Procedures: Plaque control Instruction, Removal of Supragingival and Subgingival Calculus, Recontouring Defective, Restorations and Crowns, Management of Carious Lesions, and Tissue Reevaluation” (Takei, 2012, p. 448). These procedures must be carried out with the right types of instruments and home care (tool) products.

Plaque control is as much the responsibility of the patient as it is the dental professional. Plaque control is the regular removal of microbial plaque, and the prevention of its accumulation on the teeth and adjacent gingival surfaces. “Microbial plaque is the major etiology of periodontal diseases, and is related to dental caries; therefore gaining patient cooperation in daily plaque removal is critical to long-term success of all periodontal and dental treatment" (Takei, 2012, p.452). Daily home care must be accomplished with tools customized to each patient's needs. Design for these tools for use by all the population must include some considerations of special needs. For example, larger grips for those patients with arthritis would greatly aid in better home care. Patients with special needs are those who, due to physical, medical, developmental or cognitive conditions, require special consideration when receiving dental treatment. This can include people with Autism, Alzheimer's disease, Down syndrome, spinal cord injuries, and countless other conditions or injuries that can make standard dental procedures more difficult. This area needs a great deal of design consideration and offers a new marketing opportunity.

While tools are effective in mechanically removing local factors involved with bacterial plaque, anti-infective therapy is also used. "An anti-infective agent is a chemotherapeutic agent that acts by reducing the number of bacteria present. Anti-infective agents can be administered locally or orally" (Newman, Takei, Klokkevold, & Carranza, 2012, p. 483). The following table lists the most common antibiotics used to treat Periodontal Diseases.

Category	Agent	Major Features
Penicillin*	Amoxicillin	Extended spectrum of antimicrobial activity; excellent oral absorption; used systemically.
	Augmentin†	Effective against penicillinase-producing microorganisms; used systemically.
Tetracyclines	Minocycline	Effective against broad spectrum of microorganisms; used systemically and applied locally (subgingivally).
	Doxycycline	Effective against broad spectrum of microorganisms; used systemically and applied locally (subgingivally).
		Chemotherapeutically used in sub-antimicrobial dose for host modulation (Periostat).
	Tetracycline	Effective against broad spectrum of microorganisms.
Quinolone	Ciprofloxacin	Effective against gram-negative rods; promotes health-associated microflora.
Macrolide	Azithromycin	Concentrates at sites of inflammation; used systemically.
Lincomycin derivative	Clindamycin	Used in penicillin-allergic patients; effective against anaerobic bacteria; used systemically.
Nitroimidazole‡	Metronidazole	Effective against anaerobic bacteria; used systemically and applied locally (subgingivally) as gel.

Figure 3. "Antibiotics Used to Treat Periodontal Disease" (Newman, Takei, Klokkevold, & Carranza, 2012, p 483).

Antibiotics are but one method of anti-infective therapy. There are also local delivery agents. "Locally delivered antimicrobial agents are available as adjuncts to scaling and root planning and as aids in the control of growth of bacteria on barriers membranes" (Newman, Takei, Klokkevold, & Carranza, 2012, p 483). These can include subgingival Chlorhexidine, Tetracyclin-containing fibers, subgingival Doxycycline, and Listerine products. These products can be delivered by placements of chips or fibers subgingivally placed by dental tools, or they can be injected into the tissue by a syringe-type instrument. They can be swished in the mouth or brushed into the tissue. Dental designers need to consider these agents when developing new tools to be used by both dental professionals and the patients.

2.5 Dental Tools

Dental tools are chosen depending on the procedure to be performed on the patient. After the diagnosis, the treatment of periodontal disease follows a pattern. The following chart shows the steps. At each step, different instruments would be needed. The debridement step involves both hand and ultrasonic instruments. Surgery involves scalpels, lasers, and hand and ultrasonic instruments. Local delivery and systemic antibiotics involve anti-infective agents listed above. These tools are of upmost importance in the removal and management of bacteria involved in periodontal disease.

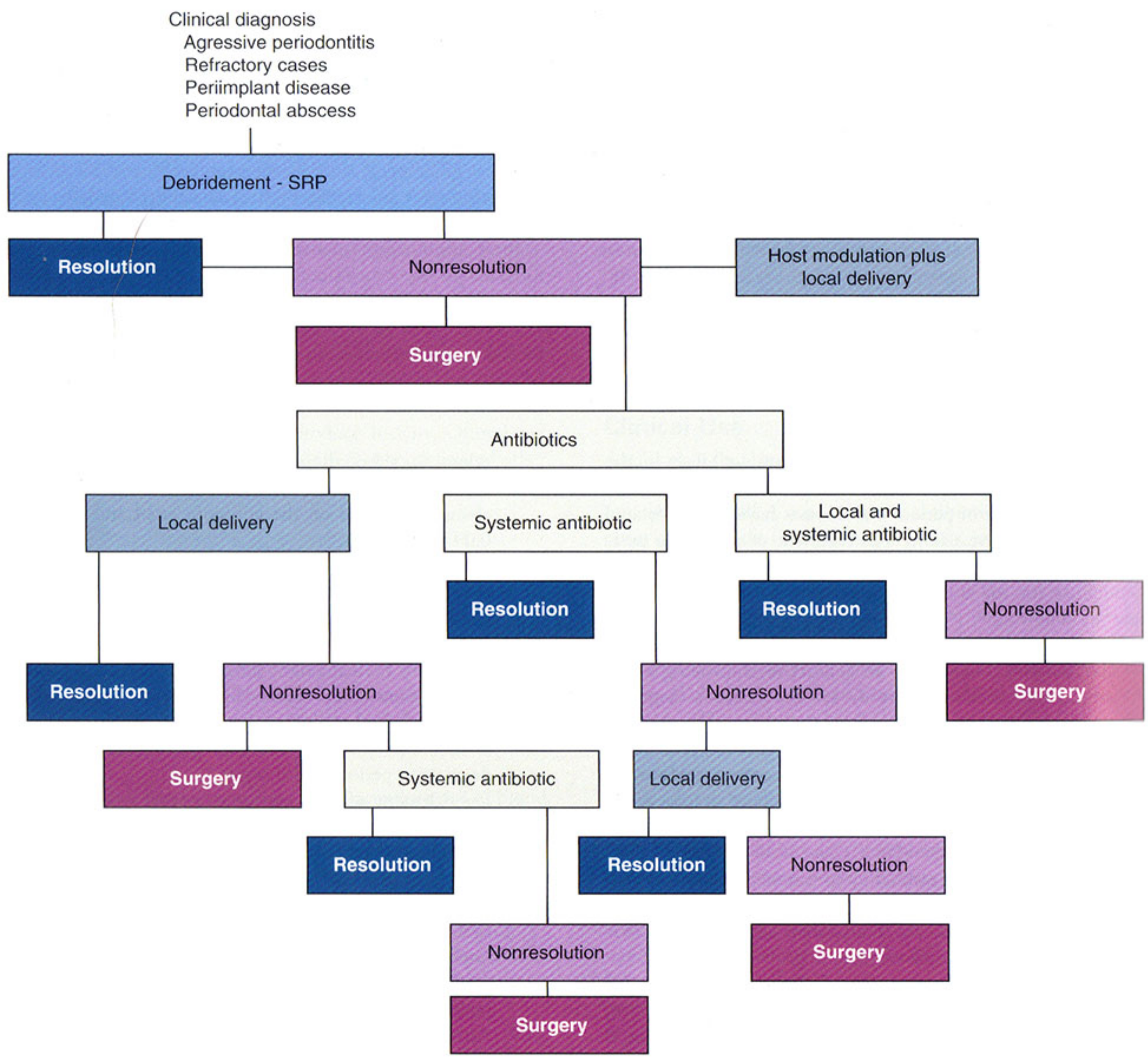


Figure 4. "Decision Tree for Selection of Antibiotic Therapy" (Newman, Takei, Klokkevold, & Carranza, 2012, p. 488).

Dental tools used by dental professionals fall into three categories. Hand instruments, ultrasonics, and lasers are all utilized to remove the debris associated with dental plaque. "Conventional periodontal therapy for aggressive periodontitis consists of patient education, oral hygiene improvement, scaling and root planning, non-invasive lasers and invasive periodontal flap surgery" (Newman, Takei, Klokkevold, & Carranza, 2012, p. 428). These therapies involve designing tools that can reach and remove debris in crevices, such as grooves in the sides of certain teeth, and furcations in the root areas. Knowledge of dental anatomy is crucial. “Periodontal instruments are designed for specific purposes such as removing calculus, planning root surfaces, curetting the gingiva, and removing diseased tissue. With experience, however, clinicians select a relatively small set that fulfills all requirements…These instruments are classified according to the purposes they serve” (Pattison, 2012, p. 461). The design of these instruments is crucial to the removal of debris in hard-to-reach concave surfaces and root furcations. New designs are needed to improve patient comfort when accessing these areas. One option is the use of lasers is a newer technology. It can concentrate light energy, and can be used on the soft tissues. “CO2 and diode lasers can be used in periodontics, but cautions must be used because thermal damage has been reported on the hard surfaces of the tooth” (Carranza, 2012, p. 605). Therefore, lasers should be considered when designing new hand tools to reduce tissue damage when cleaning teeth.

2.6 Design Process

The design process is not in a single field. Whether an engineer, architect, or designer, there is a design process that is involved. The design process can be applied to many disciplines that require a product or subject to bebeing developed, and is the most important aspect to the designer when developing a product. Most companies have a design process, but slightly differ from one another. “Both architects and product designers (or designers from any other discipline, for that matter) mainly work on a project basis - meaning that a project is acquired, a single designer is assigned or a team is put together, and work on the project continues until its completion (or until its early cancellation)” (Poelman & Keyson, 2008, p. 15). While most designers have their own design process to achieve their results, working in teams is a good way to help shape the direction of the solution to the problem. Having different opinions and feedback is critical for finding the right solution to the end result. “Most design methods have been developed for single designers. In some cases, design teams are considered to be one designer consisting of multiple persons" (Poelman, & Keyson, 2008, p. 18). Either as an individual or a team approach, the design process is an approach to solving the problem.

The design process is not a one-step process; it takes a considerable amount of time to complete a design problem. Designers must understand that, when in development, various problems will occur, and designers should step back (iterate) or revise that design. “Given the characteristics of a design problem, it follows that creating a solution is not a one-step affair, nor a matter of applying one technique to solve [problems]” (Poelman, & Keyson, 2008, p. 20). There is more that goes into the design process. Developing a design process can include multiple ways to approach a problem that occurs in a field, or product, for that field. “A process is a sequence of steps that transforms a set of inputs into a set of outputs” (Ulrich, & Eppinger, 2000, p. 14). Each approach to the same problem could produce variables with different solutions. For example, different designers working on the same dental tool with the same criteria could produce different concepts that are unique to each designer.

Each development/design process is a little different in how many steps are needed, but each design process usually has the same goals: to develop a solution to a problem. The six phases of this process is illustrated below in Figure 5.

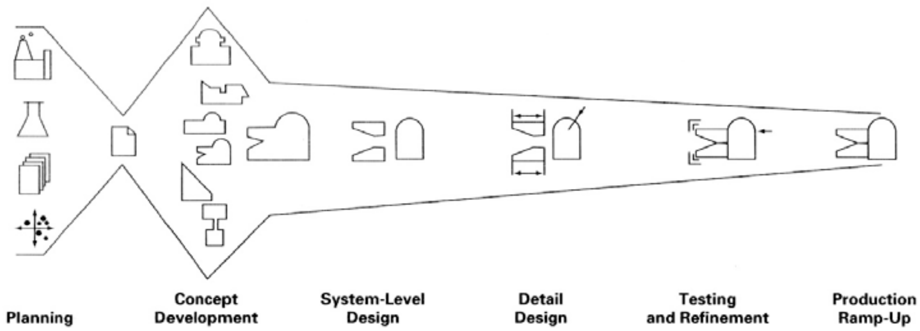


Figure 5. "Generic Product Development Process" (Ulrich, & Eppinger, 2000, p.16).

Front-end Design is what the designer usually does. "The front-end process generally contains many interrelated activities, ordered roughly as shown in Exhibit 2-3" (Ulrich, & Eppinger, 2000, p.18). By interrelating these steps in the design process, the designer will have a better understanding of what is needed to accomplish the right solution.

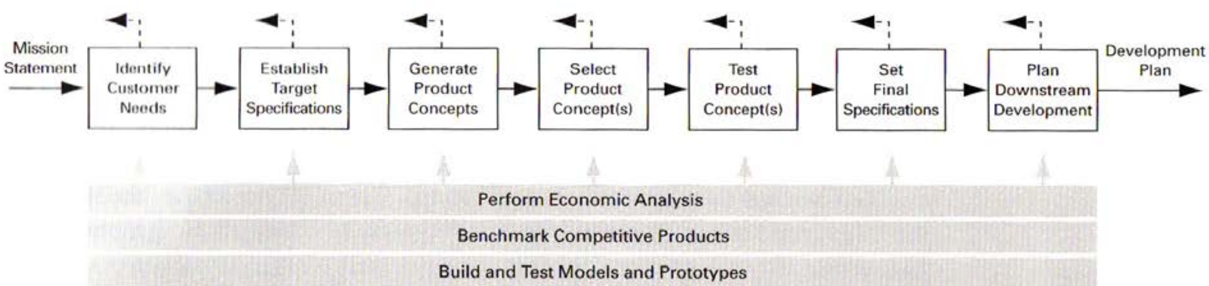


Figure 6. "Front-End Process" (Ulrich, & Eppinger, 2000, p.18).

"Rarely does the entire process proceed in purely sequential fashion, completing overlapping in time and iteration is often necessary" (Ulrich, & Eppinger, 2000, p.18). This is true for all design processes, should be encouraged to help understand problems, and finally produce appropriate products. Example: if a designer is going to design a toothbrush without looking into the research or case studies, or the concept isn't tested, a designer might develop a product that does not help, or might even hurt, the user.

Research is one of the most important parts of the design process. As a designer, learning about the background, along with the history of the products in that field, will help establish a better understanding of current problems in a certain field. The research gathered will help create better solutions to these problems with new products or processes. Cross (1984) defines design methodology as "the study of the principles, practices and procedures of design in a rather broad and general sense. Its central concern is how designing both is and might be conducted." This concern therefore includes the study of how designers work and think; the establishment of appropriate structures for the design process; the development and application of new design methods, techniques, and procedures; and reflection on the nature and extent of design knowledge and its application to design problems" (Poelman, & Keyson, 2008, p. 16). Research is the main way to understand unaddressed problems in a field.

Having a process to conduct research will help to reach the target goals for the design. Along with research, a designer must have the understanding of past products and processes, along with the pros and cons. This will help improve understanding of the direction to go in designing a product for that field. One example is invasive surgery versus non-invasive surgery for dental treatments. "Designing is knowledge intensive. Much of design is a matter of applying knowledge of previous solutions that inform the basic direction in which the current design solution has to move. Previous solutions can be referred to as precedents (prominent examples), types (generalized knowledge of cases of buildings of products), and analogies (used as metaphors rather than literal examples)" (Poelman, & Keyson, 2008, p. 21). One should adapt and modify to a point, but if there are no basic guidelines for the overall process, one might not know when to stop modifying the approach. “The methods are a starting point for continuous improvement” (Ulrich, & Eppinger, 2000, p. 8). This is the point when working in teams can be very helpful. Teams should adapt and modify the approaches to meet their own needs, and to reflect the unique character of their institutional environment.

Every group has a different process for its organization, because not every organization is the same. Even in the same field, each organization might have different approaches to their process. “Some organizations define and follow a precise and detailed development process, while others may not even be able to describe their processes. Furthermore, every organization employs a process at least slightly different from that of every other organization. In fact, the same enterprise may follow different processes for each of several different types of development projects” (Ulrich, & Eppinger, 2000, p.14). The team should not follow a very detailed development process, because it might hinder the creativity on developing new solutions to a problem. On the other hand, if one cannot describe a process, one might not have a direction on where to go, or it may be more of a challenge to get there, than if there are some guidelines on the development process. The design process is unique to each situation, and must balance the limitations of detail with that of openness.

2.7 Ergonomics

Ergonomics plays a big consideration in the development of dental tools. Dentists, and especially dental hygienists, are prone to neck, shoulder, and wrist injuries. Carpel Tunnel Syndrome is the most prominent of the problems facing dental hygienists. Dr. Dan Anton and colleagues report “in a survey of 95 dental hygienists, 93% reported at least one musculoskeletal disorder (MSD) in the past year, particularly in the region of the wrist and hand, the neck, and the upper back. At least one survey has found that dental hygienists had the highest rates of carpal tunnel syndrome of all occupations" (Michael, 2000). Posture, hand positioning, arm positioning, and position around the patients head must be considered. Design becomes very important to relieve the stress on the wrist area, so better designs are needed in this area to help prevent these problems.

Tools and equipment help the dental professional perform the tasks of plaque and calculus removal. Repetive wrist and arm motions are in use with these tools.

> "The tendons of the various forearm muscles that act on the fingers and hand run around a variety of bony and ligamentous pulleys where they cross the line of the wrist joint. Then the wrist is in a non-natural position, the mechanical loading on the tendons at their points of contact will be increased. This increased loading may lead to an increase in the wear and tear on the tendons which the working task entails and to the development of condition like Tenosynovitis, Carpal Tunnel Syndrome and other work related musculoskeletal disorders attributable to overuse" (Pheasant, & Haslegrave, 2006, p. 156).

The width of the grip of the instruments, the weight, and the balance need to be further researched to lessen damage to the wrist.

One study done by Alexander Reynolds in 2008 described the design of a pediatric dental handpiece to both reduce fear for the pediatric patient and enhance ergonomics for dentists. While this helps in the one area of the dental highspeed handpiece, many other tools need to be addressed. Another study by Hokweda, Wouters, Ruijter and Zijlstra-Shaw dealt with ergonomic requirements for dental equipment. This study was more in tuned to dental chair design than tool design. While correct posture is crucial, dental tool circumference and weight must be studied to reduce the most common injuries to dental personnel. One other study by Stacey Ahern at Kansas State University in 2010 addressed the ergonomics of dental scalers, but listed the shortcomings by stating research is still needed in designs for male vs. female bodies, as well as materials for reducing pressure on the wrist.

Dental tools need to be double ended so left and right handed users can use the same tools. Many of the tools used today do not have the length or turns needed to instrumentate the tiny spaces where the anaerobic bacteria hide and can cause bone and tooth loss. The principle of "Bend the tool's handle, not the wrist" (Lehto, 2007, p. 220) can help the professional reach the areas that can be gateways for the bacteria to enter the blood stream of the patient.

Equipment position and unbalanced weight can cause back strain. The branch of ergonomics concerned with posture and back injury is anthropometrics. "Anthropometry is the branch of the human sciences that deals with body measurements, particularly with measurements of body size, shape, strength, mobility, and flexibility and working capacity" (Pheasant & Haslegrave, 2006, p. 7). This field should be studied because posture and hand/wrist position are important for strength, access, and removal of deposits. "The posture of the dental professional is determined by the dimensions of the person's body and the relation to the patient and instrument's used" (Pheasant & Haslegrave, 2006, p. 104). Using correct posture aids in reduction of back pain. Positioning of equipment in the room, as well as unbalanced weight, can cause strain. Design of the dental stool is also important. "Neck, shoulder and back muscles may all be under tension if a seat does not provide an adequate back" (Pheasant & Haslegrave, 2006, p. 109). Also, if the seat leans too far forward, strain on the back is much greater.

Grip, strength, and torque are all important to proper usage of instruments, and to maintaining proper posture. “Both grip and strength and torque can be significantly reduced when an individual is forced to adopt a non-optimal posture…including hand tools” (Pheasant & Haslegrave, 2006, p. 157). Therefore, a designer must understand how arm and wrist position effect grip strength. “Grip strength is greatest when the wrist is in the neutral position-reducing progressively as the wrist moves from the neutral position in any direction. Grip strength is least when the wrist is flexed” (Pheasant & Haslegrave, 2006, p. 155). Dental hygienists use a pencil grip with no flexing in the wrist. This allows for a fulcrum finger to rest on a tooth as the instrument is applied to an adjacent tooth. Some instrument designs today have small diameters, causing more pressure on the wrist. Larger grips can relieve that pressure. When considering design, one must look to the United States Food and Drug Administration, the American Dental Association, the International Organization for Standards, and the American National Standards Institute for guidance on the issues described above.

2.8 FDA Standards

Among other things, the FDA regulates the design of dental tools to limit public harm. These guidelines should be incorporated into the design process as part of the design control aspect. “Design controls make systematic assessment of the design an integral part of development. As a result, deficiencies in design input requirements, and discrepancies between the proposed design and requirements are made evident and corrected earlier in the development process Design controls increase the likelihood that the design transferred to production will translate into a device that is appropriate for its intended use” (Daniel & Kimmelman, 2008, p. 55). While the FDA process can be demanding, in the long run avoiding hurtful products is worth this process. “Design controls do not end with the transfer of a design to production. Design control applies to all changes to the device or manufacturing process design, including those occurring long after a device has been introduced to the market” (Daniel & Kimmelman, 2008, p. 55). Because Americans live in a very litigious society, attempting to correct problems on the front end of design is better than fighting a lawsuit for poor design after production.

2.9 ADA Standards

In addition to FDA guidelines, The American Dental Association (ADA) and the American National Standards Institute (ANSI) work together to protect the general public and ensure good designs for dental tools. “Dental standards ensure that everyone is on the same page—those who design and manufacture dental products and the dentists who use them. Through comprehensive analysis, the ADA establishes baseline standards and technical recommendations for almost every tool of modern dentistry, from radiographic systems to sealants to manual toothbrushes” (ADA, 2013). The ADA mission statement demonstrates the desire for good design. “Our mission is to ensure the highest level of patient safety and professional satisfaction through the publication of clear industry standards for both dental products and dental informatics. The ADA is the accredited dental standards body of the American National Standards Institute (ANSI) and also designated the official United States representative for the International Organization for Standardization (ISO) Technical Committee 106 Dentistry” (ADA, 2013). The ISO has guidelines directly involved with the sterilization process and “stringent requirements for validation and routine control of moist heat sterilization in health care facilities” (Daniel & Kimmelman, p.148). When designing dental tools, the FDA, ADA, ANSI, and ISO standards help provide guidelines in the design process

2.10 Assumptions

The design process for dental tools involves many areas of study. To develop a design process for dental tools, the fields of dental microbiology and periodontal diseases must first be understood. All material of these subjects are acquired from dental and dental hygiene school curriculum books and journals.

Tool design must also include the study of dental anatomy, an understanding that allows the hard-to-instrumentate areas be defined and tools designed to reach these areas. In addition, ergonomics is very important to dental tool design. The problems associated with dental professionals and the musculoskeletal system has been discovered from dental periodicals, but a broad understanding should also include personal information acquired from discussions with practicing dental hygienists. The FDA and ADA standards, as well as the information in the design process itself, are acquired and not discovered.

