Less Twisting, Better Teeth: Ergonomic Design for Endodontist Tools

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Term Project Report

Abstract

Dental procedures require high usage and a large variety of hand tools. Repetitive movements during procedures cause repetitive strain injuries such as carpal tunnel syndrome, arthritis, and more. We designed improvements to the existing dental drill design, focusing on the grip, handle, and rotary tool exchange. We propose a study to measure muscle activity and pinching force during a dental procedure.Important factors of the device include the center of mass, finger placement, and overall weight of the device. New devices are not adopted quickly, but certain aspects of the new design may be adopted over time.This design approach and method to improve the ergonomics of tools can be applied to numerous fields across dental, medical, electronics, fashion, and culinary occupations.

I. Introduction

Dentists of all specialties are ubiquitous in our lives. Everyone at some point in their life visits a dentist, and is familiar with the procedures they perform. What most people do not consider is that these procedures can cause physical discomfort to the dentists as well, often leading to chronic pain in many parts of their body. Among these issues, musculoskeletal pain in the hand and shoulders is the most common, with 44% of dentists reporting suffering from pain there [1]. A significant cause of this pain is the fact that they perform repetitive fine movements in a small workspace and with small, thin tools for long periods of time. Considering that much of dentists' work is conducted with their hands, it is vital for them and their patients that they can work free of pain and discomfort.

A. Background

Oral health care providers include dentists, endodontists, dental assistants, and dental technicians, who work together to prevent oral and dental diseases and decay through routine cleanings, treatments, and surgeries. These procedures require the use of a large variety of hand tools, ultrasonic instruments, and rotary devices. Due to the small size of the mouth, the many procedures are conducted with a compact workspace, requiring repeated fine movements in every step of a procedure. In addition, these procedures require a mirror to be held in the mouth for better visibility. As a result, dentists are constantly needing to manipulate two tools at once, both in a small workspace and with very fine movements. Furthermore, while dentists and dental hygienists tend to have shorter work sessions (less than an hour) and more breaks, some oral health care providers such as endodontists perform longer procedures, for example root canals, that can last multiple hours with no breaks. This combination of a small workspace, repetitive motions, and long work times can lead to various musculoskeletal disorders over time, especially in the hands [2].

To work in a small area such as the mouth, dentists are seated next to a patient and must lean over their head. The positioning of the tool and mirror hands can require awkward or unnatural hand and arm positions, resulting in arm, upper back, and shoulder strain. In order to properly view the area being treated, dentists have to very finely change their upper body and head position and hold these positions for extended periods of time. This can result in neck pain and tightening of the lower back, leading to lower back pain as well [1]. However, due to the many repetitive tasks (some being repeated tens of thousands of times over the course of a procedure), many dentists suffer from hand pain and musculoskeletal diseases such as carpal tunnel syndrome and tendinitis [3]. In fact, in a study of the prevalence of musculoskeletal disorders in dentists, hand and shoulder pain was the most commonly reported chronic issue [4]. A large contributing factor to this pain is the continuous vibration from the powered drill that is used in surgery [3]. This is concerning especially because the hands are the most important for manipulating the tools involved in the procedure. While there have been some assistive technologies developed to alleviate these concerns, it is clear that tool design is not sufficiently ergonomic for the large majority of dentists.

There are a variety of assistive devices available for dentists to prevent the onset of body strain, for example, the dental microscope [5]. This helps dentists maintain a more comfortable head and back position while still allowing for viewing into the patient's mouth. This prevents the onset of neck and back pain by reducing the amount of movement required by the dentist during the procedure. This is not a complete solution, as muscle strain can still occur from maintaining a single position for a long period of time. Similarly, better chairs have also been designed to give as much support to the legs and the arms as possible to reduce soreness of the quads and strain in the shoulders. However, the issue of fine movements and the hand problems they cause have yet to be properly addressed [5].

While surgery is an option to treat carpal tunnel syndrome, it is not always effective, and symptoms can persist post-operation. Precautionary measures can and should be taken. Specifically to the hand, important factors to consider are wrist position and the amount of pinching force used when holding a tool, which brings us to workspace and tool design [5]. Research has been conducted into optimizing the current design of various dental tools in order to reduce the risk of injury. One such study concluded that the tools should have a diameter of at least 10 mm and a weight of at most 15 g [6], but these are not standard guidelines [4]. Another lack of standard is evident in the handle design. While a round handle reduces muscular stress and nerve compression, it requires a stronger pinching force to grasp. On the other hand, a hexagonal grip with edges requires less pinching force but can lead to nerve compression and increased stress [3]. Even with some research into overall tool design, a large problem is manipulation of the thin tooltips attached to the dental drill and other tools. While the tool itself may have some ergonomic improvements, these tool-tips can not be made ergonomic since they must remain small to operate within the mouth. These tooltips are replaced hundreds of times over the course of a procedure, requiring carefully fine movements and a great deal of pinching to detach and attach. As a result, regardless of the ergonomic improvements made to dental tools, a significant cause of hand pain and the risk of carpal tunnel syndrome is still not avoided.