Treatment with antibiotics, as well as invasive vs. non-invasive procedures, have been acquired and not discovered. The philosophy of dental professionals leads to the use of more noninvasive (non-surgical) procedures. This leads to less tissue trauma and faster healing. This information has to be considered in developing better tools to aid in less invasive procedures.

2.11 Procedures and Methodology

Step 1

Study dental anatomy

- Library and internet research
- Summarize collected information
- Derive the relationship between anatomy and tool design

Step 2

Study dental microbiology

- Library and internet research
- Summarize collected information
- Derive the relationship between dental bio-films and dental disease, heart disease, and other problems, and the need for specific tools to remove the plaque

Step 3

Study dental procedures

- Library and internet research
- Summarize collected information
- Derive the relationship between specific dental procedures and the tools needed to achieve good results

Step 4

Study dental ergonomics

- Library and internet research
- Summarize collected information
- Derive the relationship between dental problems associated with repetitive dental procedures, and the need for more ergonomically designed dental tools

Step 5

Study ergonomics

- Library and internet research
- Summarize collected information

- Derive the relationship between hand/wrist movements, and the tool design needed to achieve optimal hand/tool use
- Derive the relationship of musculoskeletal disorders found in hand/wrist movements in relation to tool design

Step 6

Study the design process

- Library and internet research
- Summarize collected information
- Derive the relationship between the process and dental tool design

Step 7

Research current tools in the dental field

- Library and internet research
- Summarize collected information
- Derive the relationship between current tools and the need for tools that adapt to hard-to-instrumentate areas of the dental anatomy

Step 8

Investigate the FDA/ADA guidelines for dental tool development

- Library and internet research
- Summarize collected information
- Implement the guidelines in the dental tool design process

Step 9

Develop a guideline for dental tool design

- Summarize collected information

- Develop a guideline for designers to design dental tools

Step 10

Develop a product base on the process/checklist product in the thesis

- Use checklist for guidelines for developing a dental product
- Document outcome of product development

Step 11

Develop the thesis

2.12 Anticipated Outcomes

At the end of this study, the need for better dental instrument design will be shown. Certain musculoskeletal problems, access to home care tools, and tool design for better plaque removal will be discussed. The need for more ergonomic design and a process to achieve this will be created.

Research findings show that dental hygienists have a high incidence of Carpal Tunnel Syndrome. They also have many musculoskeletal problems associated with current designs in the dental industry. The need for better ergonomically designed tools is needed. In addition, because new research shows a direct link between dental plaque, and plaque associated with heart disease, plaque removal with ergonomically designed tools is a goal for this study.

Deliverables in this study will contain a thesis on developing a process for better dental tool design. A project that supports this thesis either positively or negatively will be developed. Tangible results from this thesis will be a checklist for designers to use in developing new dental tools. A new ergonomic dental tool will be developed to be used as an example to other designers.

Long range consequences will help develop new tools to help reduce musculoskeletal problems in dental professionals. It will also lead to new home care tools for certain populations of disadvantaged persons. Tool redesign will lead to better access to the removal of plaque in hard-to-instrumentate areas of the dental anatomy, both at the dentist's office and at home.

Chapter 3

Human Factors

3.1 Introduction

The human factors surrounding dental tool design includes several areas. Factors involving patients include the study of the anatomy of the individual teeth, and the surrounding gum tissue. The measurements of the individual teeth and the placement of their grooves and furcations are important in the design of dental tools. Also, to be considered are the dental professionals themselves. The hand, wrist, and arm placements, and their relation to musculoskeletal disease, especially Carpel Tunnel Syndrome (CTS), are paramount to proper tool design. One study reported, " 5000 dental personnel, 177 dental hygienists were analyzed…in the prevalence and risk factors of hand problems and CTS…92% of dental hygienists responded with seventy five percent reporting hand probems and 56% exhibiting classic symptoms of CTS" (Lalumandier, J.A. & M. McPhee, 2001, p. 130-134). Improved tool design and environmental design for dental professional will greatly ecourage proper hand and wrist positions, decrease the likelihood of CTS and other musculoskeletal problems, and increase the longevity of the dental professional.

3.2 Patients

The anatomy of the mouth includes many structures including soft and hard tissues. The soft tissues include lips, tongue, cheeks, uvula, and tonsils. While these are important in the overall structure of the mouth, it is the hard tissues of the dentition of teeth and the soft gingival or gum tissue that are important to the design of dental instruments. The gingiva lies in close proximity to the structure of the teeth, and can cause pain with incorrect use or incorrect shape of dental instruments. The teeth themselves have many areas of concavities, including the sides of the roots. Molar teeth, and less frequently, premolar teeth, have furcations that also have to be considered in the design of dental instruments. Because of the many variations among individuals, a one-size-fits-all approach is not very effective.

The anatomy of the periodontium, or gum tissue, must be studied to ensure development of instrument tips that will remove the plaque and calculus located at and below the gum line with as little discomfort to the patient as possible. This study is aided by referring to the diagram below in Figure 7 showing the anatomical landmarks of the gingiva.

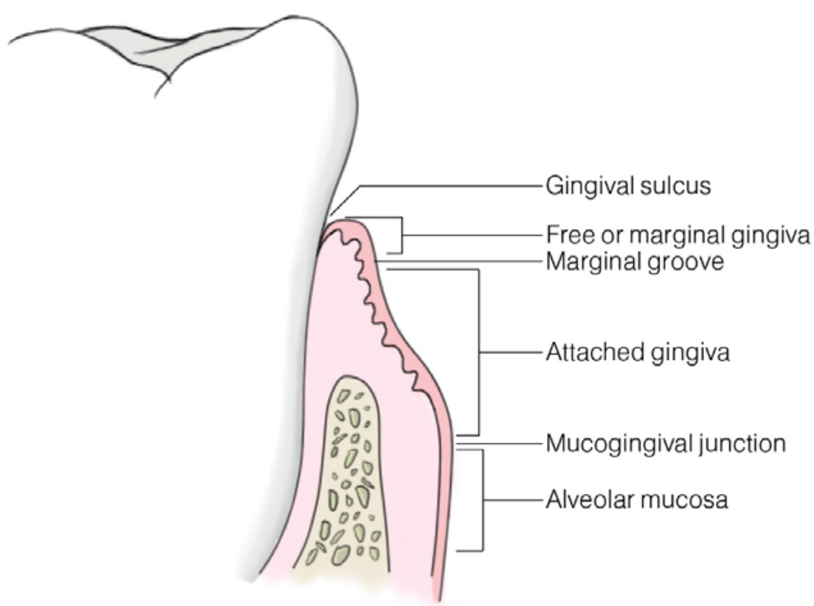


Figure 7. Anatomy of the Periodontium

The alveolar mucosa is the "firmly attached tissue melting in the floor of the mouth in the mandibular, or (lower teeth) and runs into the palate in the maxilla, or (upper teeth)" (Newman, Klokkevold, & Carranza, 2012, p. 12). This area is next to the attached gingiva which "is firm, resilient, and tightly bound to the underlying bone of the teeth" (Newman, Klokkevold, & Carranza, 2012, p. 13). These two areas are separated by the mucogingival junction. More important in dental tool design, however, is the free marginal gingiva (unattached gum) that must be understood for the development of useful tools.

The marginal gingiva, or free gingiva, is “the terminal edge or border of the gingiva surrounding the teeth in collarlike (sic) fashion (Newman, Klokkevold, & Carranza, 2012, p. 12). This marginal gingiva forms the gingival sulcus, and this is the area dental professionals must instrumentate to properly clean the debris. “The gingival sulcus is the shallow crevice or space around the tooth bounded by the surface of the tooth on one side and the free margin of the gingiva on the other side (Newman, Klokkevold, & Carranza, 2012, p. 12)”. In a healthy mouth, this sulcus measures about 1-3 millimeters. In most cases, this can be cleaned easily with instruments on the market. The problem arises as adults’ age. The sulcus depth can increase to 4, 5, or 6 + millimeters, usually in the presence of disease. Unless the debris can be removed at these depths, the sulcus depth will keep increasing till the loss of the tooth or teeth involved occurs. This same bacteria will also flow into the blood stream, contributing to other health issues. Development of new instruments are needed to successfully adapt to varied tooth structures, as well as gently instrumentate into the gum tissue.

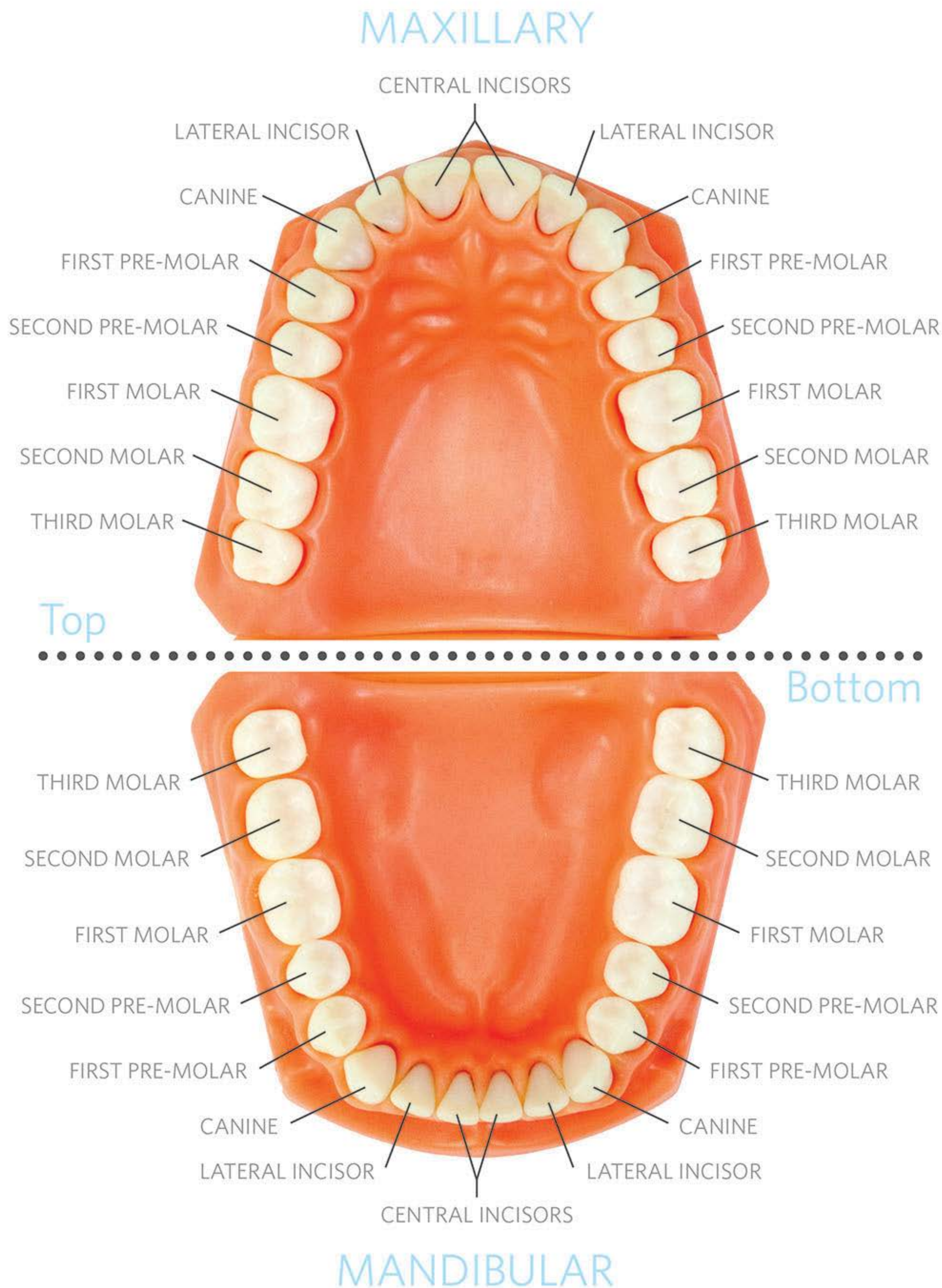


Figure 8. Diagram of full mouth: Top and bottom jaw view

The permanent teeth include the maxillary (upper teeth) and mandibular (lower teeth), shown above in Figure 8. Classifications of teeth include central incisors, lateral incisors, cuspids, first premolars, second premolars, first molars, second molars, and third molars. Each tooth includes a crown, or top part of the tooth seen in the mouth, and a root or lower, part of the tooth under the gum, with a mesial, distal, facial and lingual aspect. The mesial aspect is the side of the tooth facing toward the midline of the mouth, or more easily understood, the side toward the nose. The distal is the side of the tooth facing toward the ears. The facial surface is the area facing out toward the lips and cheeks, while the lingual area faces the tongue or inside the mouth. Each tooth has its own characteristics and dimensions (Wheeler, 1974, p. 4-5). A more detailed explanation and description of each of these teeth and surfaces follows in this thesis.

Measurements of the teeth are in millimeters. By using the generally accepted specifications for drawing and carving teeth of average size, it is possible to visualize the type of dental instrument needed to root plane or deep scale each of these areas. When discussing the individual teeth, the following chart and examples of measuring teeth in Figures 10 and 11 will be utilized.

NOMENCLATURE AND GENERAL CONSIDERATIONS

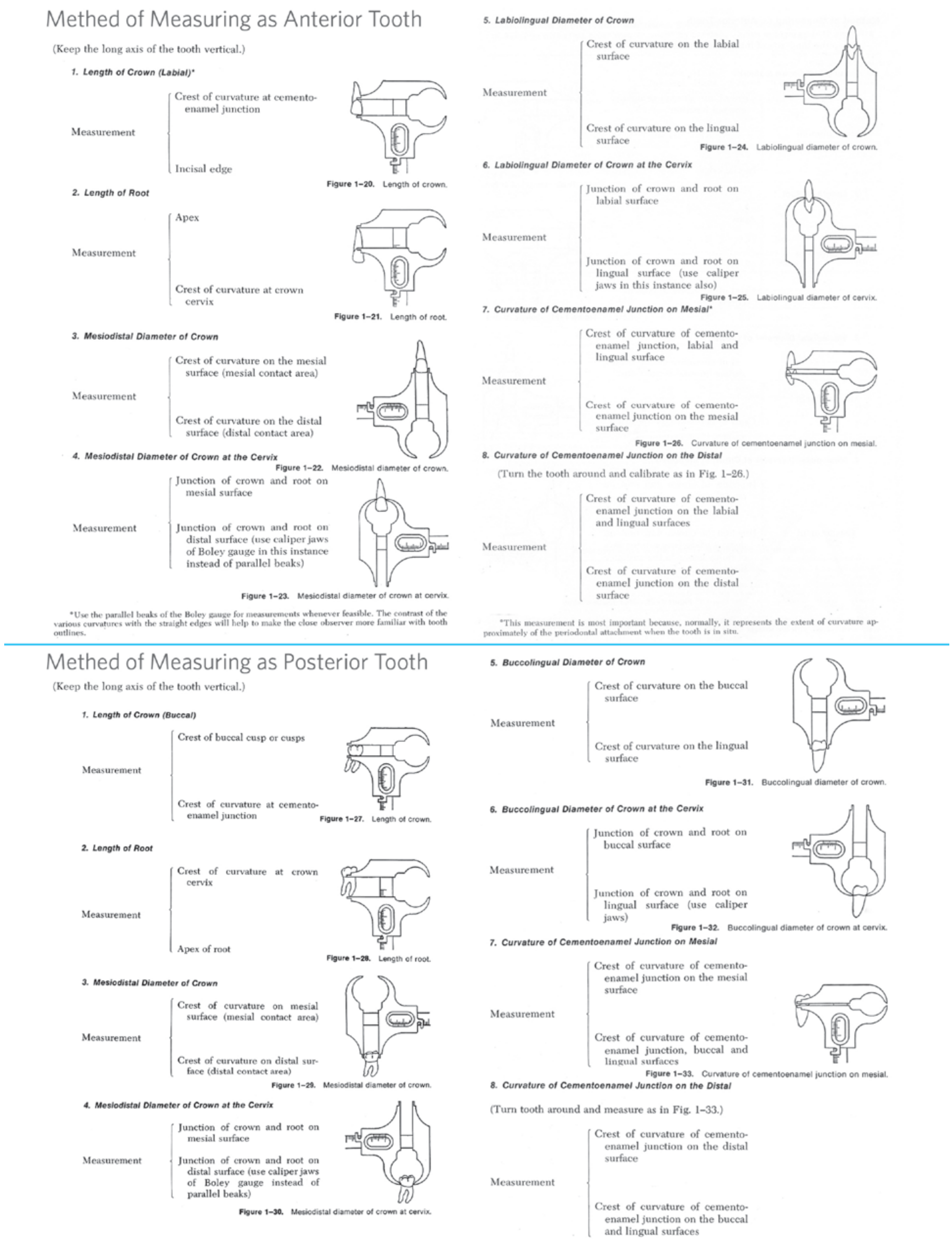
Measurements of the Teeth—Millimeters: Specifications for Drawing and Carving Teeth of Average Size (This table was "proved" by carvings shown in Figures 1–17 and 1–18 and elsewhere in this book.)

Maxillary Teeth	Length of Crown	Length of Root	Mesio-distal Diameter of Crown*	Mesio-Distal Diameter at Cervix	Labio- or Bucco-lingual Diameter	Labio- or Bucco-lingual Diameter at Cervix	Curvature of Cervical Line—Mesial	Curvature of Cervical Line—Distal
Central Incisor	10.5	13.0	8.5	7.0	7.0	6.0	3.5	2.5
Lateral Incisor	9.0	13.0	6.5	5.0	6.0	5.0	3.0	2.0
Canine	10.0	17.0	7.5	5.5	8.0	7.0	2.5	1.5
1st Premolar	8.5	14.0	7.0	5.0	9.0	8.0	1.0	0.0
2d Premolar	8.5	14.0	7.0	5.0	9.0	8.0	1.0	0.0
First Molar	7.5	b 12 l 13	10.0	8.0	11.0	10.0	1.0	0.0
Second Molar	7.0	b 11 l 12	9.0	7.0	11.0	10.0	1.0	0.0
Third Molar	6.5	11.0	8.5	6.5	10.0	9.5	1.0	0.0
Mandibular Teeth								
Central Incisor	9.0†	12.5	5.0	3.5	6.0	5.3	3.0	2.0
Lateral Incisor	9.5†	14.0	5.5	4.0	6.5	5.8	3.0	2.0
Canine	11.0	16.0	7.0	5.5	7.5	7.0	2.5	1.0
1st Premolar	8.5	14.0	7.0	5.0	7.5	6.5	1.0	0.0
2d Premolar	8.0	14.5	7.0	5.0	8.0	7.0	1.0	0.0
First Molar	7.5	14.0	11.0	9.0	10.5	9.0	1.0	0.0
Second Molar	7.0	13.0	10.5	8.0	10.0	9.0	1.0	0.0
Third Molar	7.0	11.0	10.0	7.5	9.5	9.0	1.0	0.0

*The sum of the mesiodistal diameters, both right and left, which gives the arch length, is: maxillary 128 mm., mandibular 126 mm.

†Lingual measurement approximately 0.5 mm. longer.

Figure 9. "Measurements of the Teeth" (Wheeler, 1974, p. 4-5).


Methed of Measuring as Anterior Tooth

(Keep the long axis of the tooth vertical.)

*1. Length of Crown (Labial)**

Measurement: Crest of curvature at cemento-enamel junction; Incisal edge

Figure 1–20. Length of crown.

2. Length of Root

Measurement: Apex; Crest of curvature at crown cervix

Figure 1–21. Length of root.

3. Mesiodistal Diameter of Crown

Measurement: Crest of curvature on the mesial surface (mesial contact area); Crest of curvature on the distal surface (distal contact area)

Figure 1–22. Mesiodistal diameter of crown.

4. Mesiodistal Diameter of Crown at the Cervix

Measurement: Junction of crown and root on mesial surface; Junction of crown and root on distal surface (use caliper jaws of Boley gauge in this instance instead of parallel beaks)

Figure 1–23. Mesiodistal diameter of crown at cervix.

*Use the parallel beaks of the Boley gauge for measurements whenever feasible. The contrast of the various curvatures with the straight edges will help to make the close observer more familiar with tooth outlines.

5. Labiolingual Diameter of Crown

Measurement: Crest of curvature on the labial surface; Crest of curvature on the lingual surface

Figure 1–24. Labiolingual diameter of crown.

6. Labiolingual Diameter of Crown at the Cervix

Measurement: Junction of crown and root on labial surface; Junction of crown and root on lingual surface (use caliper jaws in this instance also)

Figure 1–25. Labiolingual diameter of cervix.

*7. Curvature of Cementoenamel Junction on Mesial**

Measurement: Crest of curvature of cemento-enamel junction, labial and lingual surface; Crest of curvature of cemento-enamel junction on the mesial surface

Figure 1–26. Curvature of cementoenamel junction on mesial.

8. Curvature of Cementoenamel Junction on the Distal

(Turn the tooth around and calibrate as in Fig. 1–26.)

Measurement: Crest of curvature of cemento-enamel junction on the labial and lingual surfaces; Crest of curvature of cemento-enamel junction on the distal surface

*This measurement is most important because, normally, it represents the extent of curvature approximately of the periodontal attachment when the tooth is in situ.

Methed of Measuring as Posterior Tooth

(Keep the long axis of the tooth vertical.)

1. Length of Crown (Buccal)

Measurement: Crest of buccal cusp or cusps; Crest of curvature at cemento-enamel junction

Figure 1–27. Length of crown.

2. Length of Root

Measurement: Crest of curvature at crown cervix; Apex of root

Figure 1–28. Length of root.

3. Mesiodistal Diameter of Crown

Measurement: Crest of curvature on mesial surface (mesial contact area); Crest of curvature on distal surface (distal contact area)

Figure 1–29. Mesiodistal diameter of crown.

4. Mesiodistal Diameter of Crown at the Cervix

Measurement: Junction of crown and root on mesial surface; Junction of crown and root on distal surface (use caliper jaws of Boley gauge instead of parallel beaks)

Figure 1–30. Mesiodistal diameter of crown at cervix.

5. Buccolingual Diameter of Crown

Measurement: Crest of curvature on the buccal surface; Crest of curvature on the lingual surface

Figure 1–31. Buccolingual diameter of crown.

6. Buccolingual Diameter of Crown at the Cervix

Measurement: Junction of crown and root on buccal surface; Junction of crown and root on lingual surface (use caliper jaws)

Figure 1–32. Buccolingual diameter of crown at cervix.

7. Curvature of Cementoenamel Junction on Mesial

Measurement: Crest of curvature of cemento-enamel junction on the mesial surface; Crest of curvature of cemento-enamel junction, buccal and lingual surfaces

Figure 1–33. Curvature of cementoenamel junction on mesial.

8. Curvature of Cementoenamel Junction on the Distal

(Turn tooth around and measure as in Fig. 1–33.)

Measurement: Crest of curvature of cemento-enamel junction on the distal surface; Crest of curvature of cemento-enamel junction on the buccal and lingual surfaces

Figure 10. “Dental Anatomy, Physiology and Occlusion” (Wheeler, 1974, p. 21-24).

Highlighted in Figure 11 below to 15, the maxillary and mandibular incisors include the front four teeth, upper and lower. Two central incisors and two lateral incisors supplement each other in function, and are similar anatomically. They are used for shearing or cutting food in the process of mastication, or chewing. These teeth can have grooves on the roots, including the mesial, distal, and lingual aspects, which in the presence of bone loss and /or inflammation can cause rapid tooth loss if not properly debrided (Wheeler, 1974, p. 136).

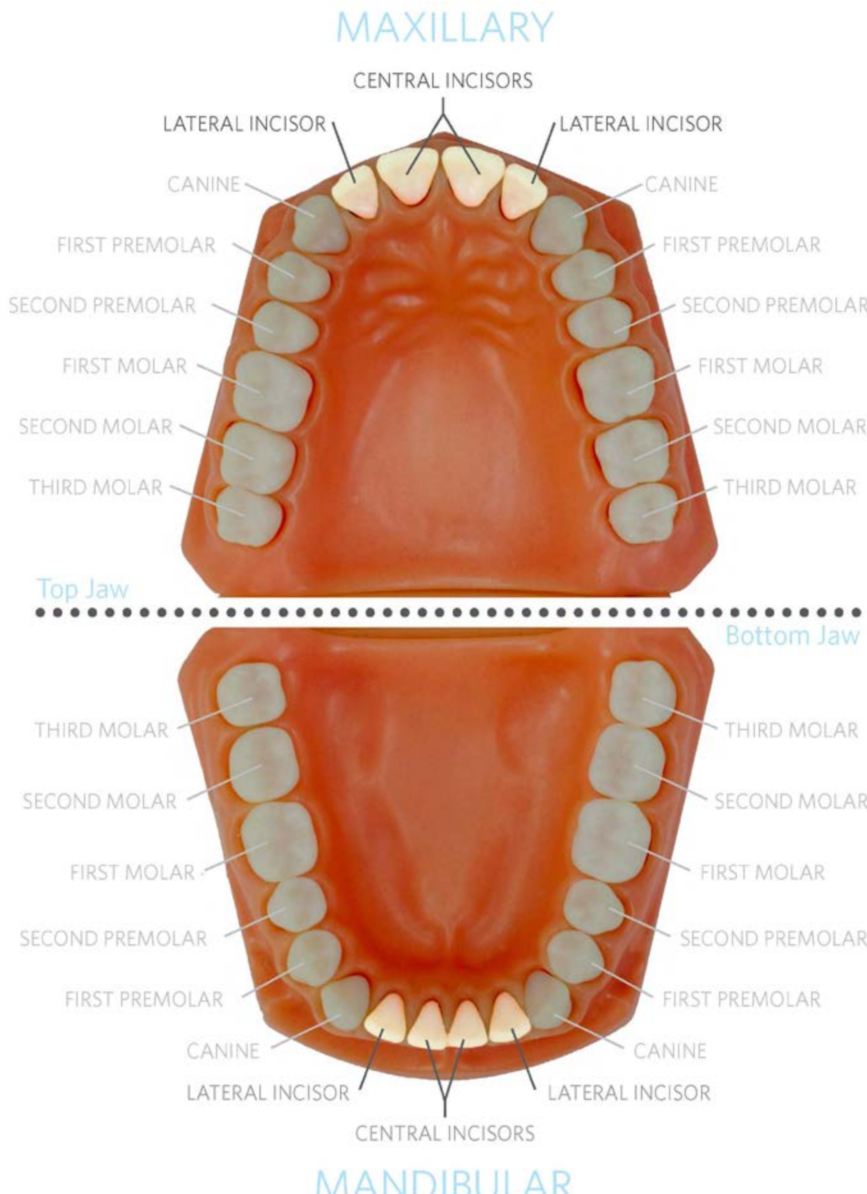


Figure 11. Diagram of Full Mouth: Central and Lateral Teeth

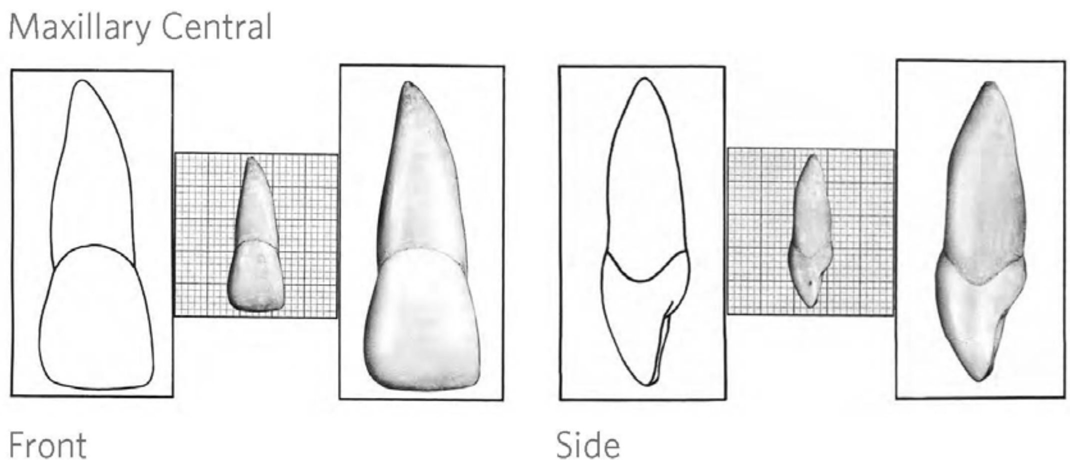


Figure 12. “Maxillary Central” (Wheeler, 1974, p. 174-177).

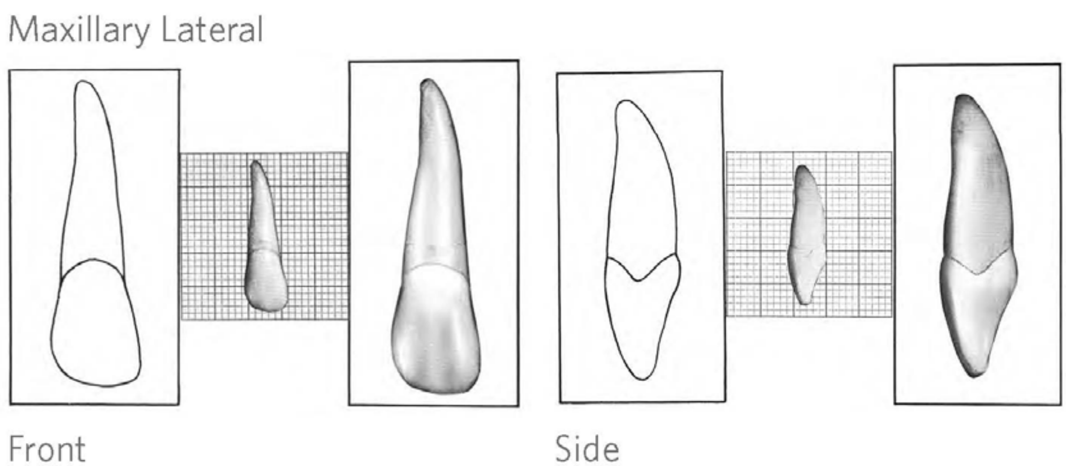


Figure 13. “Maxillary Lateral” (Wheeler, 1974, p. 148-150).

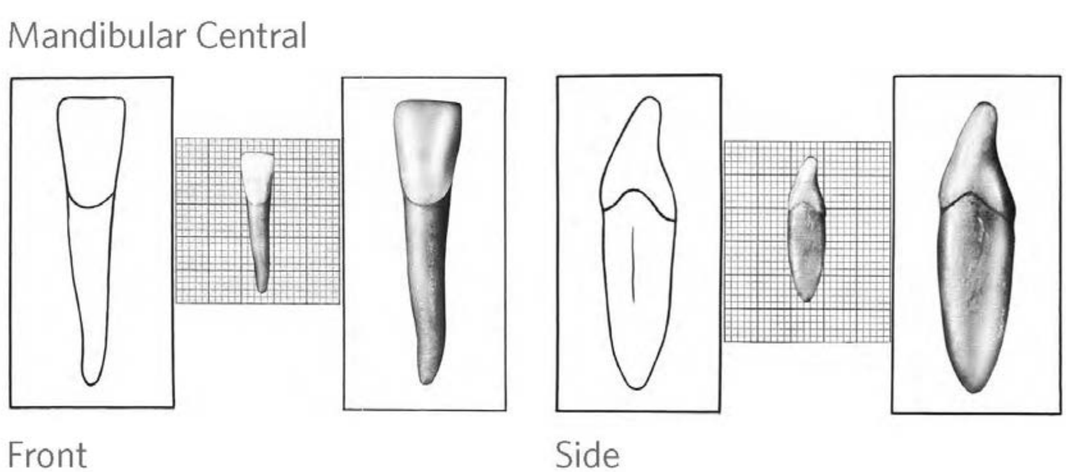


Figure 14. “Mandibular Central” (Wheeler, 1974, p. 157-158).

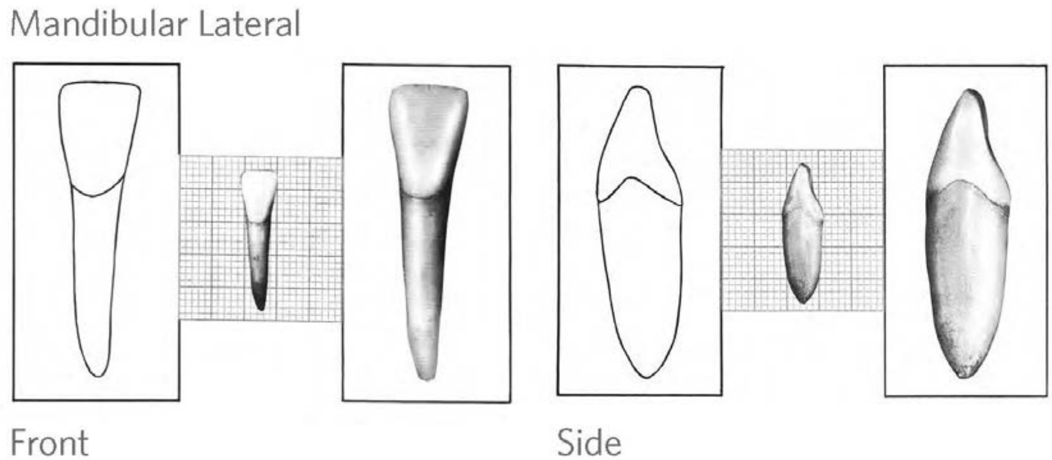


Figure 15. “Mandibular Lateral” (Wheeler, 1974, p. 166-167).

The maxillary and mandibular canines are found at the corners of the mouth. They are most important cosmetically by forming a foundation insuring a normal facial expression at the corners of the mouth. They are also important in the stability of the mouth, and aid the incisors in cutting and shredding, as well as aiding the back teeth in chewing. They are very valuable, and are maintained if at all possible (Wheeler, 1974, p. 172-173). The roots of these teeth can have mesial and distal grooves that must be properly cleaned to maintain.

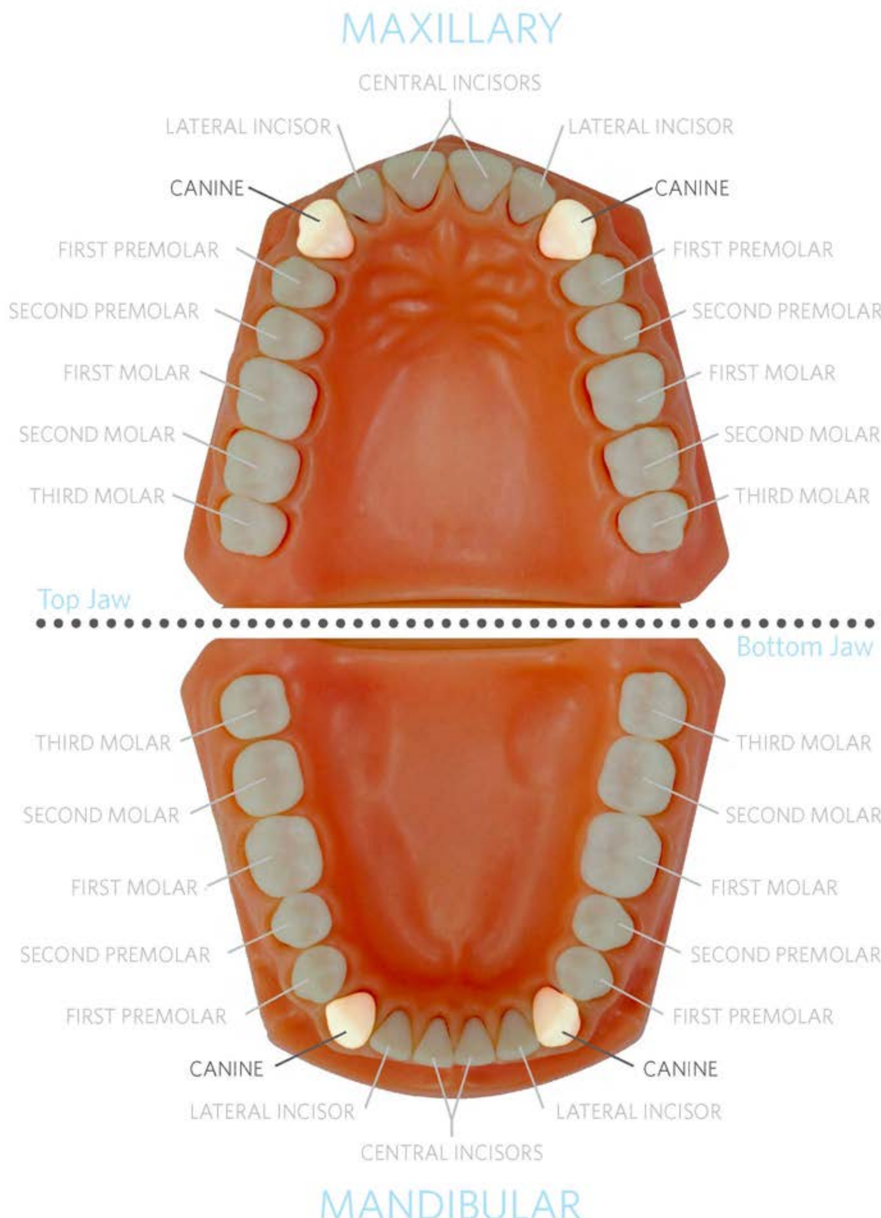


Figure 16. Diagram of Full Mouth: Canine Teeth

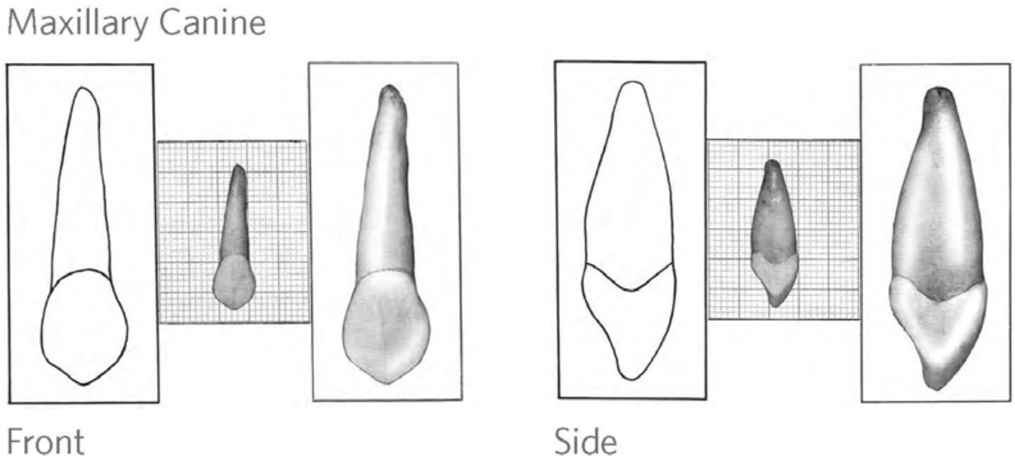


Figure 17. Maxillary Canine (Wheeler, 1974, p. 174-177).

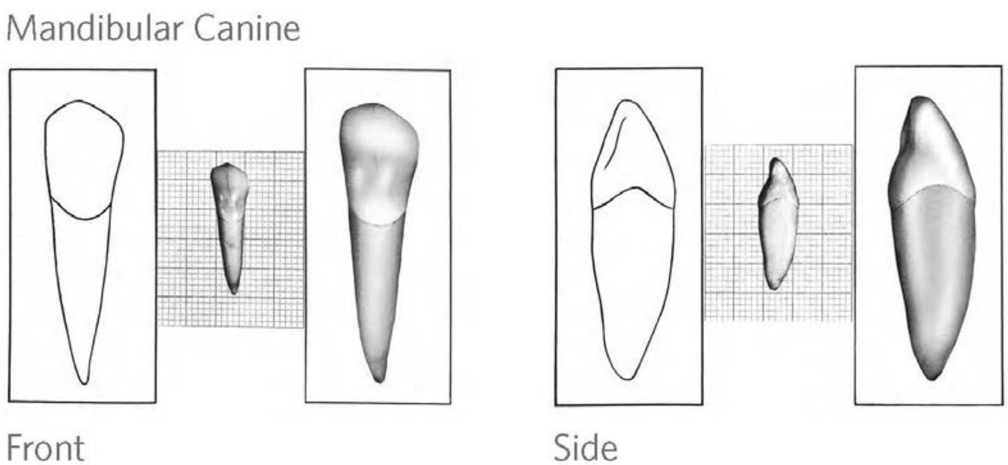


Figure 18. Mandibular Canine (Wheeler, 1974, p. 187-189).

The next grouping shown below in Figures 19 to 23 includes the maxillary and mandibular premolars whose purpose is to help in chewing food. They number eight total, four in each arch. Some have one root and some have two. Those with two roots can have furcations. All have mesial and distal grooves (Wheeler, 1974, p. 195-236). It is these furcations and grooves which pose problems in proper instrumentation.

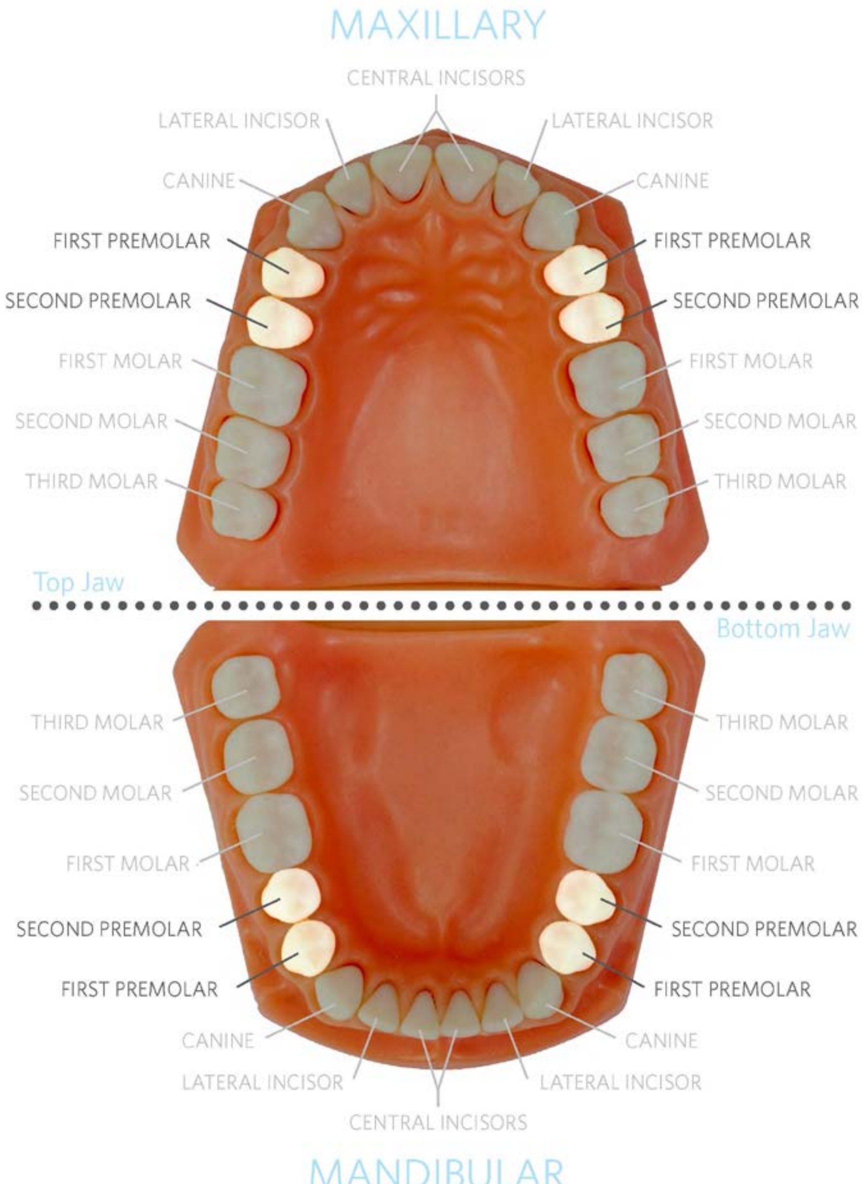


Figure 19. Diagram of Full Mouth: Premolar

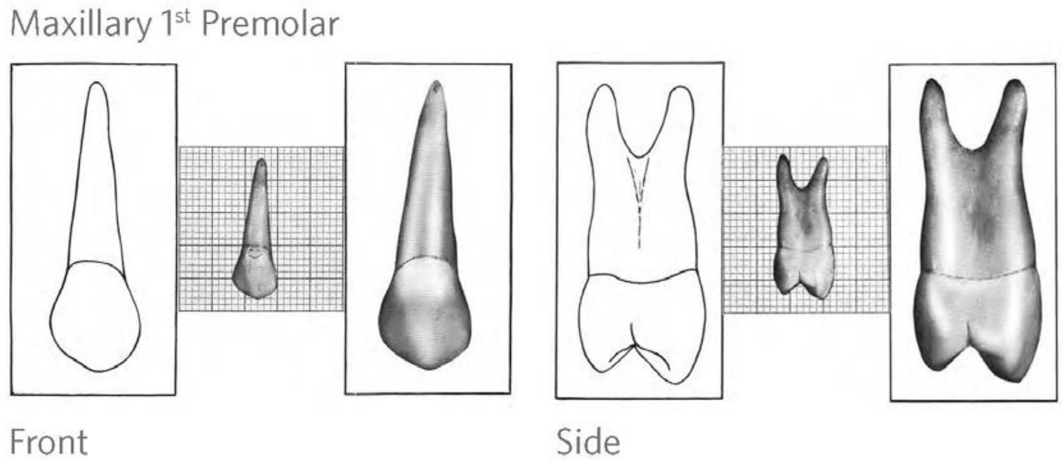


Figure 20. "Maxillary 1st Premolar" (Wheeler, 1974, p. 197-199).