B. Overview

From the prior literature, we determine that the tool transfer process is a large contributor to the hand, wrist, and fingers pains in dental professionals. Therefore, we hypothesize that an improved ergonomic design and eliminating the need to manually manipulate the small, thin tool tips will result in a significant reduction of risk factors associated with musculoskeletal pain in the hands of dentists. A preliminary interview with an endodontist, detailed in *Section II*, supports our findings and provides more specific information from an actual user. In *Section III*, we present the design of an improved dental drill with an ergonomic grip, weighed and angled tool handle, and detachable head piece. We also propose a study to test our device's effectiveness in reducing risk factors for pain. In *Section IV*, we discuss how our design approach and mindset benefited our process and could be applied to multiple fields. Lastly in *Section V*, we suggest potential expansions in the design concept that could be applied to numerous occupations.

II. Preliminary Results

We decided to interview both an expert and a need knower in order to have a more thorough understanding of the needs, functions, and limitations of the current design of assistive devices and possible solutions.

Information obtained from an expert would help us understand the design process and engineering aspects. Information from a need knower would provide us with details about the physical and emotional interaction of the user and device. After reaching out and scheduling successfully through email, we had the opportunity to interview with a UC Berkeley University health services Ergonomist in addition to an Endodontist on zoom. In our three-person team, one of us took on the role of note taking while the other two interviewed our interviewee with the list of questions and notes we had prepared. Both of them have been in their fields for over 20 years.

Our first interviewee, the Ergonomist, works with university workers in spaces such as childcare, construction, food court, and animal research laboratories. Her role consists of examining and analysing occupational risk factors and offering suggestions to improve environmental and tool ergonomics. We guided the conversation to focus on upper body and hand movements in the goal of fitting into the project topic. She mentioned commonly overlooked situations where micro and regular hand movements are repeated extensively throughout the work day. One example she highlighted was researchers in animal research laboratories, who constantly repeat the process of bending over, reaching into cages, toggling with small creatures, and adjusting and manipulating delicate tools and instruments. Another example was of food court workers who repetitively rotate their wrists and raise their dominant arm while scooping and cooking food for students. Both jobs put workers at risk for upper and lower back pain, Carpal Tunnel Syndrome, Arthritis, and other repetitive strain injuries. Although topics and questions in this conversion varied, our main goals of finding a guide to a direction and building the set of considerations and qualifications for device design later on were fulfilled. This led to a smoothly transitioned and successful second interview.

Our second interviewee was an Endodontist of 20 years. He works long hours and his typical workday consists of examining patients, performing multiple root canal surgeries, and typing a large number of reports at the office desk. We dedicated our focus to the surgical tool designs and their relationship with the endodontists' hand micromovements and wrist movements. The repetitive movements that our interviewee pointed out include rotational and pinching (fingers), and flexion, extension, radial/ulnar deviation, pronation and supination (wrist). These movements are present with all tools used in the procedure, but one particular tool with the most damaging effects is the powered drill. The power drill is used to create a vertical opening to the tooth. The interviewee is required to switch between 5 drill sizes manually, on top of 15-20 reps of drilling with each drill needle size excluding going back with adjustments. This totals to over 150-200 reps of pinching, rotating, and flexing in just using the drill tool alone in a single surgery. Health effects that the interviewee and most of his colleagues suffer include: pain that starts from small movements in the hands and that spreads through the shoulder and neck during procedures; muscle strain in fingers, forearm, and arm; bad posturing affecting back, hips, and legs; and carpal tunnel syndrome. He stated that he wakes up everyday with some parts of his hand losing sensation.

Currently, the market for these surgical tools has multiple newer and innovative designs that target different aspects such as convenience, safety, and comfort. However, the interviewee expressed that he and his colleagues mostly still prefer the traditional tools which they learned to use at school many years ago. In their perspectives, the cost of time and effort to adjust to a new tool and habit outweighs the benefits of a slightly shorter procedure and different grip. Through this discussion, we learned an important aspect of the field - "change is not instantaneous." Therefore we are making an active effort to keep our design as traditional as possible while reducing health risks by targeting specific issues with the tools.

With the gathered data, we identified five primary needs: the tool device is comfortable, the tool device is versatile, the tool device reduces vibration, the tool device requires a low pinching force, and the rotary exchange is efficient and ergonomic (Figure 1). The secondary needs we identified include: the device is convenient to interchange, the tool device requires a simpler motion that puts less strain on the joints, the device minimizes fine movements, and the tool device works well until breakage or has a clear indicator of effectiveness.