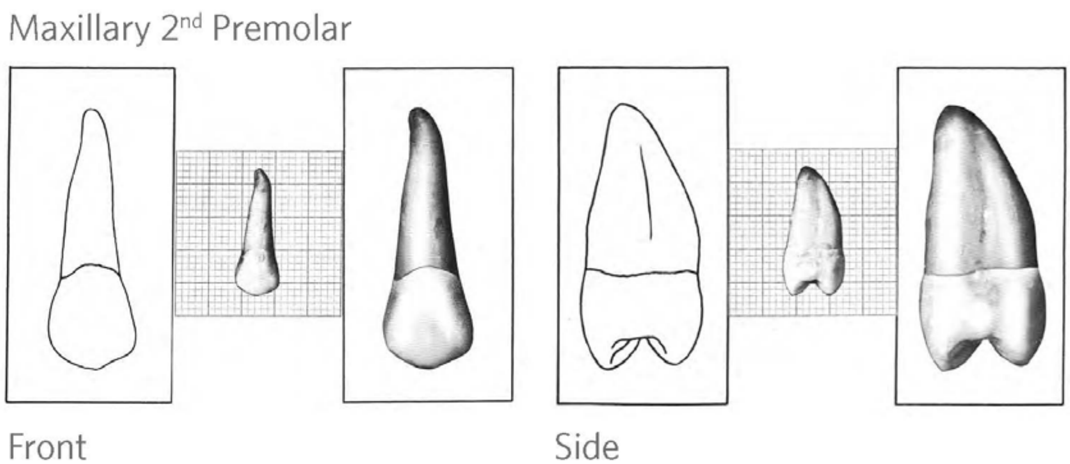


Figure 21. "Maxillary 2nd Premolar" (Wheeler, 1974, p. 210-211).

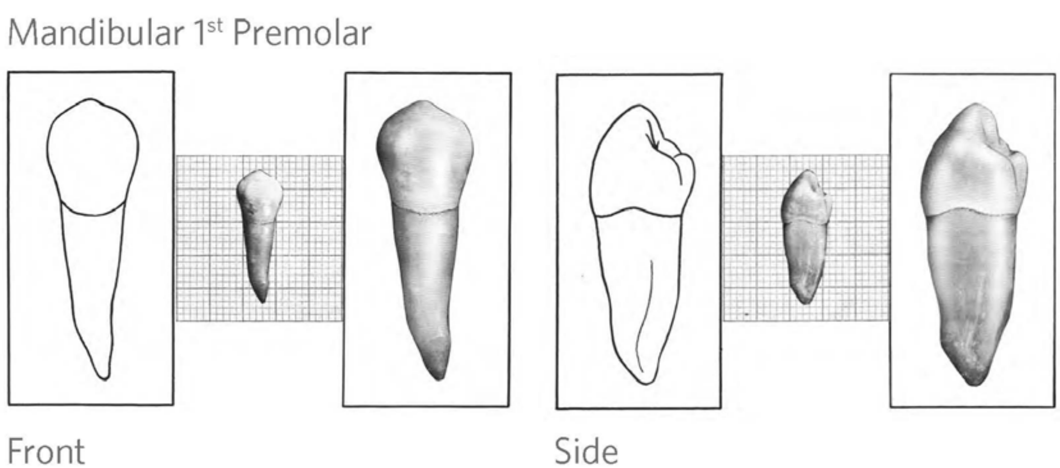


Figure 22. "Mandibular 1st Premolar" (Wheeler, 1974, p. 218-220).

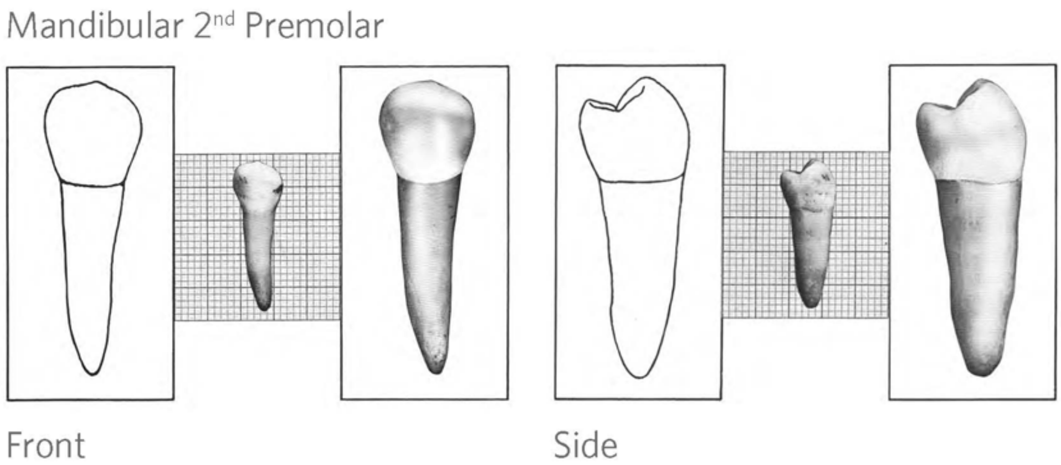


Figure 23. “Mandibular 2nd Premolar” (Wheeler, 1974, p. 230-231).

The last grouping of teeth are the molars. These teeth are made up of first, second, and third (wisdom) molars. They total twelve, six in the maxillary and six in the mandibular, whose main function is chewing (Wheeler, 1974, p. 237-238). They can be varying sizes, shapes, and can be the most difficult to scale. They have multiple roots and various furcations where bacteria can hide.

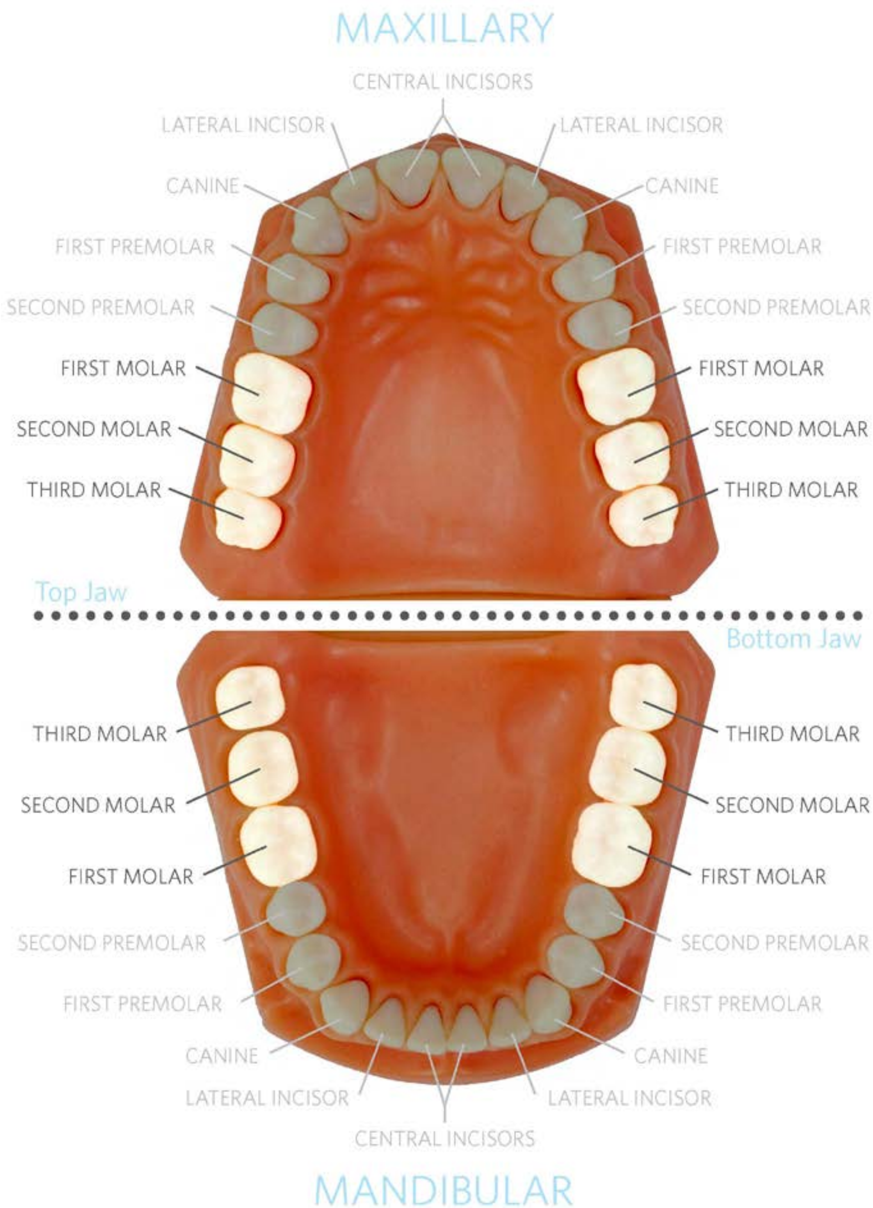


Figure 24. Diagram of Full Mouth: Molar

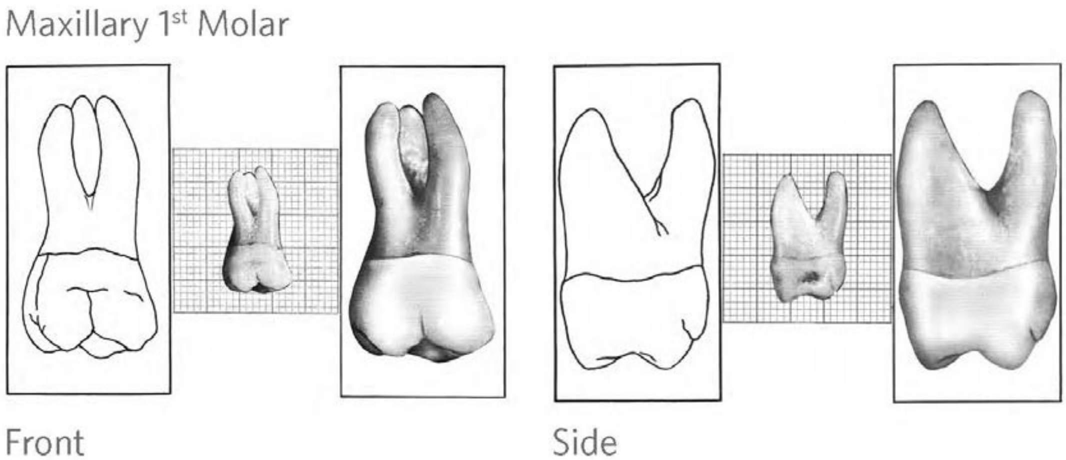


Figure 25. “Maxillary 1st Molar” (Wheeler, 1974, p. 240-243).

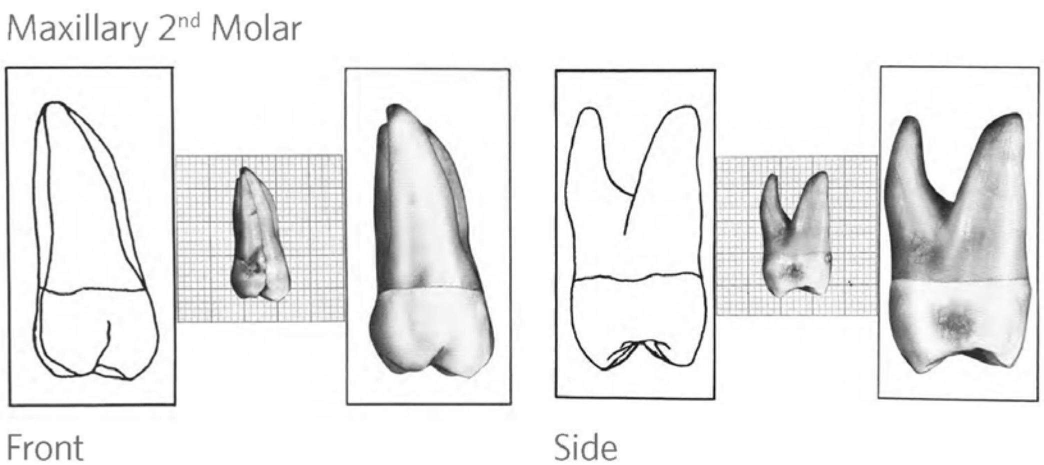


Figure 26. “Maxillary 2nd Molar” (Wheeler, 1974, p. 240-243).

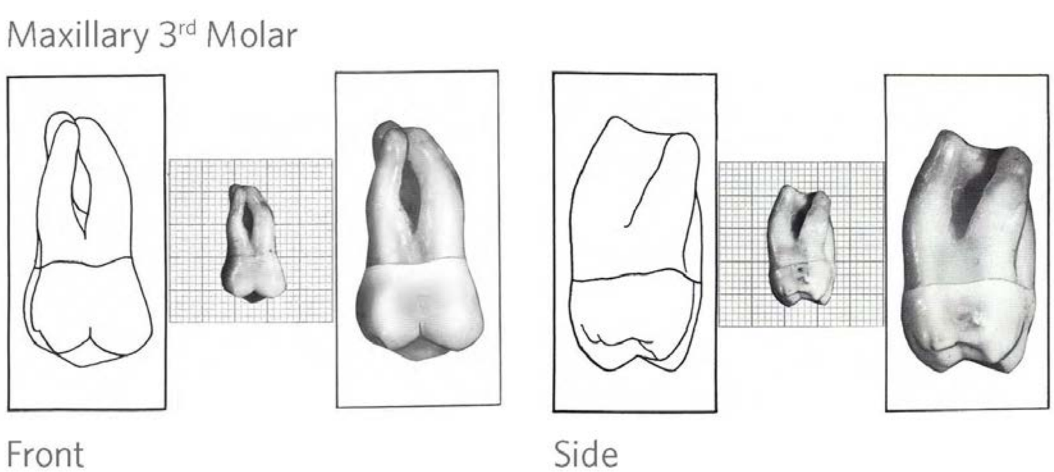


Figure 27. “Maxillary 3rd Molar” (Wheeler, 1974, p. 261-263).

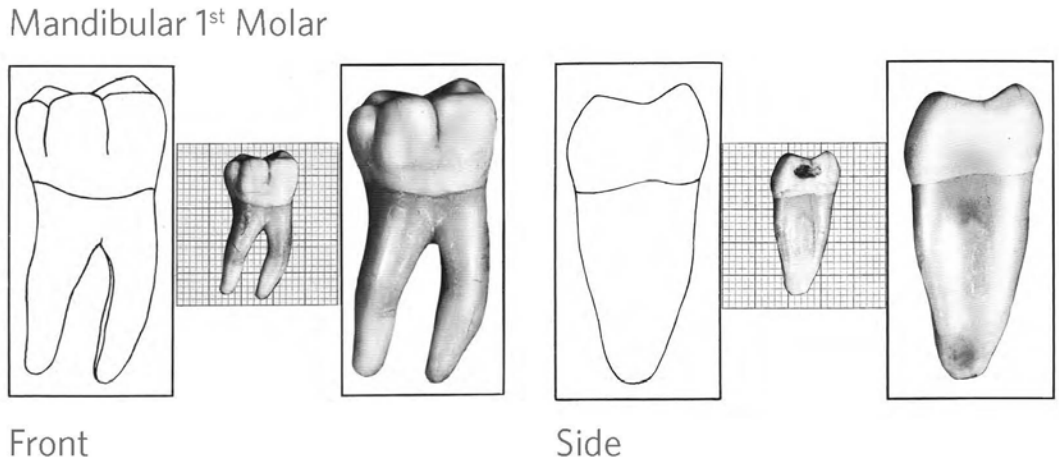


Figure 28. “Mandibular 1st Molar” (Wheeler, 1974, p. 269).

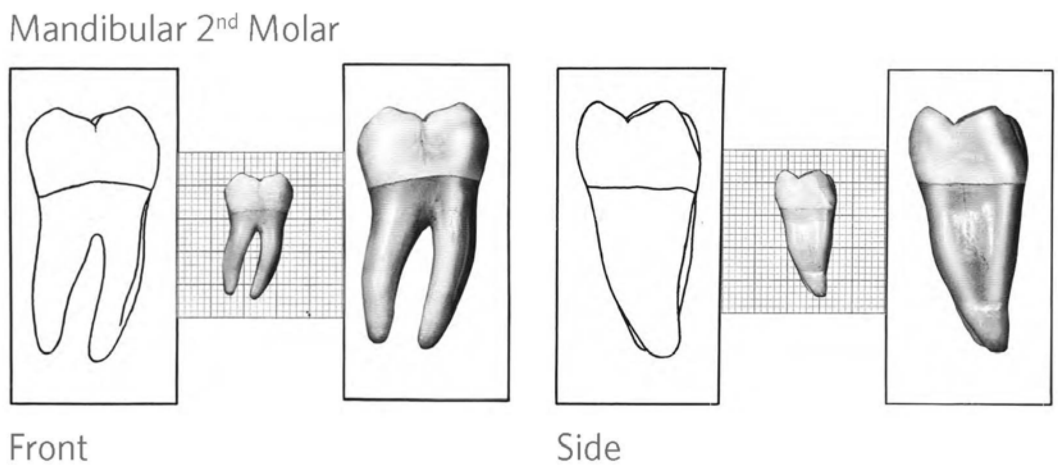


Figure 29. “Mandibular 2nd Molar” (Wheeler, 1974, p. 286).

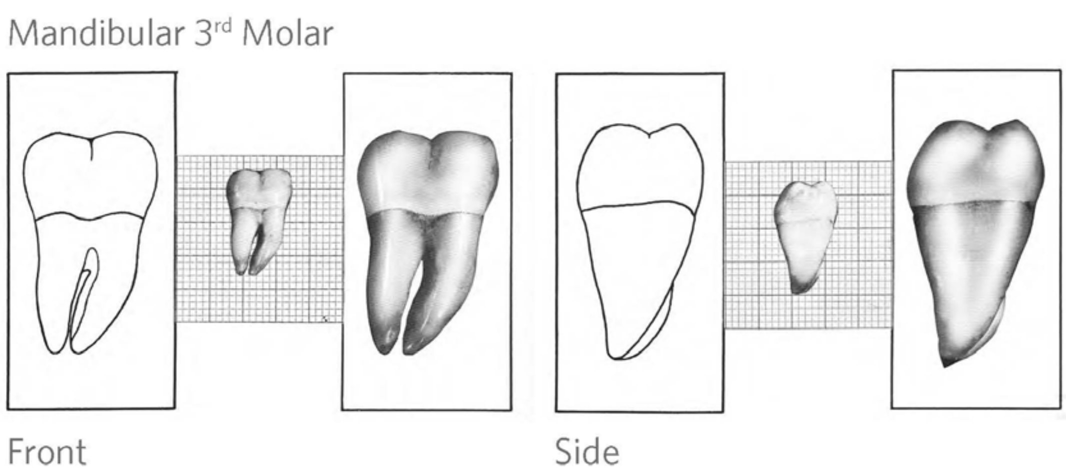


Figure 30. “Mandibular 3rd Molar” (Wheeler, 1974, p. 292).

As seen from the diagrams above, the challenges of accessing the anatomy of each tooth can be challenging. This is why musculoskeletal tool design is very important. However, before studying that design, one must first understand the problems facing the dental professional.

3.3 Hygienists/Dentists (Hands, wrist, arm and posture)

When studying human factors relating to the practices dental hygienists and dentists, musculoskeletal (MSDs) injuries to the hands, wrist, arm, back etc. are related to many environmental issues, as well as improper posture and improper movements of the above. Loss of income, and even loss of the ability to continue in the person's career choice, can be the result of poor dental tool design. Therefore, the techniques and ergonomics in the dental professional's daily routine need to be considered. These considerations should lead to better dental tool design, as well as a better environment design, which are key to relieving musculoskeletal problems by aiding the dental professional in maintaining correct posture. In this study, first to be considered are the most common trauma disorders and their impact on productivity and the profitability of the dental professional.

Colin Graham (2002) is an ergonomist specializing in occupational and hand therapy, and works with dental offices in the San Francisco Bay Area. He writes in *Ergonomics in Dentistry*,

> Prior to 1985, low back pain was the most commonly reported musculoskeletal disorder (MSD) or repetitive injury for dentists and dental hygienists. Since then, there has been a rise in MSDs from extended workdays, awkward postures, prolonged standing/unsupported sitting, and a host of other problems caused by poorly designed workstations, improper work habits, and instruments that are difficult to manipulate. The current workstation in most dental offices requires

that the practitioner lean forward, flex his neck forward and laterally, hold his shoulders abducted and his arms flexed, with this position being held statically for most of the workday. Dental hygienists need to tightly grip thin, sharp instruments and make a high volume of short, forceful movements with the muscles of their wrists and hands to treat heavy calculus and other conditions. The human body is not built to handle these kinds of stresses, and the positions in which dentists repeatedly put themselves through their work place them at great risk for developing MSDs. (p. 1)

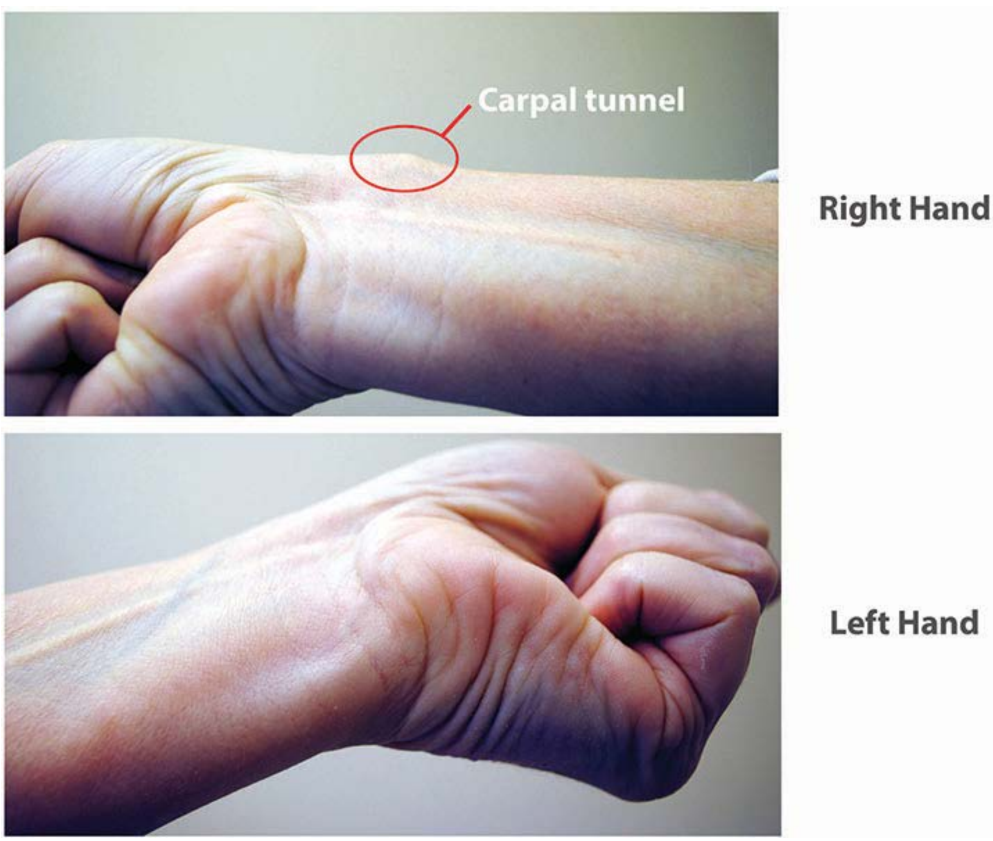


Figure 31. Carpal Tunnel Hand vs. Non-Carpal Tunnel Hand

The right hand pictured in Figure 31 is of a dental hygienist who has practiced for 40 years. The nodule circled impinges on the carpel tunnel, and causes the hygienists' fingers to tingle and sometimes go numb. Pain sometimes shoots up the fore-arm to the elbow. The second picture shows the left hand of the same hygienist showing a smooth wrist with no nodule. This nodule is the result of years using small diameter instruments.

It is these thin instruments that can be redesigned to relieve some of the stress. The thinner the handle, the more tightly the dental professional must grip, putting extreme pressure on the hand and lower arm. Larger diameters could greatly ease this pressure. While Graham's observations are important, another source should be considered.

Bethany Valachi (2008), PT, MS. CEAS, is a physical therapist and dental ergonomic consultant. She has consulted many renowned dentists and dental hygienists in writing her book, *Practice Dentistry Pain-Free*. She states, "The musculoskeletal problems often begins in dental or hygiene school…37-70% complain of pain sometime in school or shortly into their early practice" (p. 4). Valachi (2008) goes on to state, "it is clear from the research the delivery of dental care poses potentially significant risk of injury to practitioners" (p.4). With this great of risk, it is important to look at the impact on productivity and profitability to the dental profession and the personnel involved.

The loss of income can become a significant problem. Valachi (2008) has some significant findings concerning these losses. She states, "In 1987, the estimated loss in income due to musculoskeletal pain in dentistry was $42 million…Financial losses can also be significant for dental hygienists whose average wage is $32.50 an hour…One in five hygienists who permanently leave the profession is affected by a disability; and very few disability insurance companies are willing to take the risk of protecting the income for those in the dental hygiene profession" (p.4-5). To minimize the risk to a dental professional's income, better design in dental tools can help promote more neutral positions for the practitioner and reduce the impact of instrument use on the hands and wrists. To design better tools, one must first be familiar with the risk factors and symptoms involved in MSDs.

Both Graham and Valachi list very similar risk factors. The following chart shows the leading causes.

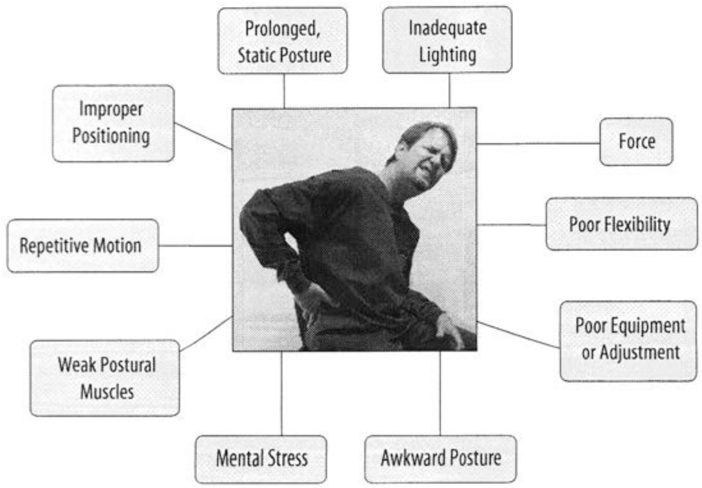


Figure 32. "Risk Factors Leading to CTDs in Dentistry" (Valachi, 2008, p. 8).

Graham (2002) also lists the symptoms of MSDs. He states, "These include decreased range of motion, loss of normal sensation and movement, and decreased grip strength. These signs lead to symptoms of tingling, burning, pain, cramping, numbness and excessive fatigue" (p.1). While some factors can be genetic in nature, the ones listed in the chart above can be controlled by proper dental tool and work space design. If risks and symptoms are ignored, permanent damage and pain can occur. Before ergonomic design can be discussed, and recommendations made to this design, one must understand why the changes need to be made.

In the study of human sciences, the human body is shown to be a complicated machine. Movement is a natural function of one's body parts. In dentistry, static positions can be the norm for extended periods of time. This lack of mobility can lead to several traumas to the body.

Valachi (2008) lists four classifications of “microtrauma from prolonged static postures…including muscle imbalances, muscle ischemia (an insufficient supply of blood), spinal disc degeneration, and trigger points” (p. 9-10).

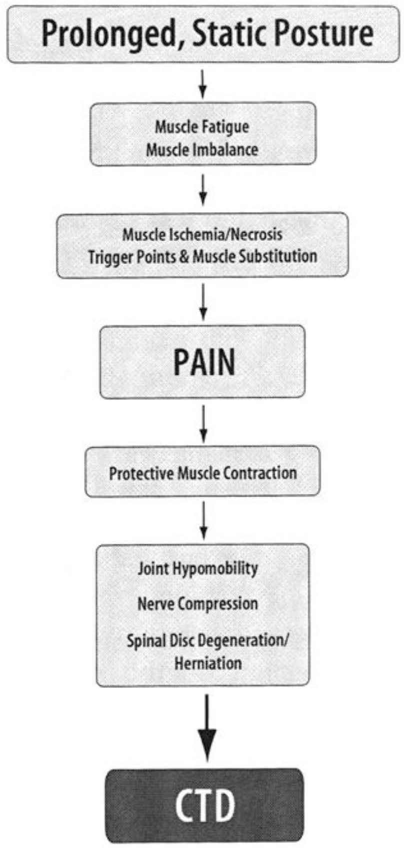


Figure 33. “Flowchart of Static Postures Can Progress to Pain a CTD” (Valachi, 2008, p. 8).

This chart in Figure 33 above shows how a static posture can lead to Cumulative Trauma Disorders or CTDs. The muscle imbalances can happen over time. When a dental professional leans in one direction more than another, the muscles can shorten, causing misalignment of the spinal column, and result in loss of range of motion. Examples of these imbalances occurring in dentistry are cervical instability, rotator cuff impingement, and trapezius myalgia, each described by Valachi. Dentist and Hygienists use forward head posture, which can cause instability in the cervical spine. Valachi (2008) states, “This posture leads to flattening of the neck curve…muscles, ligaments, and tendons stretch, shorten and weaken to adapt leading to risk of disc injury or herniation where in tear in a spinal disc allows the soft, dental portion to bulge out” (p.64). Rotator cuff impingement is another injury found in dental professionals due to the lifting or abduction of the shoulders out to the sides when working on patients. This results in microtears from overuse, which result in muscle weakness and can lead to a complete tear. Valachi (2008) states, “Dentists and hygienists tend to abduct the left shoulder more than the right probably due to positioning challenges and using the mirror to retract soft tissue. This abduction impedes blood flow causing ischemia” (p.66-67).

Ischemia results when a muscle is contracted for long periods of time, resulting in a rise in intramuscular pressure, which compresses the blood vessels within the muscle and obstructs blood flow. The result is muscular pain and fatigue. The third, trapezius myalgia, can be a very painful condition. The trapezius muscle is a triangular shaped muscle connecting the shoulder to the spine and neck, and it supports the weight of the arm. Myalgia refers to muscle pain. Valachi (2008) states, “Symptoms include pain, spasms, tenderness or trigger points in the muscle, often on the side of the mirror, or retracting arm. In spinal disc degeneration, chronic low back pain as well as radiating pain to hips occurs when spine is denied up and down movements. In dentistry, sitting for long periods of time rob the spinal disc of needed nutrients to function correctly” (p. 48-49). All of these issues can be improved through informed design of the dental environment and equipment, which will be discussed later. While the three issues mentioned above are responsible for problems for the dental professionals, the fourth, trigger points, pose the most significant problems.

A trigger point is a hard knot or nodule found in a group of muscles. It can be painful when pressed, and if left untreated, syndromes can result, most notably Carpel Tunnel Syndrome or CTS. Pain, tingling and numbness in the hand and fingers are indicative of CTS, and is caused by pressure on the median nerve in the wrist. Valachi (2008) states, "CTS is the most common peripheral nerve problem and affects seventy one percent of dental professionals at one time or another" (p.77). Valachi has done extensive studies on this syndrome.

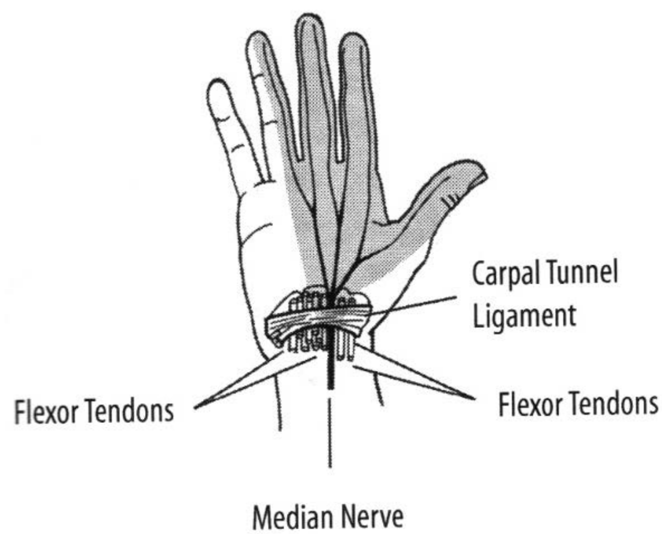


Figure 34. "Pain or Tingling of the Median Nerve (shaded)" (Valachi, 2008, p. 77).

The median nerve can be seen running from the arm to the fingers and thumb. It passes through the flexor tendons and the carpal tunnel ligament. The carpal bones are a row of bones on the back of the hand and are attached to the thick carpal tunnel ligament seen in Figure 18. It is the median nerve, when constricted or entrapped, which results in the CTS syndrome.

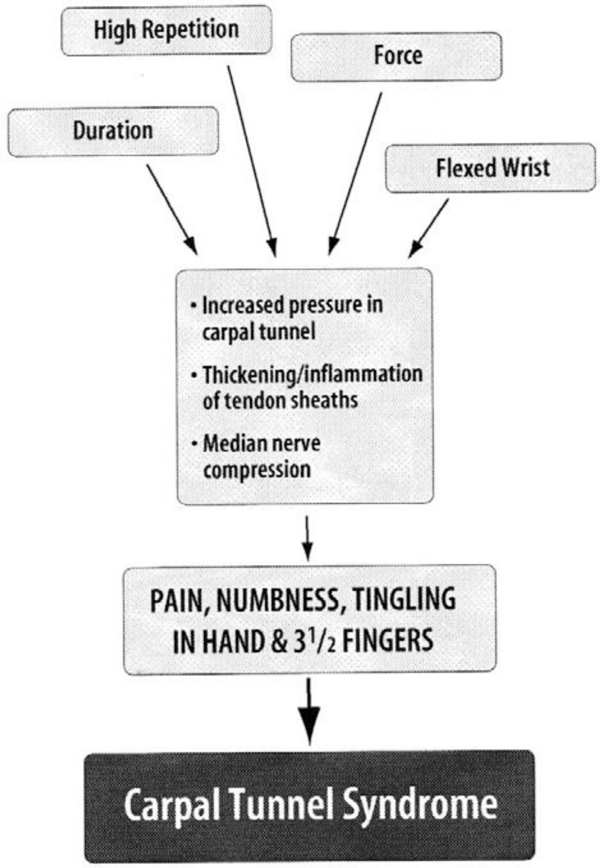


Figure 35. "Primary Risk Factors Contributing to CTS in Dentistry" (Valachi, 2008, p. 78).

In Figure 35, the primary risk factors for CTS in dentistry is shown. Valachi (2008) states, "These risk factors cause trauma to the carpal tunnel causing fibrosis and edema of the lining of the tendons and eventually cause increased pressure within he carpal tunnel" (p. 78). All four of these risk factors affect the practice of the dental professional, especially the dental hygienist. In reaching for the molar teeth, flexed wrists are the norm. Longer shanks extending from the handle can help maintain a neutral wrist. When scaling the teeth, significant force, high repetition, and duration are especially important to consider in hand tool design.

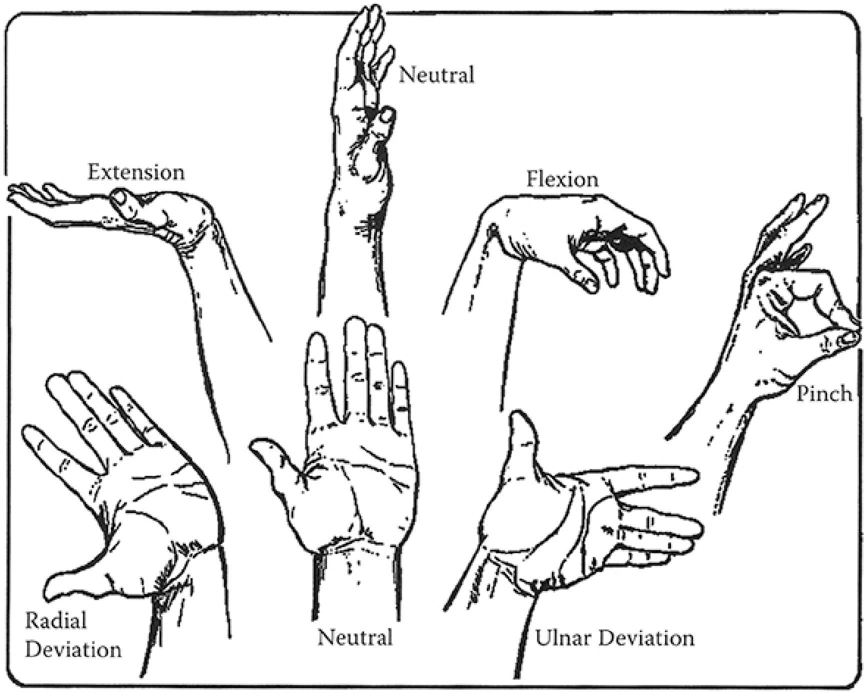


Figure 36. “Hand and Wrist Postures” (Pheasant & Haslegrave, 2006, p. 147).

In Figure 36, the neutral position of the wrist is shown, as well the deviations in the wrist that can cause the problems associated with dentistry. The pain associated with these nonneutral positions can be severe, and can lead to the dental professional having to retire from the profession. The pinch or pencil grip is used by all dental professionals, and current designs cause flexion, radial, and ulnar deviations which lead to debilitating CTS.

In the practice of dental hygiene, all four of these primary CTS risk factors are a repeated part of the daily routine. Using a precision grip (or pencil grip) on the tiny diameter of scalers now in use, with repeated force needed to remove calculus over a long durations, puts undue pressure on the carpel tunnel. Using a flexed wrist also adds to the problem. Dr. Kathleen Romito in Web MD (2012) states, “making the same hand movements over and over, especially if the wrist is bent down (the hands are lower the wrists), or making the same wrist movements over and over can cause injury to the CTS". A new hand tool design incorporating a larger diameter, as well as redesigned tips to access the furcation and grooves of the teeth allowing gentler movements, will reduce this pressure as well as help the dental professional not flex the wrist. A closer look at ergonomic tool design is needed to address all four of these contributing factors.

3.4 Dental tools

Having looked at the four risk factors contributing to Carpal Tunnel Syndrome (CTS), as well as the economic impacts associated with these factors, the need to ergonomically design tools to relieve these risk factors, as well as removing debris in the patient's mouth, is apparent. Instrument selection, whether hand, ultrasonic, or lasers, must be considered. Designs that help the clinician avoid a sustained improper wrist position will aide in reducing pressure on the carpal tunnel. Also to be considered is the pencil grip now used by all dental professionals. Several other factors must also be considered, including diameter, weight, texture, sharpness, length and curvature of the cutting edge. From these factors, a design process can be established.

When removing the debris from a patients' mouth, a hygienist must choose either hand scalers, ultrasonic scalers, or lasers. "At the present time hygienists are allowed to use lasers in only thirty-one states, but this is expected to expand to all fifty states in the next decade" (States that, 2012). In many cases, hygienists use a combination of these three tools.

Manual scaling with hand instruments require the most force by the dental professional. These hand instruments have been utilized as long as modern dentistry has been practiced, and are utilized even in the presence of the more modern ultrasonics and lasers. They can also can be responsible for more wrist flexion causing more pressure in the carpel tunnel than the other two methods. Valachi (2008) states, “Keeping the wrist straight, and moving the entire hand, wrist, and forearm as a unit transfer the load from the smaller hand muscles to the larger arm and shoulder muscles” (p. 79). The use of a fulcrum or a stabilizing finger point in the mouth aids in proper wrist technique. She also points out, “When accessing molar regions, an instrument with multiple accentuated angles, and longer terminal shanks are needed”. In use of hand instruments, proper design will lead to less flexion in the wrist, and help reduce CTS in the dental professionals. Larger diameter and textured surfaces can reduce the tight pencil grip on tools. These handles should be produced with medial grade materials and be autoclavable (sterilized with steam under pressure at a certain temperature).

Ultrasonic instruments require less force when removing deposits from teeth. “Ultrasonic scalers are considered by many to be the standard of care in clinical dental hygiene, supplemented by hand instrumentation…a change must be made to ensure the tool is adapted for the work” (Guignon, n.d.). This statement is also backed up by Valachi (2008), who states, “The effectiveness of quality advanced periodontal instrumentation is often hard to match with an ultrasonic unit” (p.81). While less force is required, the inset tips in current use are a small diameter and cause excessive squeezing when using a pencil grip. A larger diameter would help this problem. Another drawback can be the cord attached to the end of the ultrasonic unit. This cord adds weight to the back end of the tip being used, and can cause flexion in the wrist. This is especially seen in cords that are coiled instead of straight. These concerns should be addressed when constructing dental ultrasonics.

Figure 37. Tooth and Hand Tip

Figure 37 shows the tip design currently in use. The tip falls short of the furcation area and will not allow the users to access the area. This leaves damaging bacteria in the area, and will likely lead the patients to more invasive periodontal surgery. Tips designed to access the grooves and furcations of the teeth are needed to make the tool more effective in removing deposits in the hard-to-reach areas. A light emitting from the tip of the tool would also aid with illumination of the immediate work area, providing improved use of the tool for the operator. Longer tips with several bends would accommodate the hard to scale areas. Less need for manual scaling will help in reducing carpel tunnel pressure and injuries to the dental professional.

Lasers are the newest technique for removing deposits. It also has some added benefits that manual and ultrasonic instrumentation do not. Less bleeding and pain are associated with laser use. In *The Registered Dental Hygiene* magazine, Lisa Dowst-Mayo (n.d.) describes the principles of the laser use. Laser use kills the pathogens involved with periodontal disease. It will not only remove diseased and necrotic tissue, as does the manual and ultrasonic techniques, but is selective in the killing of only the "bad guys" not the "good guys." In other words, the healthy tooth structures are left unharmed. This is one difference between the removal techniques. But Dowst-Mayo (n.d.) describes the most significant difference: "This system can regrow attachments a patient has lost due to the disease, instead of just trying to maintain what they have left, like the technology in manual and ultrasonic techniques".

The problem with lasers mirrors the problem with the other tools. The current design only reaches so far. Dowst-Mayo (n.d.) poses a concern as well as a question: "The concern is the research articles discuss using the diode laser on patients with 4mm pockets or less for patients with gingivitis. So if a patient has advanced gum disease with 10-12 mm pockets, is this really the best tool for treatment?". Other drawbacks can be increased costs of using lasers, though this problem could take care of itself over time as more dental professionals use this technique. Another problem is limited access to certain areas of the mouth. Again, applying design considerations will help in reaching the deeper pockets, and in doing so, may someday eliminate other methods of removal including surgery and extraction of teeth. Longer tips with bends would achieve the goal of reaching the crevices where the anaerobic bacteria hides. This design in Figure 21 also shows a tip not designed for deeper pockets. A redesign could revolutionize the practice of dental hygiene.

Figure 38. Laser Scaler

To this end, the three major choices of tools for the dental professional have been identified, with the features for design and/or redesign that need to be considered. As mentioned at the beginning of this section, these include diameter, weight, texture, sharpness, length and curvature of the tips. Each of these factors in dental tool design are important in reducing CTS's.

Dental instruments are available in varying diameters. Currently most fall under the 7mm range. In reading *Bodyspace* by Pheasant and Haslegrave (2006), the section on *Fundamentals of Handle Design* states, "The purpose of a handle is to facilitate the transmission of force from the musculoskeletal system or the user, to the tool being used in the task" (p.150). The section goes on to state "high precision instruments should have diameter of 8-16mm…and must be increased when the user is wearing gloves”. The dental professionals do wear gloves, however thin, and a larger diameter may help in reducing CTS. This increased diameter needs to be considered in the design of hand instruments, as well as the ultrasonics and lasers. While the diameters of the dental tools may be the biggest factor to consider, weight and texture also play a part.

Weight is considered by most to be less important. Valachi (2008) states, “Weight is not as significant a risk factor as handle diameter, but lightweight instruments (15 grams or less) help reduce the muscle workload and pinch force” (p.82). Most dental tools fall within the weight limit, but ultrasonics with cords attached can be heavier on the back end, especially if a coiled cord is used. All cords attached to dental tools should be uncoiled to reduce this extra weight. Textured surfaces also help decrease the use of pinch grips. Pheasant and Haslegrave (2006) state, “Surface texture should neither be so smooth as to be slippery nor so rough as to be abrasive” (p. 151). A more textured surface on a dental tool helps with the grip when exerting force, and lessens the pinch pencil grip that has to be used.

One more important aspect must be considered in dental tool design: the cutting edge. The cutting edge of the dental hand instrument has to be sharp, and both the right length and curvature to properly reach all areas of the tooth. Dental tools must be made with cutting edges that can be sharpened. Valachi (2008) states, “Dull instruments can have a profoundly deleterious impact on musculoskeletal health, as they require increased force” (p. 82). This extra force has already been identified as a factor in CTS. Other considerations include a tool design that helps in reaching the deeper pockets, especially those in the curvatures and furcations of the roots. Longer tips on the hand, as well as ultrasonic and laser instruments will help. Curvatures, or multiple exaggerated angles in the tips, can also help in instrumentation of these areas, and at the same time, keep the cleaning comfortable for the patient.