Instrument is versatile	The instrument supports quick and convenient exchanging of different sized rotary files.
Instrument is comfortable	The instrument is comfortable to hold.
Rotary exchange is efficient and ergonomic	The rotary files are easily handled and exchanged without fine movement or pinching required.
Instrument reduces vibration	The instrument should reduce the vibration transmitted to the user.
Instrument reduces pinching grip	The pinching/grasping force required to operate and hold the instrument should be minimized.

Fig. 1: Summarized Needs Chart

III. Methods

From our interview, we learned that the primary obstacle to a new tool being used in the field is how different it is from the current tools being used. Therefore, throughout our design process we tried to maintain a similar shape and overall design as a standard dentist's drill. Our design has a larger handle with more weight towards the back, allowing it to act as a counterweight. The weight is balanced such that the center of gravity of the drill rests on the hand between the thumb and index finger. Additionally, the back end of the drill is curved around the back of the hand slightly, distributing the weight over a larger area. These two design changes reduce the amount of pinching needed to hold the drill in place (see Figure 2).

The ergonomic grip will be a triangular prism with one surface each meant for the thumb, index finger, and middle finger, respectively. It has a depression on each side curved to allow the finger to conform better to the grip. Since each finger contacts the grip in a different manner, each depression is slightly different in shape, size, and orientation. The ergonomic grip and the handle will have a tacky surface to aid in gripping (see Figure 2). As opposed to current designs where the drill bit is replaced, the entire head of our tool will be replaceable. By pressing a button located near the grip, for ease of use, the current drill head will be disengaged from the body. The other drill heads will either be placed in a stand or be held by the assistant. Since the entire drill head is being replaced, the dentist and the assistant do not have to use extremely fine pinches and motions to manipulate and replace just the drill bit. The new drill head is replaceable by just pressing it in, where it will lock in and engage with the motor. The dentist can then continue the procedure, and repeat the process for the next drill bit switch (see Figure 3).

The weighted tool handle has a pear shape with most of the weight on the bottom. The handle's weight would be at least half of the tool's weight, since our goal is to shift the center of mass towards the end instead of the middle. That part would also be bent downward at 40 to 45 degrees, sitting naturally on the back of the hand.

To further refine our device design, we plan to conduct multiple studies with the intended users, dentists and dental surgeons (e.g. endodontists). For a comparison, we will use a drill that is representative of the typical size, weight, and shape of dental drills used in surgeries. We will have multiple variations of sections of our design based on design concepts we developed when prototyping. For the head, we have: a) a press-fit and button release option; and b) a twist-and-lock mechanism. For the grip, we have: a) a rounded, pliable grip; and b) a contoured grip. For the handle, we have: a) a straight weighted handle; and

b) curved weighted handle. We plan to measure muscle activity and pinching force, following a similar process performed in the study by Dr. Hui Dong, DDS [6]. The dentists will perform a dental procedure with the tool on a mock patient in a simulated clinical environment. The procedure being performed will cover multiple poses and movements and include a tool switch. We will measure muscle activity using surface EMG sensors placed on the upper forearm. We will also place a force sensor on the ergonomic grip to measure the pinching force being applied. Our volunteer pool will consist of dentists and dental hygienists with a range of experience. We would also give the volunteers some time to become comfortable and familiar with the new device prior to taking measurements.

From this study, we expect to see a reduction in muscle activity and pinching force from the existing device to our new designs. During our design process, we were able to consult with our interviewee, who suggested that the contoured grip and curved handle would likely be the most comfortable, so we expect our results to support this. We plan to collect qualitative data from the volunteers on their experience as well, specifically regarding their comfort level with the new device and if they would consider adopting the new design in practice. As we mentioned earlier, new device designs often meet resistance in adoption. We expect the handle design change to be implemented first, followed by the grip, since these changes do not significantly change the protocol. The new drill head may be slower to become accepted because it changes a major protocol step, but we hope to get more information on how open dentists would be to the idea from our qualitative study survey.