Figure 39. Scaler

The tools used by patients at home can also be designed with the principals mentioned above. Floss only helps in 4mm pockets or less. While there are other tools available, none reach below the gum more than 4mm. Design of new tools, or redesign of old ones, need to consider patients with deeper pockets for at home use. These tools paired with better dental tool design used in the office can aid the patient in reducing periodontal disease. Tool design is the most important aspect to be considered in reducing CTS. Other musculoskeletal problems need to be addressed by the general design of the office space, and more particularly the equipment used in this space.

3.5 Environment

When discussing the dental operatory (working space) environment, several factors must be considered. The operatory stool, the patient chair, the lightening, and placement of the dental tool tray as well as other needed dental equipment, must be designed for ergonomics. The neck and back pain syndromes already discussed are directly related to improper positions used by dental professionals. These improper positions can be directly related to dental equipment not ergonomically designed for the operator. While several ergonomic books have been written on the subject by non-dental professionals, many of the guidelines have been blurred by the manufacturers of dental equipment. Written guidelines need to be clarified so dental manufacturers can better serve the dental professional. The dental stool design is one of the most critical factors to be considered.

As dentists are graduating, many with student loan debts, outfitting a dental office for both the dentists and hygienist may seem overwhelming. The dental suppliers often have a set product for set prices that have nothing to do with long-term practice. The dentist may see the less expensive stools and chairs as a way to keep cost down as they start their practice. The most common dental stool used in dental schools are older models made before ergonomics were a major consideration. In fact, ergonomics are not generally taught in most dental settings. Valachi (2008) states, “By graduation, students often have acquired postural imbalances and pain syndromes they believe simply come with the job and may choose equipment that merely supports a poor posture acquired in dental school” (p.92). She also goes on to state, “With increasing attention to work-related pain, manufacturers have shifted their focus to ergonomic features. The result is a multitude of ergonomic design concepts that make purchasing equipment confusing". Several considerations need to be addressed by the dentist when outfitting the dental operatory with dental stools.

One consideration with dental stools is the old rule, one size does not fit all. The design may be very operator-specific and needs to be adjustable to fit each individual operator. Valachi (2008) found, "Dentists and hygienists are commonly taught to sit on flatseat(sic) pans with thighs parallel to the floor or hips at a 90-degree angle"(p.94). In *Bodyspace*, this idea is discredited. "A radical new approach to seat design has recently been proposed. Mandal argued that the seat surface should slope forward, hence diminishing the need for hip flexion and encouraging lumbar lordosis (or the normal inward curvature of the lumbar and cervical regions of the spine)" (Pheasant & Haslegrave, 2006, p. 128). Thus a downward tilting chair of saddle style stool with adjustable heights may reduce lower back pain. Another consideration are stools that allow seated spinal movements. Valachi (2008) states, "Air filled bladder component design in chair seats will reduce low-back pain but also balance the muscle activity in the core stabilizing muscles as swell as improve working posture" (p.94). Adjustments of these stools should be easily controlled with hydraulic controls and tilting adjustment in the seats. Lumbar adjustments for the lower back should also be incorporated.

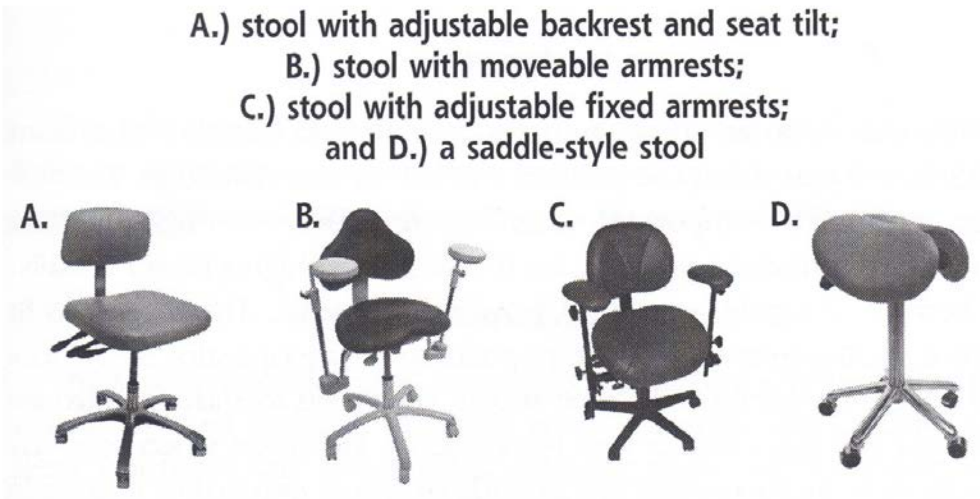


Figure 40. "Dental Stools and Seating Posture" (Valachi, 2008,p. 95).

Figure 41. Proper Posture

Figure 42. Improper Posture

Figure 40 illustrates a few designs on the market and proper seating of the dental professional. The purchase of true ergonomically designed chairs is the best investment for the dental professional, and can aid in the longevity of his or her dental practice. The other chair consideration is position of the patient's chair and it's relation to the dental professional's posture. Figure 41 and 42 illustrate proper and improper posture while working on patients.

Patient chairs are made for patient comfort. Wide backs and wide roomy arm rests are the norm. But more ergonomically designed chairs have more narrow upper backrests and smaller headrests, making access easier for the dental professional and lessening the need for bending in an awkward position. While the patient is seated for an hour or less in most appointments, the dental professional is seated around the chair for eight hours. The need for operations in neutral seated posture is key to reducing musculoskeletal symptoms.

Lighting is also a consideration in the dental environment. The overhead lighting used in most offices is hot and very bright. Many times, it causes patient discomfort in children and light-sensitive adults. The light also has to be adjusted many times during an appointment, so the working field is illuminated. New lighting technology has integrated into ultrasonic instruments, which lights the immediate working area, reducing the need for the bright overhead light while illuminating the dental field. Seeing the dental field is a must for the dental professional.

The final consideration to be addressed, the delivery system, is concerned with instrument tray placement, suction placement, handpieces, and water/air tip placement around the patient. Valachi (2008) states, “Dental professionals should be able to retrieve suction, syringes, instruments and handpieces without shifting of the field of view…the hoses should be lightweight and flexible” (p. 116). Whether a rear, side, over-the-patient, or over-the-head delivery system is used, the positives and negativies must be considered.

Figure 43. Rear Delivery System

In rear delivery systems, illustrated in Figure 43, all the instruments are behind the patient's positon. This system is the least expensive, and also is used to help reduce anxiety in patients by hiding the tools to be used from their sight. But while this system works well when an assistant is utilized, a dental professional working by themselves must twist and turn, causing undue strain on the back. Valachi (2008) states, "It is difficult, if not impossible, to reach the rear-delivery system without leaning or extended reaching (a risk for neck and shoulder pain)" (p.118). While most dentists work with an assistant, most hygienists, at this time, work alone, making this rear system not a good choice.

Figure 44. Side Delivery System

The side delivery system also has its pros and cons. As seen in Figure 44 above, the side delivery system places the tools at the side of the patient, and to the right of the operator. Less twisting is required by the dental professional, but it prohibits movement around the patient. This long term stationary position has already been shown to cause musculoskeletal problems. Valachi (2008) states, “The tendency to lock into one working position relative to the patient, hour and hour, day after day, can lead to overwork and fatigue of certain areas of the body and can lead to pain” (p. 118). Because the tools are hard for assistants to reach, this placement is not as often used by the dentist.

Two other systems are moving in the right direction for ergonomic placement. Over-the-patient delivery systems are used more today in dentistry. It allows more freedom in moving around the patients head. This access diminishes the need to strain the neck and shoulder muscles. Handpieces and instruments are within easier reach. Unfortunately, the tools are more easily seen by the patient, thus increasing anxiety in some, and because it is directly above the patient, it is easily bumped. Another disadvantage is use with large patients that requires the tray to be raised higher and causes the operator to have to abduct the arms more, causing shoulder problems. These problems led to a brand new system of delivery called over-the-head.

Figure 45. Over-the-Head Delivery System

An over-the-head delivery system, shown in Figure 45 above, combines the best of rear and over the patient systems. The instruments in the rear are out of sight of the patient. It frees the operator to move around the patient's head as needed. Valachi (2008) also notes one more plus: "Additionally, over-the-head layouts, when properly configured, convert from right to left hand function rapidly" (p.121). This accommodates both right and left handed users, making the operatory much more user friendly, and less likely to cause musculoskeletal problems for a left-handed operator.

There are so many considerations when designing a dental operatory such as equipment placement, tool placement, patient seating, and dental operator seating. Ergonomically designed operatories can lessen greatly the chance for musculoskeletal disorders, especially carpel tunnel syndrome. Enhancing the quality of life for the dental professional and extending the years of a pain-free work environment can be a great reward for following the principle of good ergonomically-designed dental tools and equipment. Written guidelines for manufactures are an important step torward toward this end.

Chapter 4

Dental Tool Design Guideline

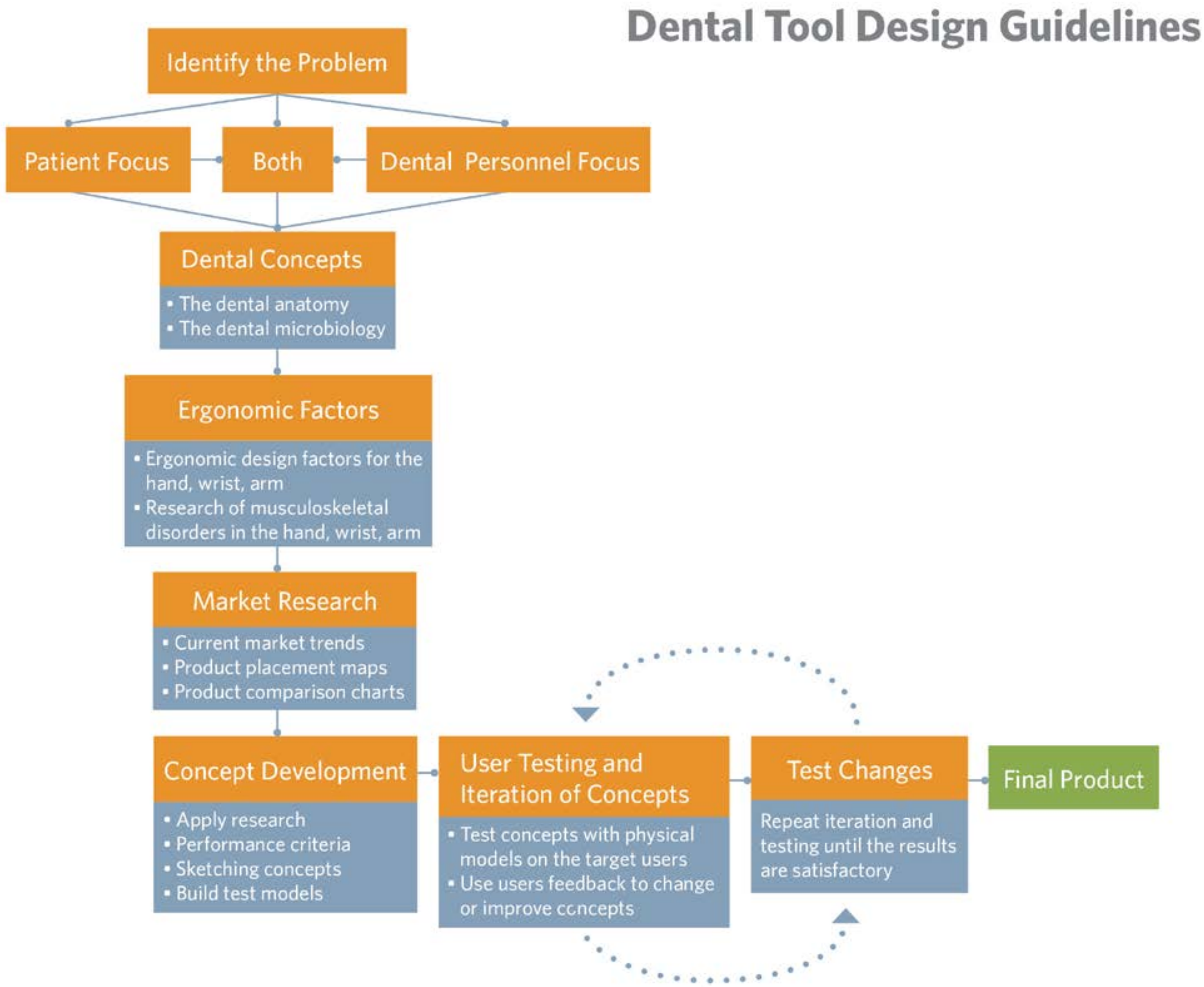


Figure 46. Dental Tool Design Guidelines

4.1 Introduction

Figure 46 is the flow chart of guidelines developed for the research and study. This set of guidelines may be used by designers to improve old tools or design completely new tools. The non-working project uses this set of guidelines to develop the prototype found in chapter four.

4.2 Identify the Problem

The first step in the process is to identify the problem. Is it a tool related problem? It is a homecare product problem? The problem may be related to any dental product, instrument, or equipment design in the realm of dentistry. Once the problem is identified, the next step is ready to be taken.

4.2 Is it Dental Personnel or Patient Focused, or Focused on Both

The second step is to determine the focus of the design. In some instrument designs, the dental personal would be the focus, for example, laser tool design. In homecare design, the patient would be the focus. The focus on both areas would be considered in most hand tool designs, for example, hand instruments. The hand instrument is one piece with the end used in the patient's mouth, while the shaft is held by the dental professional. Once the focus is determined, dental concepts for tool design must be considered.

4.3 Dental Concepts for Tool Design

In the third step, consideration for the dental anatomy and microbiology must be recognized. Is the design for a specific part of the dental anatomy such as accessing a dental furcation or a groove? Are the bacteria aerobic or anaerobic in nature? The length of the tip and the ability to use antimicrobials in hard-to-reach areas must be considered.

4.4 Ergonomic Design

The fourth step is very important in the area of tool design. The musculoskeletal problems must be taken into consideration. In the area of hands, wrists, and arms, diameter of the instrument is important. In neck and back problems, positioning of dental equipment is a consideration.

4.5 Market Research

Market research is to determine what is currently trending on the market, discover opportunities for new tools, or improve existing tools. Product placement maps identify critical design variables of a product. These design variables can be human, technical, production, and/or marketing functions. After this research phase, concept development is the next step.

4.6 Concept Development

In the phase, all research findings are applied. The performance criteria is pulled from this research. This will establish specific parameters and criteria for the design project. This is a critical part of dental tool design. It sets up requirements and expectations of the user as a check list for design evaluations. Using the performance criteria the concept sketching phase is started. The designer comes up with possible solutions to the problem. From these possible solutions, concept models are developed.

4.7 User Testing and Iteration of Concepts

Concept models are tested by the users, and feedback is applied to improve these concept models.

4.8 Test Changes

The improved concept models are again tested, and 4.7 and 4.8 are repeated until results are satisfactory and accomplish the performance criteria.

4.9 Final Product

When final solution is reached, the final product is produced and marketed.

Chapter 5

Non-Working Prototype

5.1 Introduction

The non-working prototype will focus on a redesign of a current ultrasonic tool that is used in the industry. The development process of the no-working prototype will follow the guideline created from the research of this thesis.

5.2 Identify the Problem

Dental microbiology can be difficult to remove. The invention of the ultrasonic has lessened the need of hand instruments. This design will greatly enhance the ability to remove more debris than other tools from the mouth in a shorter period of time. The hand instruments require more time and much more applied pressure to remove the harmful debris.

The first step in the guidelines is identify the problem, whether it is patient or hygienist-focus for the ultrasonic design Cavitron Thru Flow Insert 25K TFI-1000. This study is industry focused for the dental hygienist. The current design in use at the present time has a grip size that is too small, causing the hygienist to have to grip too tightly, which causes pressure on the carpal tunnel in the wrist. In Figure 48, the length of the ultrasonic shaft is too long, causing the back-end weight to pull on the wrist causing pressure, and over time causing musculoskeletal disorders including carpal tunnel syndrome.

Figure 47. Ultrasonic Process: Holding and Using the Ultrasonic

In Figure 48, the actual length of the Cavitron Thru Flow Insert 25K TFI-1000 is nine inches or 229 millmeters. Most hand scalers by comparison are around five inches or 127 millimeters.

Figure 48. Ultrasonic Length Measurement

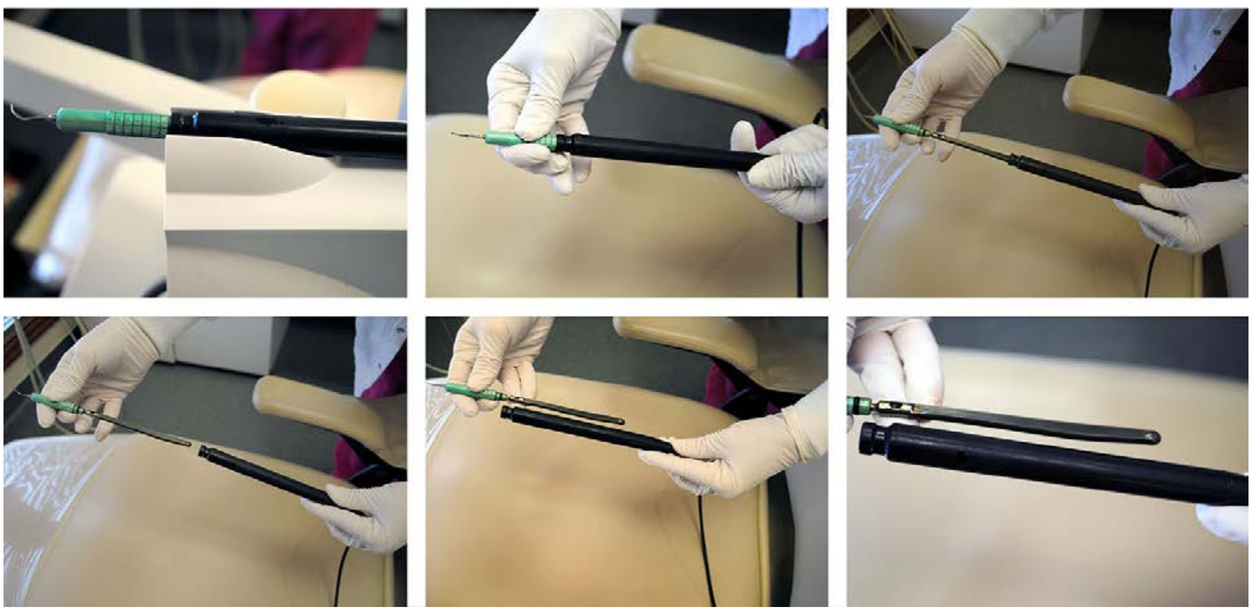


Figure 49. Ultrasonic Process: Insertion of Ultrasonic Tip and Rod into Sleeve

5.3 Is it Dental Personnel or Patient Focused, or Focused on Both

This area of study is not patient-related so the current ultrasonic tip design is not considerd in this redesign. This study was focused on the hygienist aspect of the tool. Understanding the ergonomic design factors in relation to the hand, wrist, and arm of the dental hygienist is key to developing a better grip design; Most hygienists use a pencil grip. The smaller the diameter of the dental tool, the tighter the grip. This, in turn, increases the pressure on the carpel tunnel in the wrists. The redesign of the ultrasonic grip will help reduce the pressure caused by the small diameter tool.

Musculoskeletal disorders, of which carpal tunnel syndrome is a big part, is related to the grip, pressure on the grip, and the continual repetition of the ultrasonic instrument over an eight hour day.

Figure 50. Grip Comparison Chart

The pencil grip is the most used by the dental hygienist. A few schools still teach the palm grip. Both of these grips use the third finger as a fulcrum. This finger stays in constant contact with a tooth close to the working area. The open finger grip is dangerous because no finger is designated as a fulcrum, and slipping of the sharp instrument can easily happen. This can result in injury to the patient.

5.4 Dental Concepts

One of main problems when working in the mouth is the limited opening of the individual patient, which can make access to the molar teeth very difficult. The soft tissues of the mouth which include the gums, lips, cheeks, tongue, and musculature, must also be considered in the tool design. The ultrasonic is used in a slow, repetitive motion on each area of the tooth to remove this same debris. A larger grip diameter eases the pressure on the working hand and wrist, and will allow the non- working hand to be used more efficiently in holding back the soft tissues while working. The hygienist will also be able to use the tool for longer periods of time.

5.5 Ergonomic Factors

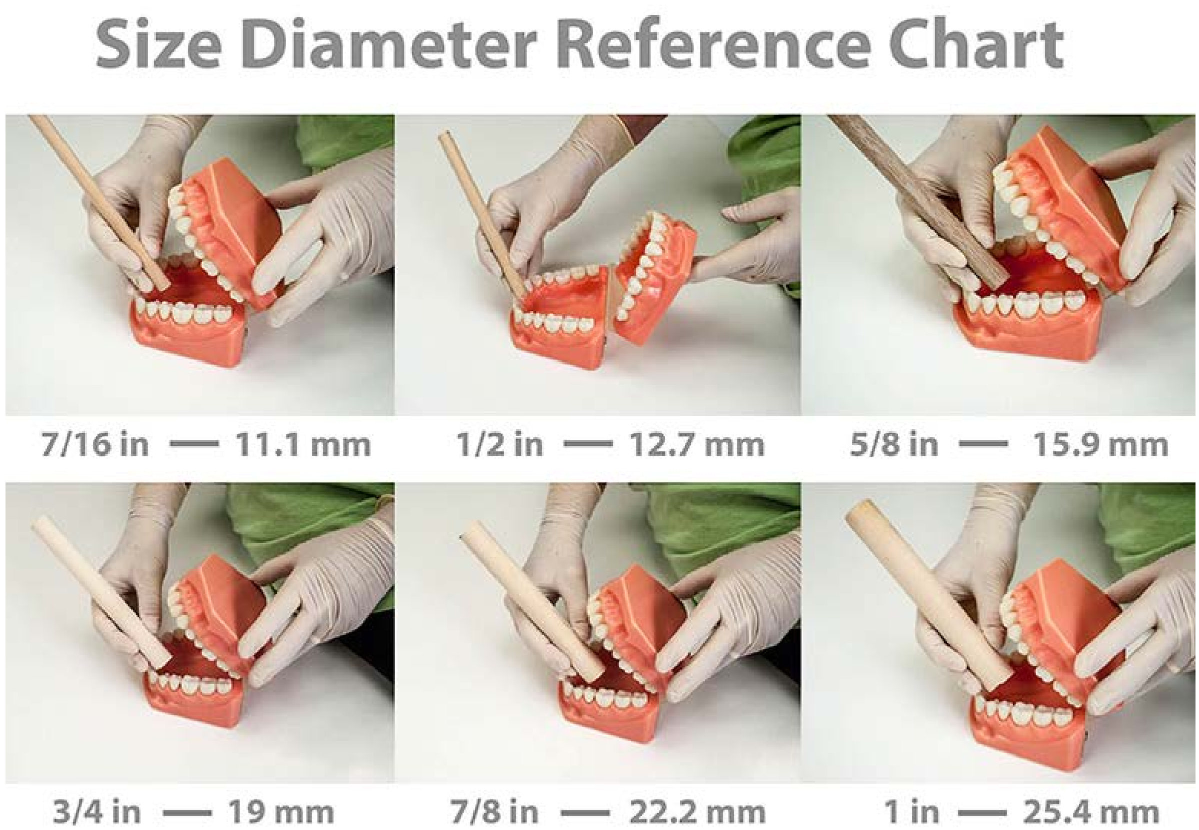


Figure 51. Size Diameter Reference Chart

The first step in concept development in redesigning the ultrasonic tool involved having a dental hygienist try different dowel diameters to determine size and comfort of use. This also tested the information in the book, *Body Space,* which Pheasant & Haslegrave (2006) states "Where high precision is required, handles should have a smaller diameter (8 to 16 mm)" (p. 150). The standard diameter size now in use for most ultrasonic instruments is 9.5mm, which is too small, and causes a very tight grip by the user. For a starting point in ideation, the range of 11 to 16 mm was used. The larger diameters shown on the lower row in Figure 51 are too large to be of practical use in the mouth, and becomes too hard to grip in a precision form.