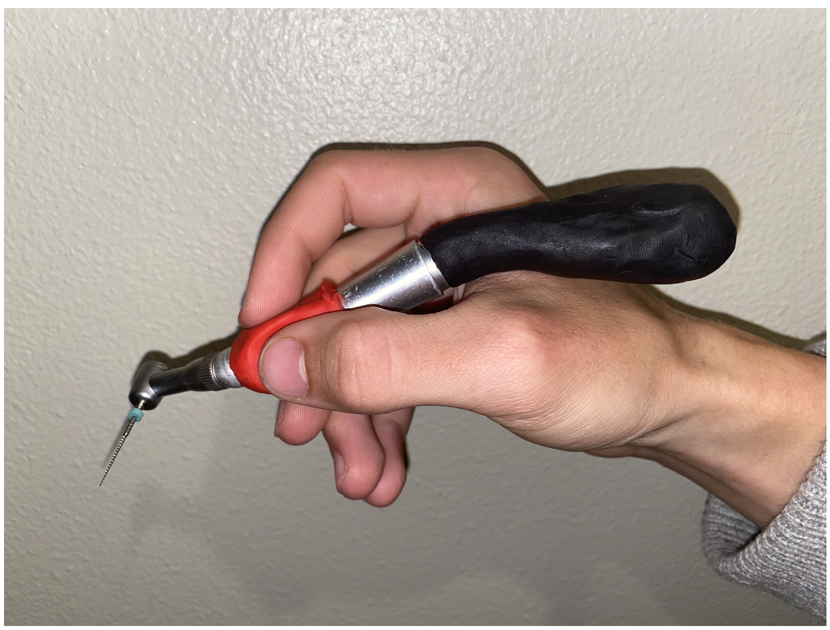

Fig. 2: Final Grip and Handle Prototype

IV. Intellectual Merit

From our conversation with the need knower, we learned an important lesson that applies to all creative projects involving recreating existing products: change is not instantaneous. Since professionals tend to use tools they are most familiar with, introducing design changes slowly is the best way to bring a new device into the field. Additionally, these new devices should be introduced during professional education as well, so new professionals are trained with the new device. We also discovered that targeting the cause of a problem may be more effective than alleviating symptoms. This mindset led us to more closely analyze the problematic motions and positions, and create a design that removed them from the process. These two design tenets that we followed are not limited to dental tools, and can result in more effective devices.

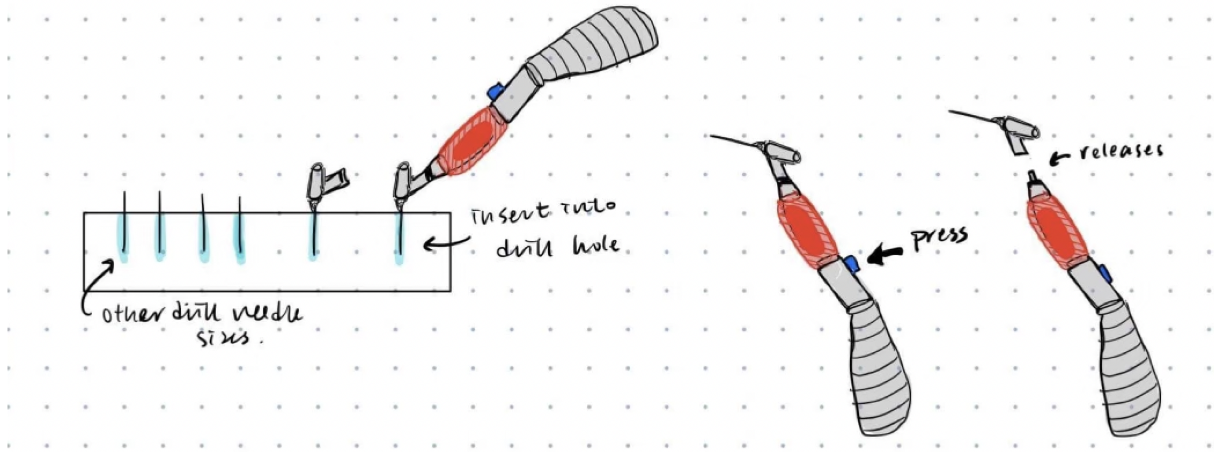

Fig. 3: Final Head Change Prototype

V. Broader Impact

This ergonomic design improvement can potentially be expanded to other tasks within occupations that require similar fine hand and finger dexterity. Movements include and are not limited to rotational, pinching, wrist flexion, extension, radial/ulnar deviation, pronation and supination. Occupations including jewelers, musical instrument repairers and tuners, surgeons, electronics repairers are potential need knowers for further exploration. This improvement in the design feature may seem small, but it can greatly improve workplace productivity, safety, and both the physical and mental health of the need knower. Additionally, less manual forces and cost required.

References

[1] J. Szymanska, “Disorders of the musculoskeletal system among dentists from the aspect of ergonomics and prophylaxis,” *Annals of Agricultural and Environmental Medicine*, vol. 9, no. 2, pp. 169–173, 2002.

[2] E. C. Alexopoulos, I.-C. Stathi, and F. Charizani, “Prevalence of musculoskeletal disorders in dentists,” *BMC musculoskeletal disorders*, vol. 5, no. 1, pp. 1–8, 2004.

[3] A. Gupta, M. Bhat, T. Mohammed, N. Bansal, and G. Gupta, “Ergonomics in dentistry,” *International journal of clinical pediatric dentistry*, vol. 7, no. 1, p. 30, 2014.

[4] M. Simmer-Beck and B. G. Branson, “An evidence-based review of ergonomic features of dental hygiene instruments,” *Work*, vol. 35, no. 4, pp. 477–485, 2010.

[5] S. Abichandani, S. Shaikh, and R. Nadiger, “Carpal tunnel syndrome–an occupational hazard facing dentistry,” *International dental journal*, vol. 63, no. 5, pp. 230–236, 2013.

[6] H. Dong, A. Barr, P. Loomer, C. LaRoche, E. Young, and D. Rempel, “The effects of periodontal instrument handle design on hand muscle load and pinch force,” *The Journal of the American Dental Association*, vol. 137, no. 8, pp. 1123–1130, 2006.

APPENDIX A
INVESTIGATIONAL DEVICE DETAILS

Fig. 4: Prototype 1

Fig. 5: Prototype 2

APPENDIX B
REQUEST FOR INTERVIEW SCRIPT

A. *Initial Contact:*

Hello [Interviewee],

We are UC Berkeley undergrads taking a course taught by Professor Hannah Stuart in the Mechanical Engineering department that focuses on improving human dexterity. As part of the class, we are conducting interviews to discover and design new assistive technologies.

We are reaching out to you to ask if you are willing to be interviewed about your experience as a Campus Ergonomist to guide our design process, or if you could put us in contact with someone who has suffered from a workplace or ergonomics related injury who would be willing to talk about their experience. The interview would be no more than 1.5 hours and would take place sometime in the next two weeks.

We respect your time and privacy, and we understand if you do not have the time to participate. If you change your mind or would like to end the interview at any time, that is perfectly fine as well. Additionally, we cannot offer any compensation for your time. However, we would be happy to share our final project report with you along with the notes from this interview.

Your information will be used only for our class project. We will not use your name or likeness publicly unless we have your permission.

Please let us know if you are willing to share your time and expertise with us. We look forward to hearing from you.

Best Regards,
Justin Radatti, Computer Science B.A.
Loren Lee, Computer Science B.A.
Nikhil Gupta, Bioengineering B.S.

B. *Follow up if accepted*

Hello [Interviewee],

Thank you for getting back to our request. What date/time works best for you in the next week?

We look forward to meeting you.

Best Regards,
Justin Radatti, Computer Science B.A.
Loren Lee, Computer Science B.A.
Nikhil Gupta, Bioengineering B.S.

C. *Follow up if declined*

Hello [Interviewee],

Thank you for getting back to our request. We understand [their reason for declining].

If you are comfortable, could you direct or connect us to someone in your mind who would be a potential interviewee?

Best Regards,
Justin Radatti, Computer Science B.A.
Loren Lee, Computer Science B.A.
Nikhil Gupta, Bioengineering B.S.

Appendix C
Collecting and Analyzing Interview Data

A. *Report 0: Reading Preparation*

1) Since our focus is on interviewing experts, we have to change some of the questions suggested in the reading. We want to focus on discussing their experience with customers and need-knowers. We want to ask about shortcomings they've observed in current products and how new research is addressing these. We also will ask about positive feedback they've received on current products.

To avoid limitations by only talking about existing technologies, we should ask directly what problems they aim to fix and what their customers/research volunteers/need knowers' request when they ask for a device.

Another line of questioning could focus on improving costs and accessibility, based on their experience with material costs and development costs, which customers may not know exactly.

2) Capturing wording verbatim is important to avoid putting our own biases and assumptions into our notes. We can catch details like non-verbal hints and emotions we might have missed during note taking. This also allows us to go back and re-interpret various statements later down the line when we may have forgotten the context for a certain statement. Video recording and transcript generation via Zoom is really helpful because it does this job automatically without relying on someone to do the job accurately. Furthermore, it is much more efficient and allows us to get a sense for the end users environment.
3) It is important to follow guidelines during interviews as it allows us to efficiently group data into different sections, making further analysis easier. Also guides the flow of the interview and makes sure that the conversation is staying on track. At this stage, we want to identify the needs of the customer but not solve them yet. This is to ensure that we don't come up with a piecemeal solution to the overall problem and to make sure that we focus on the root needs that inform the statements the customer makes. We also don't want to assign importance or a hierarchy to the needs yet. We should only indicate the importance of a need if the interviewee explicitly says so, since otherwise we would be imposing our biases and assumptions on the situation. This is not the final step because we do need to establish a hierarchy of needs, but that process should not be done at the same time since we should conduct that process while going over the results of the interview. This will allow us to better understand connections between various needs.
4) The virtual interview process will be similar to an in-person interview. We will each take a specific role (note taker, questioner, etc.) so that the process will run smoothly. With the interviewee's permission, we can use Zoom's recording feature to record the interview for later analysis. After taking notes following the guidelines in the reading, we'll do a debrief after the interview and then set up a time to discuss how to organize the needs into a hierarchy, probably using a Google Jam Board (or any application where we can visualize together at once). We can use that to also assign relative importance to the needs.