5.6 Market Research

Figure 52. Product Placement Map

The product placement map shows current ultrasonic tools in the industry today. Using a product comparison map can help target certain market areas as well as new areas of design

5.7 Concept Development

Factors	Performance Criteria
Human	• Reduce carpal tunnel syndrome, wrist problems • Grip size of current ultrasonic tool is too small • The length of the ultrasonic is too long (problem is the back-end weight pulls on the wrist, causing pressure to the wrist)
Technology	• Material able to withstand sterilization procedures • FDA, ADA Standards • Able to use water for vibration • Grip diameter 11-16mm
Production	• Hard rubber • Metal rods (stainless steel) • Able to exchange tips when needed
Marketing	• $500-1,000 range

Figure 53. Performance Criteria Chart

Having a performance criteria helps designers pinpoint and cultivate designs to achieve the desired finished product. This criteria is for the development of the ultrasonic redesign.

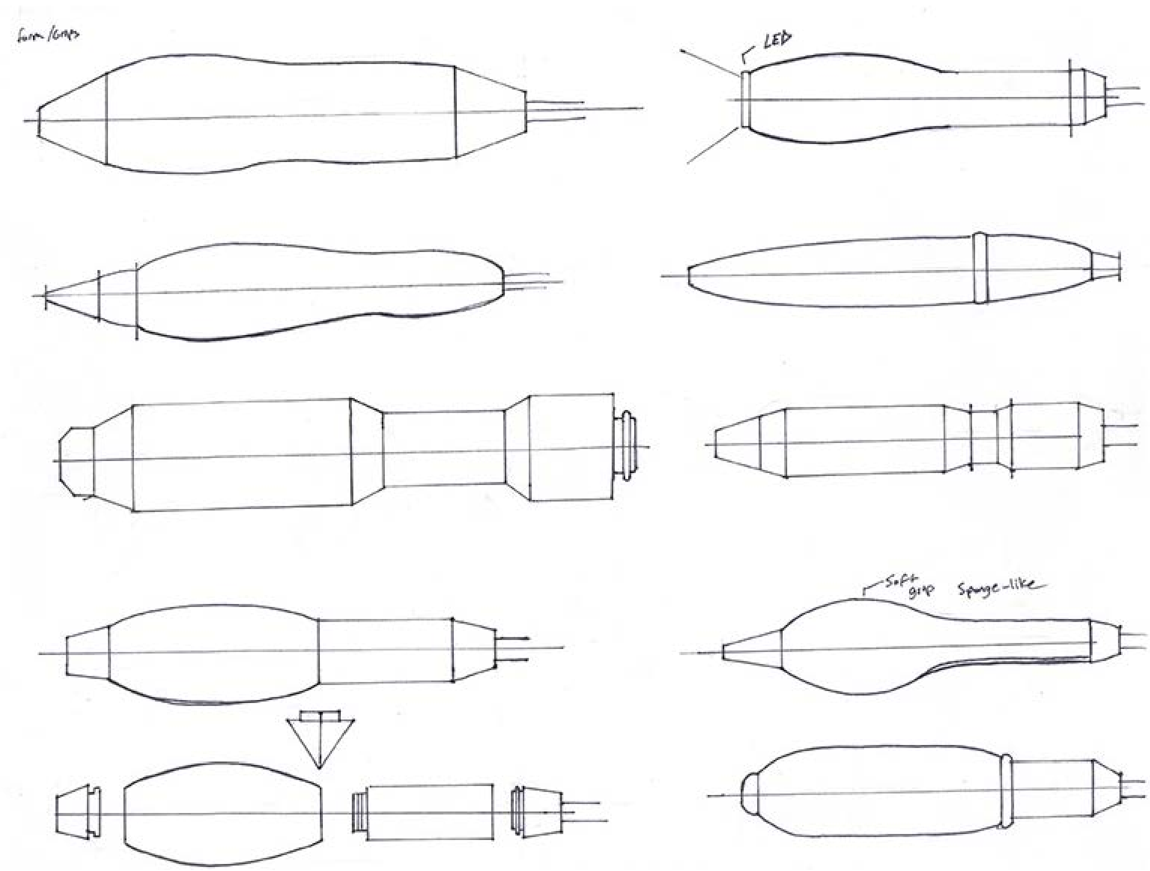


Figure 54. Preliminary Sketches

The sketching phase in the design process is crucial to developing potential new ideas and products. This allows designers to create concepts and ideas with little limitation, also It helps the designer understand form, size, and other areas of focus. Preliminary sketches are usually quick for creating as many concepts in a short amount of time. In Figure 54 shows rough ideas of grip concepts.

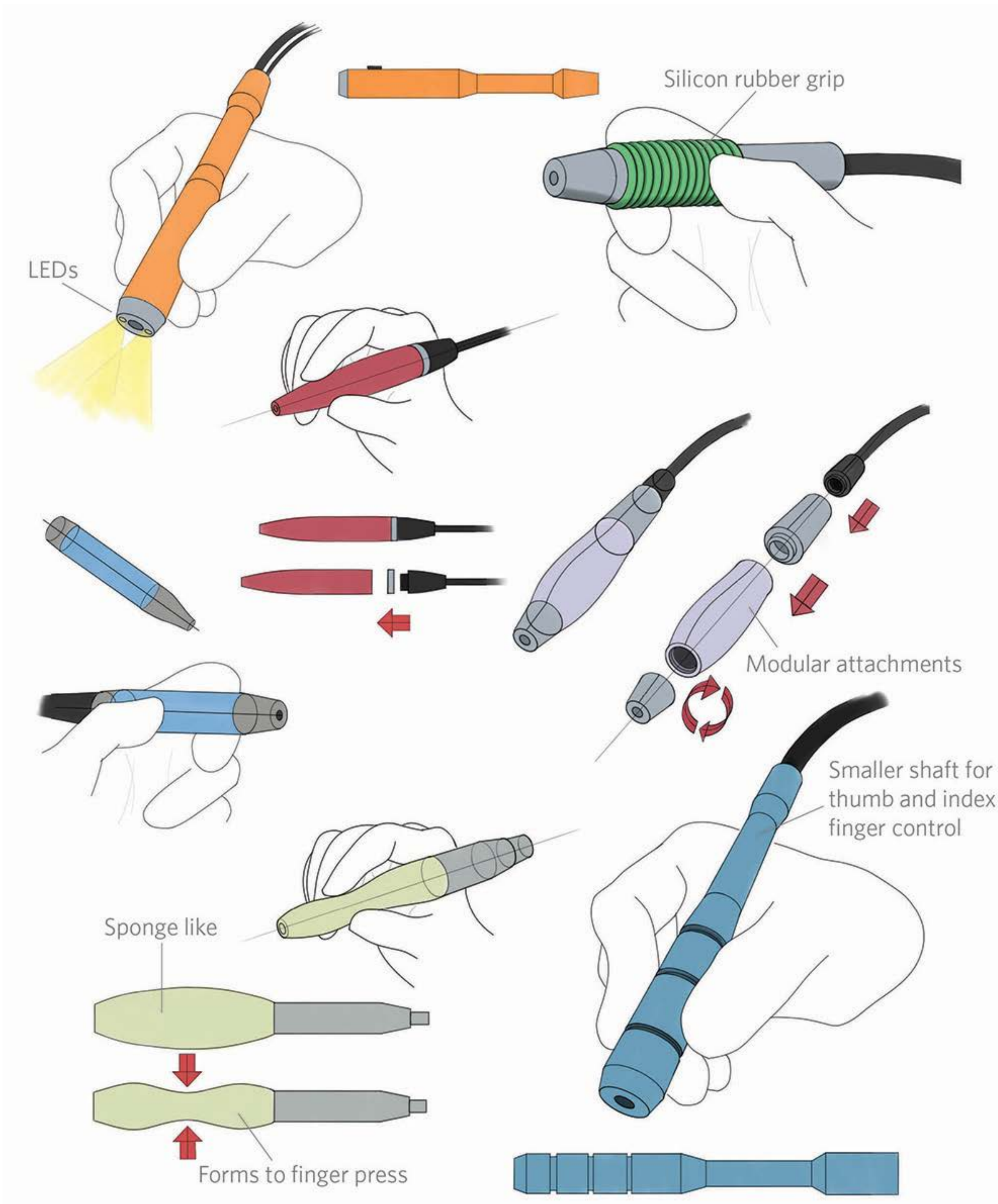


Figure 55. Generation One Sketches

Figure 55, shows the first generation concept sketches of the ultrasonic redesign. The second phase in sketching is used to refine the preliminary sketches, and also flush out potential concepts that would carry over into testing. The sketches in Figure 55 give an idea as to how the ultrasonic tool is held, and how the different grips would function.

5.8 User Testing and Iteration of Concepts

Figure 56 shows the first generation models of the ultrasonic tool. It is important to consider the ergonomic aspects of the grip and the length of the ultrasonic shaft. The first generation models are not finished appearance models, but they are rough and unfinished. The importance of these models is to prove the sketches and concepts work. Often times during this phase, many ergonomic adjustments are made to better improve the design to achieve user comfort.

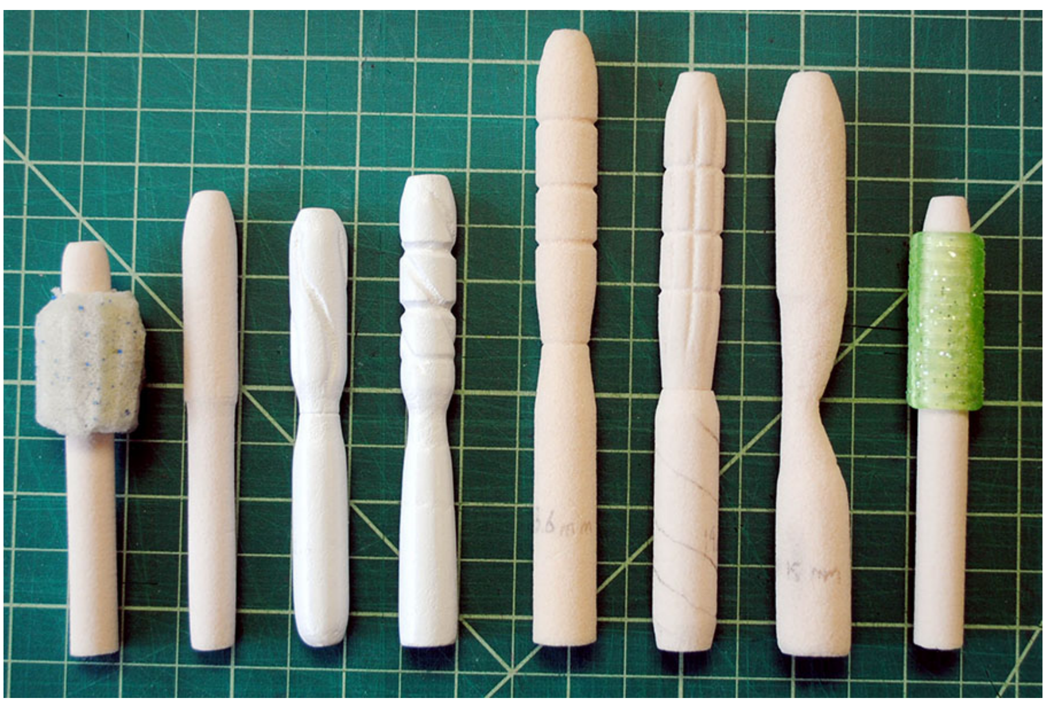


Figure 56. Generation One Models

The models were tested by dental hygienists and dentists, as shown as shown in Figure 57. Generally, testing would occur in several offices with multiple personnel because the more testing, the better data will be accumulated for analysis in developing the product. However, time constraints limited testing for this thesis to one office.

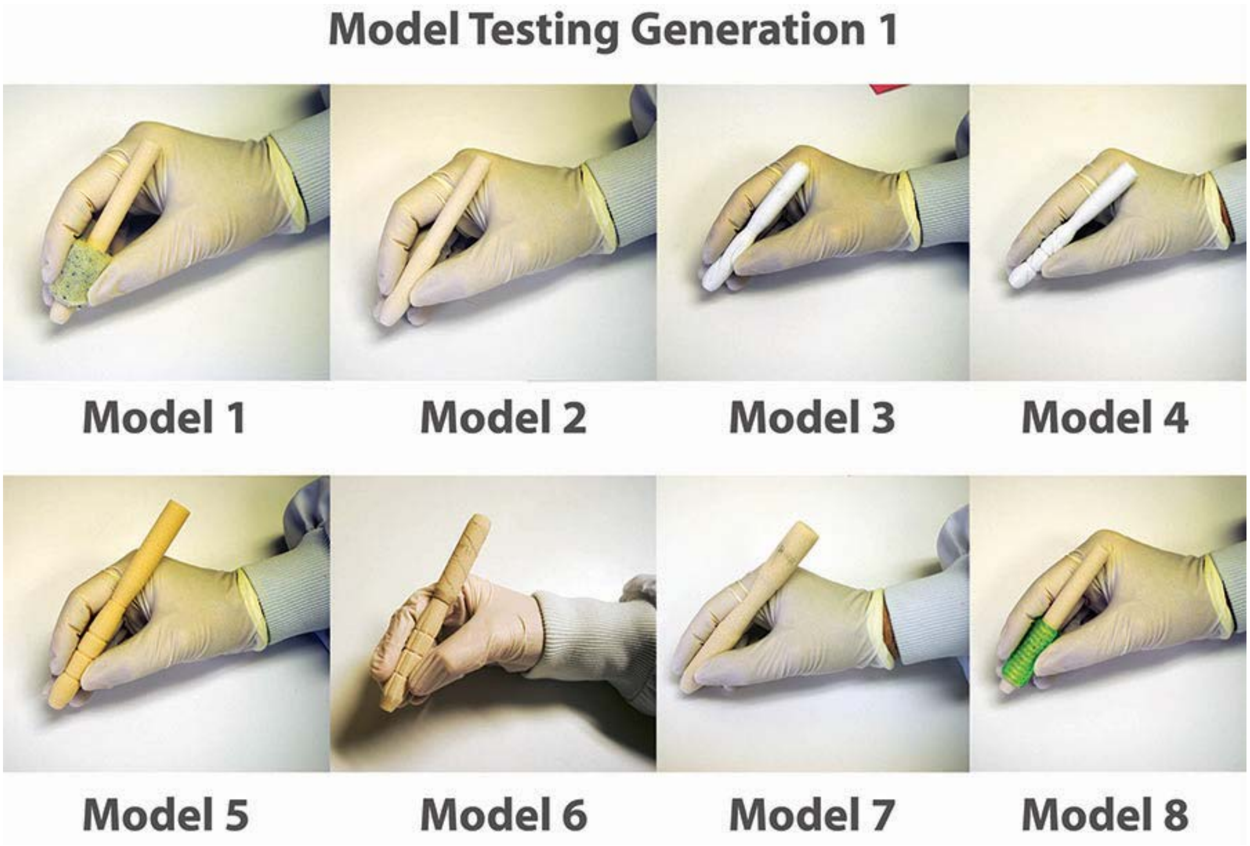


Figure 57. User Testing of Generation One Models

Figure 58 shows the data analysis of the first generation of models. Each ultrasonic handle was labeled one through eight. Each hygienist/dentist tested the models independently, and chose the diameter grip and length according to comfort. Comments were recorded about each model to get a better understanding of why or why not the model worked for them. The blue boxes show the majority of user's preferences.

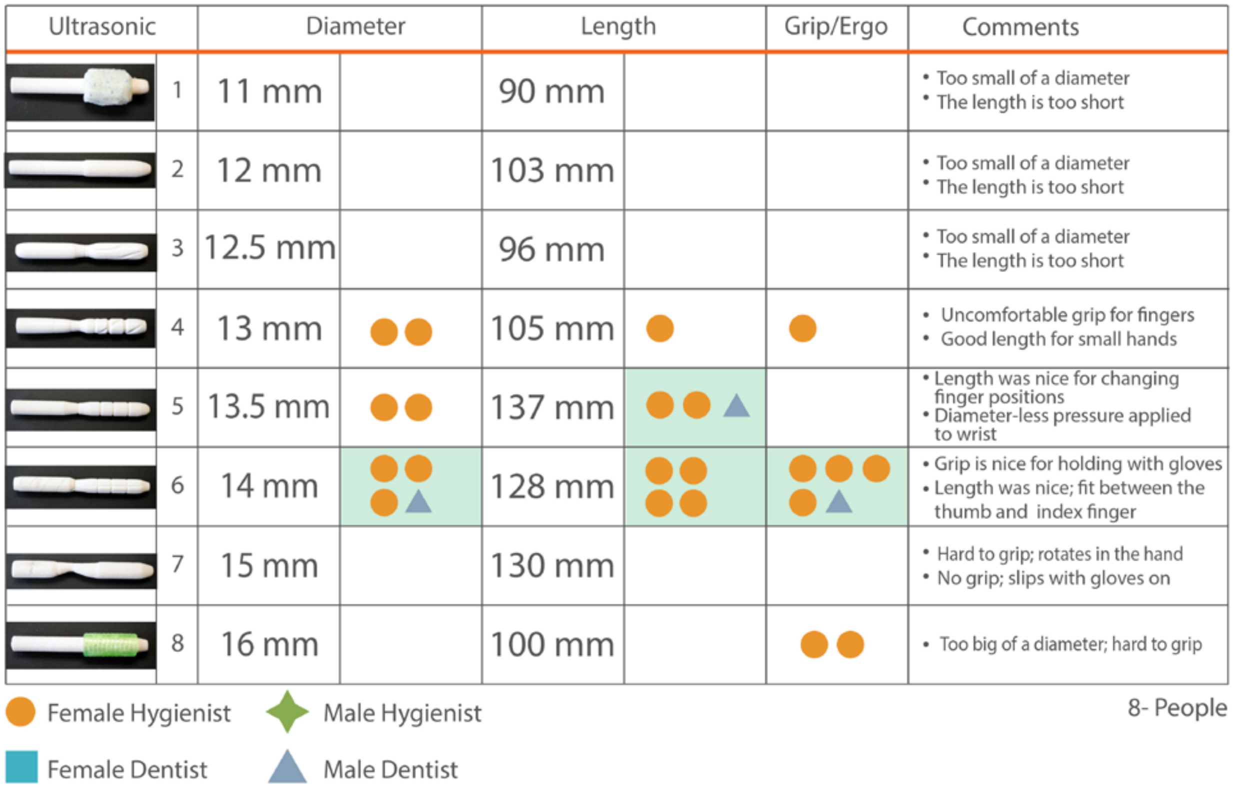


Figure 58. User Feedback Chart of Generation One Models

The general comments for the models one through three described the length as too short to properly hold the tool with a generally used grip. The diameter for most was too small, and resemble the current models on the market. The comments for model four showed the length to be good for smaller hands. Two hygienists liked the diameter, but the rest found it too small. The grip design was also found to be uncomfortable for most.

Models five through six were the popular choices. The length was considered to be optimal for changing finger positons when using the ultrasonic. The diameter of both models were comfortable for the user, and also the appropriate size for use in the patient’s mouth. The grip of model five was too slippery for use with gloves, but model six had more grooves to provide an anti-slip surface when using gloves.

Models seven through eight were deemed too large in length, and too wide of a diameter for use in the mouth. The grip for model seven was too slippery when used with gloves, and also had a sharp indention on the handle that prohibited finger and hand movement. In model eight, the silicon grip was comfortable, and provided slip resistance when wearing gloves, but is not sterilizable at high temperatures under pressure.

The importance of testing and iteration is to help develop the best product to meet the goals of the design. With the first generation model testing, the results were used to further develop the design process. Producing improved sketches and new models (second generation models) were the result from the testing of the first models. Using the data analysis from the first generation models, the range was narrowed for the length and diameter. The length ranged from 115.5 to 138mm. The diameter ranged from 14 to 15.5mm. The grip was still being tested to find the best anti-slip surface when using gloves. The changes from the data analysis were implemented in the second phase of sketching, and are shown in Figure 59.