B. *Report 1: Interview Preparation*

1) Introduction:

- Thank interviewee for agreeing to be interviewed
- Introduce ourselves and our roles
- Clarify the reason we are interested in talking with the interviewee – We're here to learn as much as we can – you're the expert
- Ask for permission to record interview, confirm that we will not be sharing the interview and will delete the file after finishing the project
- We will keep the data confidential and delete the recordings at the end of the semester when we are done with the project – If agreed, ask to repeat confirmation once the recording has begun
- Make sure interviewee knows that they can stop the interview at any time
- Clarify interview/project goal: learn about the repetitive dexterous tasks that you do on an everyday basis, how these tasks effect your body, and apply that knowledge to a product to help fix the issue.
- Ask if interviewee has any questions before we start

2) Important topics:

- Background?
- Please describe your workday.
- What tools do you/other doctors use that require fine movements?

- What tools do you/other doctors use that require bigger movements?
- What are the pros/cons of these tools?
- Often people who sit at a desk all day get pain on the dominant side of their body, do you/other doctors have similar issues.
- What kind of repetitive tasks do you perform most often?
- What are the common injuries that you/other doctors experience?
- What are the most intrusive/annoying injuries that you/other doctors experience?
- Do you have any ideas about how to improve the issues you discussed?

3) Conclusion:

- Thank the interviewee
- You Ask if she has any questions/comments for us
- Ask if we can reach out to her for more information or advice during our design process
- Remind them that their data is confidential
- Any follow up questions

4) Roles:

- Loren Lee – Note taker
- Nikhil Gupta – Interviewer
- Justin Radatti – Interviewer

C. Report 2: Interpret the Interview Results

Our user needs charts are depicted in Figures 6, 7, and 8.

Question Type	Interviewee Statement	Interpreted Need
Laptops	When working, the screen should be at eye level. The keyboard and mouse should be at elbow level.	Workstations are large enough to put the screen at eye level while the keyboard and mouse are at elbow level.
Using a mouse	When using a computer, pain develops along the dominant side from the skull down to the spine.	Users should know how to correctly use the device.
Risks assessment	The same task has to be repeated multiple times. Repetition	The device supports repeated motion in the correct posture.
Risks assessment	Awkward posture	The device maintains or forces correct posture throughout the motion.
Risks assessment	Force	The device assists with both the weight of the object and the weight of the body part being supported.
Risks assessment	Contact stress (Feeling the different textures and surfaces)	Device is compatible with a variety of contact surfaces with regards to friction and protection.
Risks assessment	Temperature	Device protects against temperature extremes.
Usability	Don't want to be aware or thinking about the device	Device is inconspicuous or unobtrusive outside of its function.
Proper ergonomics	In table work, the arm should be level with the task being done.	Device supports the arm when not level or adjusts the task or arm to make them both level.
Risk/Injuries	Head and neck hurts when working at a table or on a laptop.	Device supports the head or neck.
Risk/Injuries	Slow, careful movements can still lead to problems in repetitive tasks.	Device supports motion at multiple speeds.
Prevention	Hard to keep thinking about posture while performing tasks, only pay attention when pain begins.	Device monitors posture or movements and alerts the user to bad posture or dangerous motions.
Prevention	Trainings and educational sessions But it is often "one ear in and one ear out" for people	Device needs to be intuitive and it is not the user's responsibility to use the device in an ergonomic fashion
Prevention	Users rarely pay attention to the products and the relationship their body and health have with them. Ending up noticing AFTER health issues have arisen.	Products make ergonomic risks clear and provide suggestions to prevent them.

Fig. 6: Ergonomist Needs Chart

Endodontist Needs		
Constraint	Mouth is very small.	Device is small enough to fit in the mouth without obscuring vision.
Possible solution	Some devices have fleece around the handle for comfort when holding.	Device is comfortable to hold.
Repetitive movement in hands	Micromovements with both hands	Device is easily maneuverable
Repetitive task	Often needs to exchange instruments	Device is convenient to interchange
Issues	During procedure, hands and forearms become cramped	The repetitive fine muscle movements that are required for the job result in discomfort/pain that interferes with the procedure
Tools	Some people use cordless tools but he likes the cord because he can use it to take some of the pressure off of his fingers	Tool helps alleviate repetitive pinching motions when holding tools
Tools	He uses both mechanical and hand powered tools. Mechanical/auto tools still have some tactile feedback, but not as good as the hand powered tools.	Device provides good tactile feedback. Device is precise.
Repetitive movement in hands	Extensive flexion/extension in hand when working with the mechanical drill which leads to carpal tunnel and other issues.	Device moves the tool on its own without the hand needing to flex/extend.
Switching tools	Looking for an easier way to switch between tools, there is some variety in approaches but it is one of the most repetitive tasks with small tools.	Tool device attachments are easily handled and switched out without fine control or movements required.
Tool types, automated vs Manual	There is a lot of switching between automated and hand tools, tactile feedback is very important.	Tool device provides tactile feedback related to resistance and tool movement.
Tool versatility	Hand tools are better for initial cuts, mechanical tools require a certain depth before they can be used.	Tool device works at varying depths.
New vs old blades	Prefers older design of blades that are planar rather than the newer cutting blades. The newer blades require a circular or figure 8 motion while the older blades only need a pistoning motion.	Tool device requires a simpler motion that puts less strain on the joints, minimizing fine movements.
Tool preferences	The pistoning motion allows him to use different body parts to achieve the same motion (wrist, elbow, shoulder), giving them a rest when needed.	Tool device requires motion that can be achieved with different sets of muscle groups.
New vs. Old blades	Newer blades have a higher breakage rate, older blades are 3-5 per procedure, newer blades are ~15 per procedure, thereby costing more.	Tool device is strong and does not break easily.
New vs. Old blades	Newer blades are more flexible, but in his experience that is not as important as strength.	Tool device prioritizes strength over flexibility.
New vs. Old Blades	Newer blades can “unwind” and become less efficient suddenly or without indication.	Tool device works well until breakage or has a clear indicator of effectiveness.
Tool versatility	Many different canal widths, some are more difficult than others. The mechanical tools are useful for some sizes, but for others only the hand tools will work.	Tool device works for multiple canal sizes or facilitates changing size easily.
Tool functionality	Canal work requires lower rpm and higher torque drills compared to other dentistry drills.	Tool device delivers high torque, both in the hand driven version and the drill version.
Grasping the tool	Feels quite a bit of effort going into grasping the tools during use, on top of the effort going into using the device.	Grasping device holds the tool while still allowing fine control and movement of the tool.
Multiple tools	There is a lot of repetitive switching between different tools and different sizes of attachments.	Tool device accomplishes multiple functionalities in one. Grasping device allows for easy and quick changing of tools.
Head positioning	Neck is often in an awkward position for most of the procedure, results in pain and requires constant care.	Device supports the head and alleviates stress on the neck without impeding movement.
Tools	Most of the instruments are thinner than the diameter of a pen, so some tools are designed to have fleece around it to increase the diameter for holding comfort. Better hand ergonomics.	Bigger tool diameter = less micro gripping = less strain from pinching motion.
Tools	Maybe plastic ends to hold onto (pear shaped or oval shaped) to increase the diameter of the tools.	Tool device provides an easy and comfortable grip for the hand.
Tools	To decrease the frequency of micro-pinching and rotary motion, maybe there should be something that holds the tools for him	Device secures and holds tools for the hands.
Tools	Drills have different button locations depending on the design. The buttons have to be easy to reach. Some dentists have hand switches but most use pedals. He prefers pedals because it works and nothing has to be changed.	Device on/off switch must be convenient

Tools	Prefers tools with cords attached at the end instead of newer designs of cordless tools as the cord weight helps alleviate the stress on fingers to hold the tool in hand for a prolonged time by locking down the object with its weight and torque. "Takes hand grip pressure away."	Device is easy to hold and does not put too much pressure on the pinching motion of holding small tools.
Tools	He needs to understand the materials of the tools before using them. -> Good ratios of metal designs and how their stiffness get affected when being sterilized.	Tool is compatible with different materials and can maintain structure and stiffness under many rounds of sterilization.
Daily tasks	Right handed, and therefore has worse strain and pain on his right hand, arm, and shoulder after days of repeated tasks	Device offers better distribution of task/weight of both hands and arms.
Daily tasks	Hunching over the patients a lot because of the positions and placements. It is even harder when patients cannot open their mouth wide enough. Started relying on posture correction on his own instead of the chair for lower back support.	The device supports different postures and positions without the need knower relying on self posture correction.
Daily tasks	During procedures, due to intense and repetitive movements, fingers and muscles cramp up a lot. So they have to switch hands and change their body position often.	Device supports the grasping of tools to reduce stress of constant muscle contraction leading to a cramp.
Daily tasks	Job requires a lot of typing for reports and paperwork. Current dictation technology does not work well.	Device offers accurate dictation(?)
Daily tasks	Job requires a lot of sitting, a lot of colleagues experience shortening of hip flexors. Need to sit and hunch the backs everyday.	Device supports back and promotes good posture on its own.