5.9 Test Changes

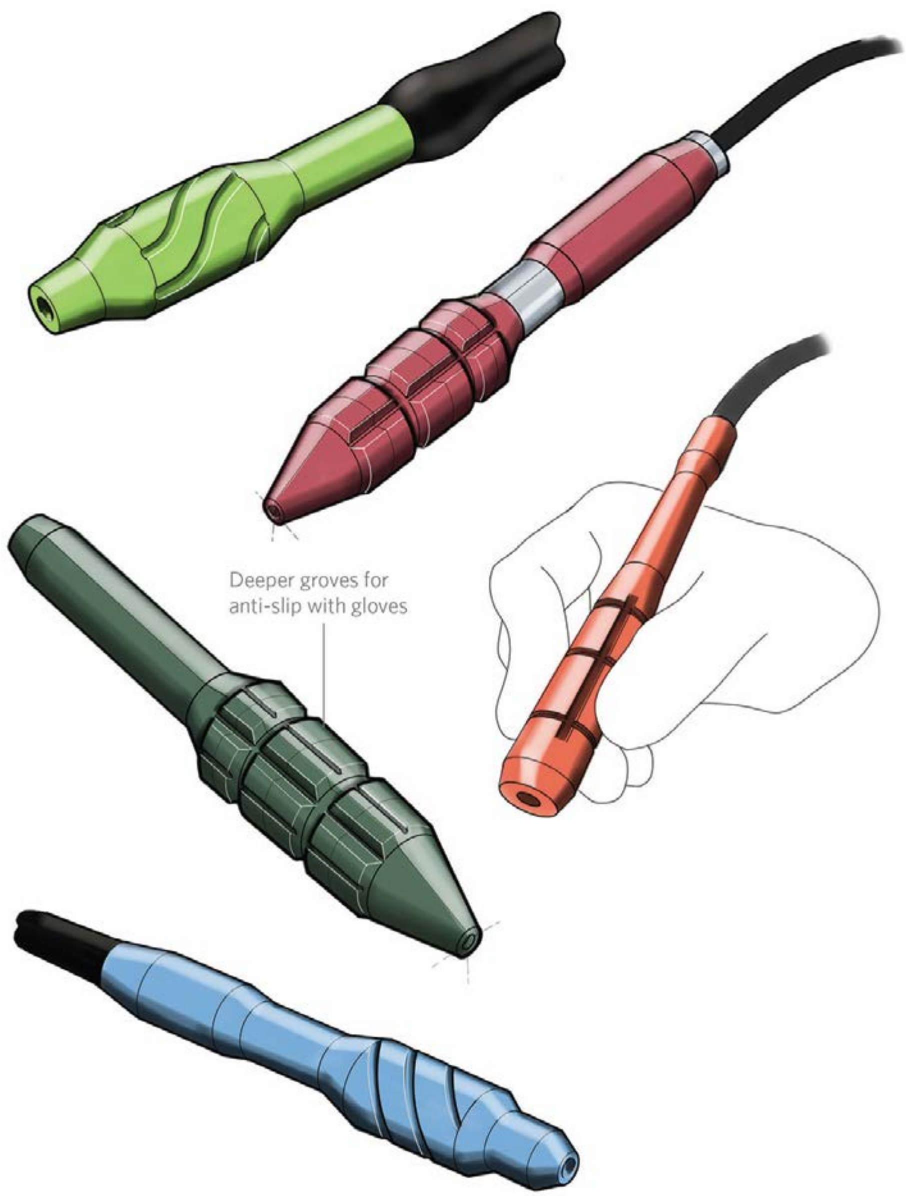


Figure 59. Generation Two Sketches

The second generation of sketching was a precursor to develop the second generation of models. Figure 60 shows the second generation of models with the changes from the first generation data analysis.

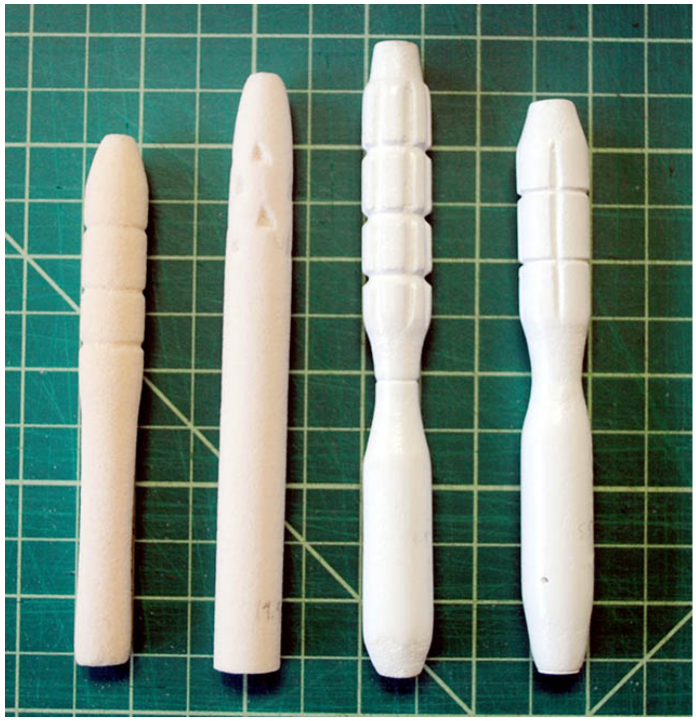


Figure 60. Generation Two Models

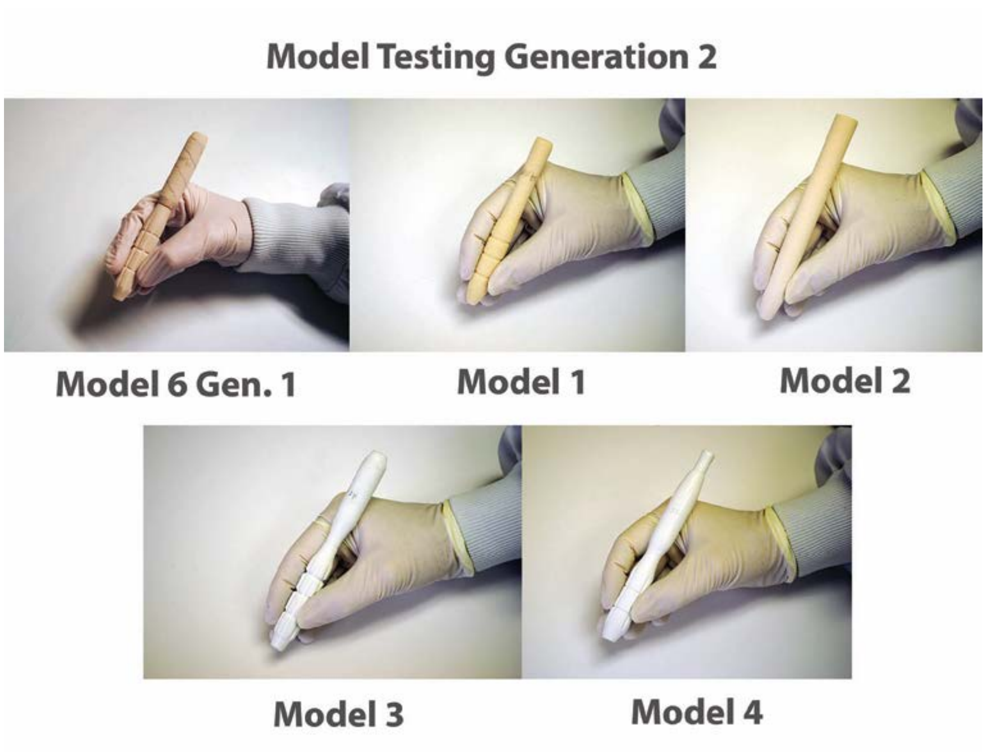


Figure 61. User Testing of Generation Two Models

The second generation of models, shown in Figure 61, were tested by the same group of dental hygienists and dentists, allowing for constancy in development of the ultrasonic tool from the first to the final stages in a design.

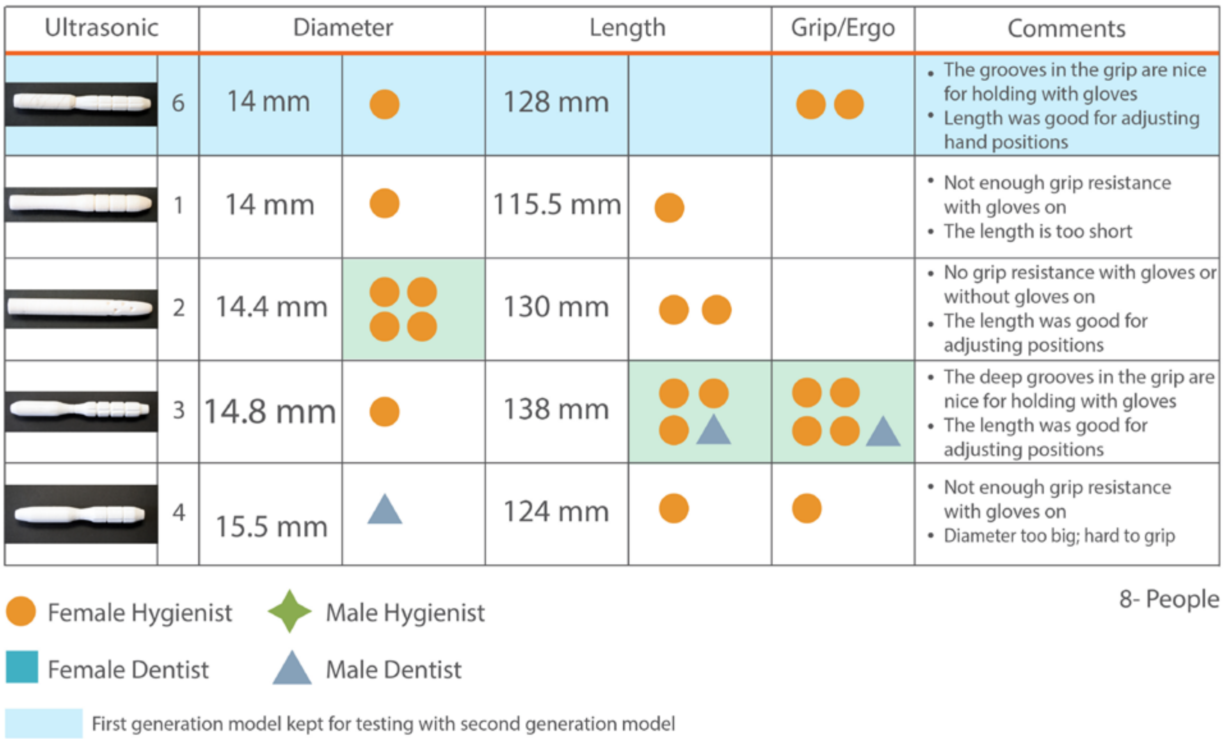


Figure 62. User Feedback Chart of Generation Two Models

In Figure 62 the data analysis used the preferred generation one model six. It also showed four second generation models. In generation two model 1, most found the diameter too small compared to the other diameters tested. The length was found by most to be too short. The grip provided little slip resistance when wearing gloves.

In generation two model two, the diameter provided the most comfort. While the length was better, it was not the preferred length. Model three provided the most chosen length, and the best grip of all the models. Model four's diameter was chosen by the dentist whose hands were bigger. Most found that grip to be too large. Due to the analysis of the second generation models, the diameter of model two was combined with the length and grip of model three to develop the final sketches and model, as shown in Figure 63.

5.10 Final Product

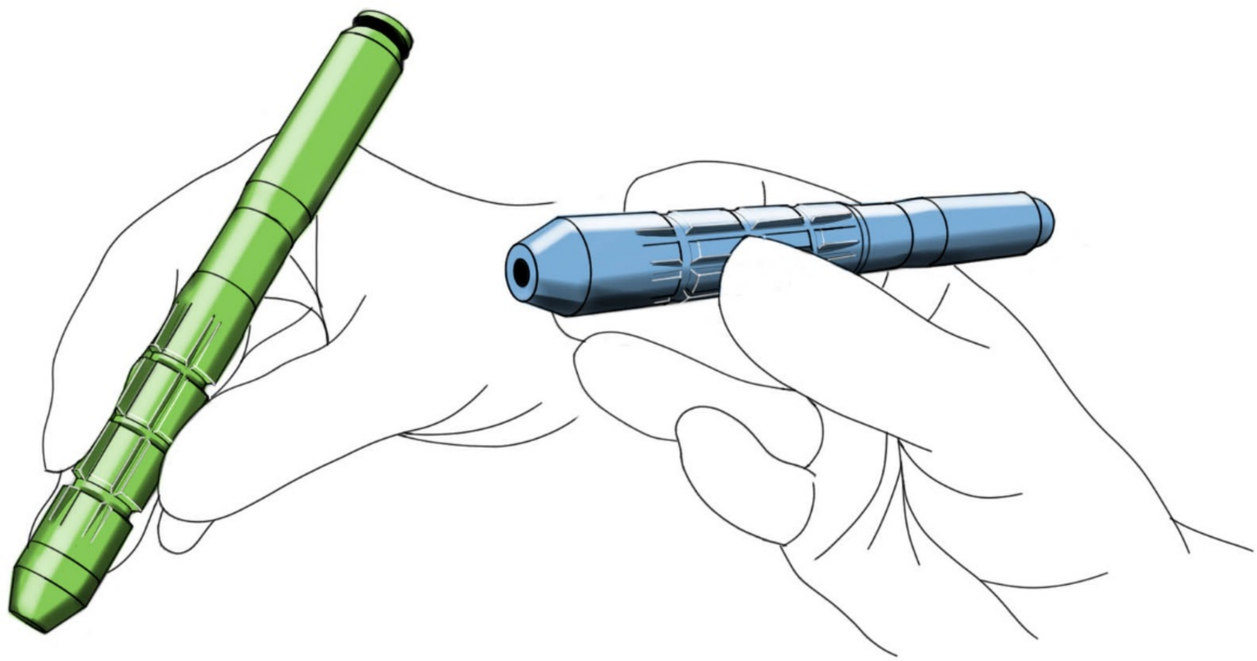


Figure 63. Final Model Sketches

The CAD model was developed from the final sketches. A CAD model is used to visual a product three-dimensionally on a computer before any prototypes or production pieces are made. Figure 65 gives an overview of the final model specs, material, and assembly.

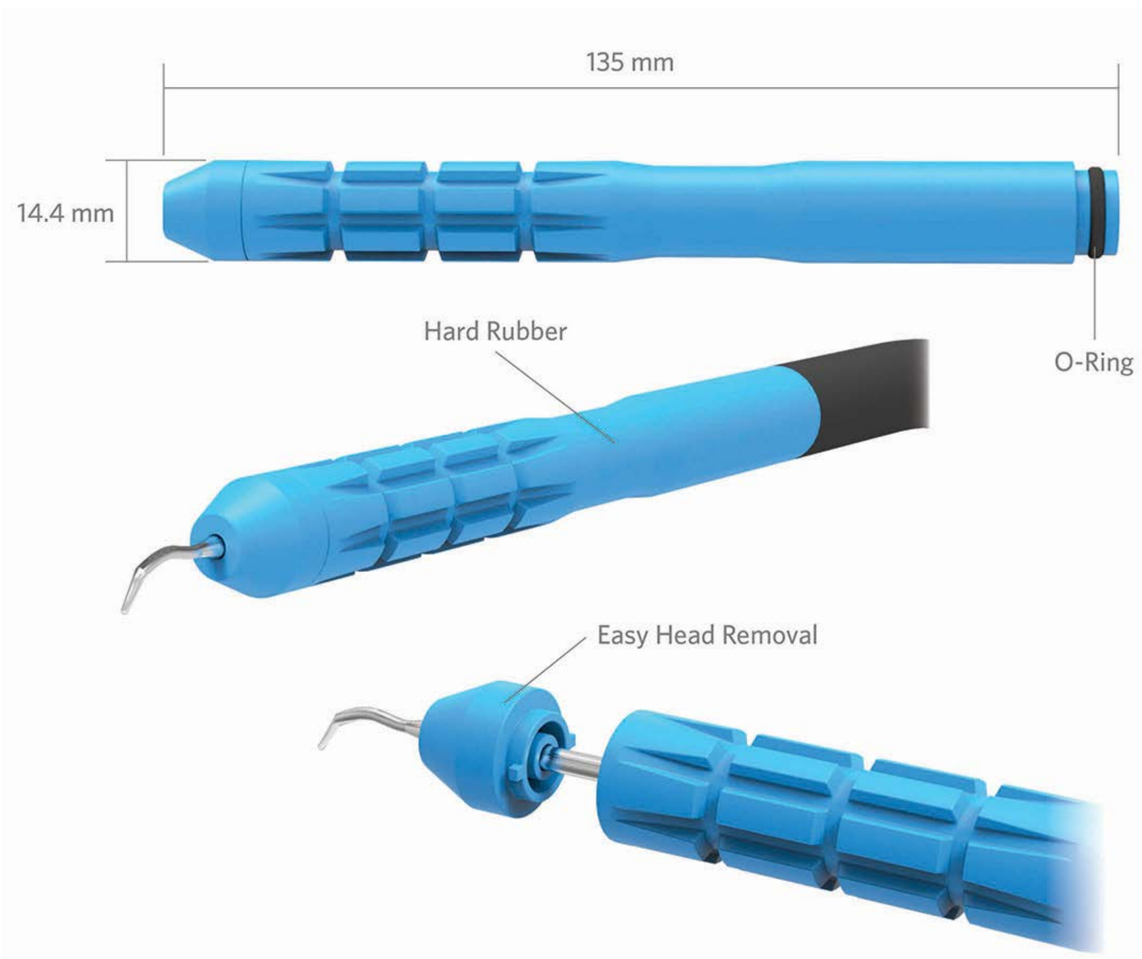


Figure 64. CAD of Final Model

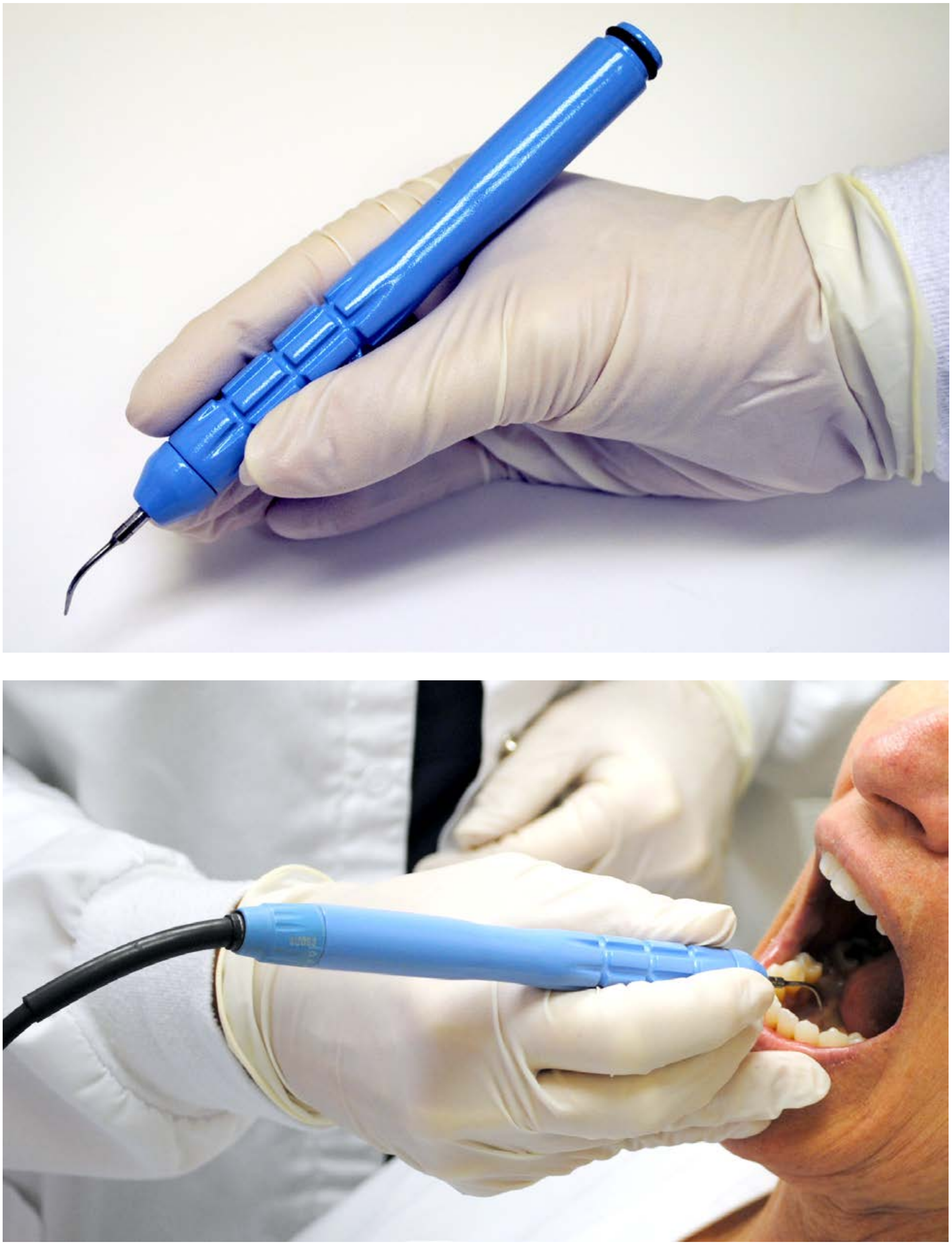


Figure 65. Final Model in Context

The final model is the result of testing concepts and analyzing data from the research. The final design has a 14.4 mm diameter with a 135 mm length. It also meets all of the performance criteria. The diameter of this design reduces the stress caused from the pinching of the original design. This, in turn, will reduce the chance of carpel tunnel syndrome. The length is almost half of the original design, helping to reduce the amount of pressure to the wrist from the back end of the ultrasonic.

The hard rubber will withstand the sterilization process, and the ridges provide a non-slip surface for glove wearing technicians. The easy head removal will allow changes in the length and contour of the working tips, and the replacement of tips due to wear and tear, will be cost efficient compared to replacing the entire sleeve. The sleeve can also be detached from the hose for easy replacement from wear and tear. The O-ring seals the area around the sleeve, and the hose limits water leakage.

Chapter 6

6.1 Conclusion

With the professional and economic problems associated with current dental tool design, a need for more ergonomically designed tools can be seen. Understanding the reason for design is essential. The oral microbiology can be difficult to comprehend, but understanding these microscopic bacteria and the damage they can cause in the mouth, the heart, and impacts on knee and hip replacements shows the designer the need for developing tools for use by the dental professional and the patients. Understanding the dental anatomy is also crucial. The concave areas of the roots, as well as the limited access involved in accessing the areas beneath of the gingiva (gums) and accessing the furcations of the molar teeth make the design of tools important. Better designs can lead to easier use by the dental professional and greater comfort for the patients under their care. A designer must also be informed regarding dental procedures, which involves which tools are needed at any one time. Ergonomics are also an important concern. Injuries such as Carpel Tunnel Syndrome can be reduced with proper balance, and reduction in improper use of the wrist and arm motions. Finally, following FDA, ADA, ISO, and ANIS standards can help in designing and production to reduce chances of injury to the public.

Human factors are one of the most important aspects of designing tools. With the professional and economic problems associated with current dental tool design, a need for more ergonomically designed tools can be seen. Creating guidelines from the information gathered in this chapter will provide a better blueprint for developing proper dental tools that are used in the professional field. The designer needs to understand the function of the tool, whether it is a hand, ultrasonic, or laser, as well as the procedure in which the tool is used; this is critical in developing the tool. Also, the designers must understand the problem areas, such as musculoskeletal injuries (ex. Carpal Tunnel Syndrome), who develops to musculoskeletal injuries, (ex. dental personnel), and results of improper tool design. Finally, parts of the guidelines from the human factors can be cross implemented into other areas of dental design, such as dental operatories and home care products to be used by the patient.

Developing a guideline for dental tool designers, developing a non-working prototype, and identifying areas of future study are all results of this study.

6.2 Areas of Further Study

Areas of further study involve the development of dental home care tools for patients with problems such as arthritis. Patients with limitations, such as the loss of a hand or arm, and those with developmental problems, like Multiple Sclerosis, and congenital problems such as Cystic Fibrosis have difficulty using current dental home tools. This line of study could lead to a new market opportunity for dental designers.

The scope of this study does not include a working prototype. Further study is needed with a working prototype of the dental ultrasonic hand piece to determine if other improvements to the ergonomic design are needed.

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