Fig. 7: Endodontists Needs Chart

Primary needs	Secondary needs
Tool device is versatile.	Tool device works for multiple canal sizes or facilitates changing size easily.
	Tool device accomplishes multiple functionalities in one.
	Tool is compatible with different materials and
Tool device is strong and does not break easily. (Robust)	Tools maintain structure and stiffness under many rounds of sterilization.
	Tool device works well until breakage or has a clear indicator of effectiveness.
	Tool device prioritizes strength over flexibility.
Tool device is convenient to use	Device is easily maneuverable
	Device is convenient to interchange
	Device must be convenient to turn on/off
	Tool device requires motion that can be achieved with different sets of muscle groups.
	Tool device requires a simpler motion that puts less strain on the joints, minimizing fine movements.
	Device moves the tool on its own without the hand needing to flex/extend.
	Tool device provides an easy and comfortable grip for the hand.
Device supports the upper body and neck.	The device supports different posture and positions without the need knower relying on self posture correction.
	Device supports back and promotes good posture on its own.
	Device offers better distribution of task/weight of both hands and arms.
	Device supports the head and alleviates stress on the neck without impeding movement.
Grasping the device holds the tool for the user.	Device supports the grasping of tools to reduce stress of constant muscle contraction leading to a cramp.
	Grasping device holds the tool while still allowing fine control and movement of the tool.

Fig. 8: Hierarchical List Of Needs

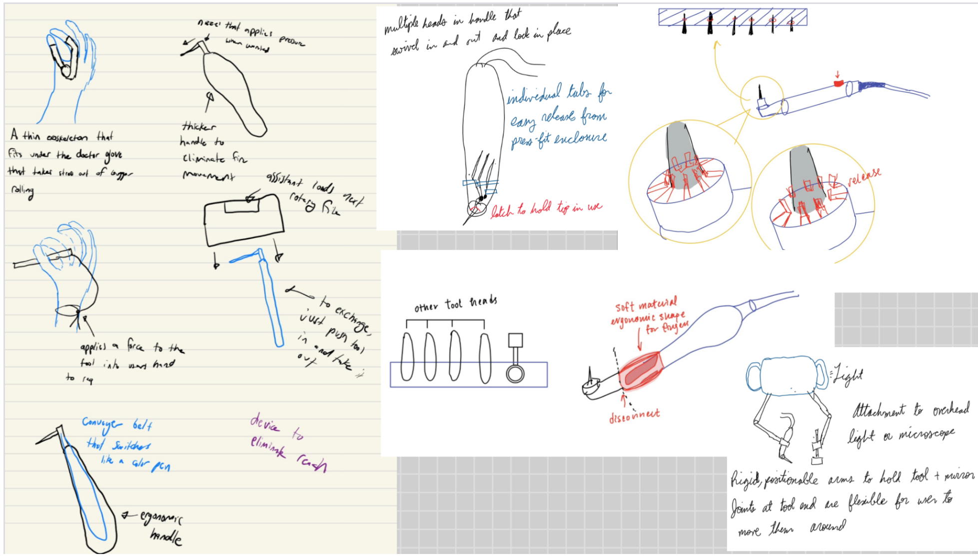

Fig. 9: Brainstorming

D. Report 3: Remote Brainstorm Session

The rough sketches of our brainstorming session are pictured in Figure 9.

E. Report 4: Converge

Criteria	**Weight**	**Design 1: Hand Exoskeleton**	**Design 2: Tool with swivel tips**	**Design 3: Tool with replaceable heads**
Comfort	3	-	0	0
Versatility	2	+	+	+
Effectiveness	3	+	+	+
Simplicity	1	-	-	-
Feasibility	1	+	+	+
Final Score		2	5	5

Fig. 10: Weighted Matrix

Tentative Final Design

Ergonomic Tool with Replaceable Heads The tool resembles a standard drill but with a larger bottom end to act as a counterweight for better control and has an additional ergonomic grip. The head of the tool can detach with a single button and has a simple press-to-lock function. The various tool heads are held in a stand on the user's table, and the user can easily deposit a tool head in its slot and lock in a new tool without having to pick up and align the small, thin tool heads. Sketch pictured in Figure 11:

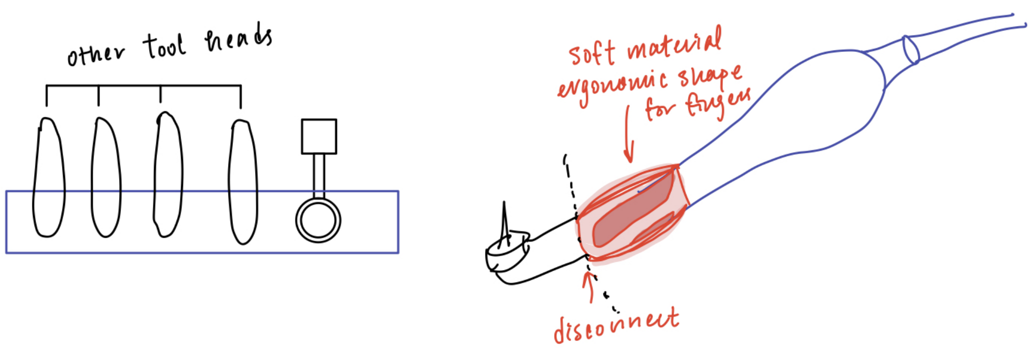

Fig. 11: Final Brainstorm Sketch