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UNIVERSITY OF CALIFORNIA SAN DIEGO

**Designing and Exploring the Mechanical Advantage of an Endoscopic  
Gripping Device**

A thesis submitted in partial satisfaction of the  
requirements for the degree  
Master of Science

in

Bioengineering

by

Andrew Chen Zhang

Committee in charge:

Professor Shanglei Liu, Chair  
Professor John Thomas Watson, Co-Chair  
Professor Nathan Joseph Delson  
Professor Mary Lee Krinsky  
Professor Bruce Christopher Wheeler

2022





The thesis of Andrew Chen Zhang is approved,  
and it is acceptable in quality and form for  
publication on microfilm and electronically.

University of California San Diego

2022

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## ABSTRACT OF THESIS

### **Designing and Exploring the Mechanical Advantage of an Endoscopic Gripping Device**

by

Andrew Chen Zhang

Master of Science in Bioengineering

University of California San Diego, 2022

Professor Shanglei Liu, Chair

Professor John Thomas Watson, Co-Chair

Physicians who perform colonoscopies are at great risk for developing Repetitive Stress Injuries (RSIs) due to the repetitive stress. Currently there is little literature in Ergonomic in colonoscopies and nearly none in ergonomic devices. Our group created a device called the "EndoGrip" as a small device intended to assist physicians in manipulating the shaft and tip of the endoscope. This device went through several iterations of design and feedback and resulted in a prototype with two features increasing mechanical advantage. These features are the interior grip angle and exterior grip diameter. To prove the efficacy of the features, mechanical tests were performed. These resulted in a 45% increase in the gripping frictional force and nearly 200% increase in torquing force. Next, EMG studies were performed with the grip on a mock endoscope. These studies

were done using the ACGIH's TLV standard. These studies confirmed both the effects of the mechanical advantage of both the interior grip angle and outer grip diameter. However further studies with more subjects and prototypes with a higher coefficient of friction are necessary.



# Chapter 1

## Introduction to Physician Injury

Physicians who perform colonoscopies are at great risk for developing Repetitive Stress Injuries (RSIs) due to the repetitive, prolonged stress, and awkward positions during such procedures [8]. Survey studies have found prevalence of musculoskeletal injury among gastroenterologist of between 37% to 89% while on average they spend 43% of their time performing endoscopy [8]. The high rate of injury is due to the endoscope's thin design which focuses on being able to maneuver within the bowel of the patient. Studies have taken a look at physician injury rates and tried to address the problem of RSIs through training and positioning [6][9]. These studies report high rates of injury in the upper body, specifically the thumb, hand, neck, wrist, back, and shoulder [8]. The rate of injury among physicians will only increase as the recommended age for colonoscopies has recently been dropped from 50 to 45 [10].

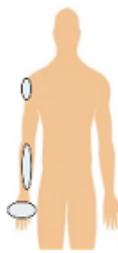


Figure 1.1: Area of focus for this project.

One particular area of injury that we decided to focus on is the right hand, forearm, and upper arm. This area of the body is used to manipulate the tip and shaft of the

endoscope into and out from the patient while the left hand manipulates the controls. To relieve the stress of the right side of the body, we created a simple mechanical device, named the **EndoGrip**, to reduce the stress on the physician's right hand.

# Chapter 2

## Device Design

### 2.1 Design Process

The original design of the EndoGrip was to increase the mechanical advantage (which will be explained in Chapter 3) of the endoscopist on the endoscope to relieve the amount of stress on their right hand, wrist, and arm. Throughout the design process while the overall mechanical advantage of the original design was preserved, many usability features were added to the EndoGrip to make it usable and comfortable to the user.

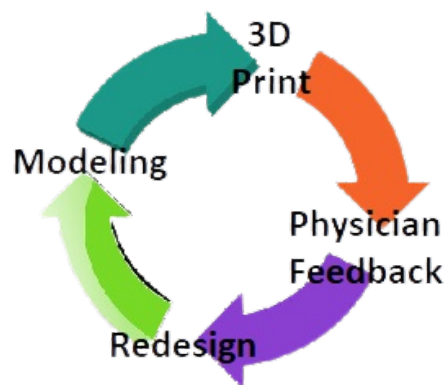


Figure 2.1: Illustration of the cyclic design process used to create the EndoGrip.

The design process used to create the EndoGrip was characterized by iterating over a loop of initial 3D modeling, rapid 3D printing, physician feedback, and redesign to

accommodate for the feedback. It was repeated resulting in 6 generations of grip designs, the last of which was used for further EMG experimentation as well as presentation during the DDW 2022 conference as well as the UCSD Surgical Symposium.

All the 3D modeling done for this project was done using Fusion 360, and printed using tough Polylactic Acid (PLA) as the primary material and dissolvable Polyvinyl Alcohol (PVA) a support material. After printing, the support material was removed for 48 hours in a water bath and mechanical agitation. After the bath, 12 more hours of air drying was required before the devices were fit to be assembled as the PLA shells printed held water within the 3D print outs.

Physician feedback occurred roughly once per generation on either a colonoscope simulator or on regular colonoscopes at UCSD Health. Almost all feedback was given by Dr. Mary Lee Krinsky and Dr. Shanglei Liu. After general feedback was discussed with the engineering team, the next generation of devices could be modeled.

## **2.2 Initial Design (Generation 0)**

The working design at the beginning of the project was a basic two piece design that used two identical halves to create a cylinder that grips around the endoscope. The two pieces were attached by two thin axles that protruded from the interior side of each piece, allowing for the two pieces to form a hinge and rotate around a center of axis. The notable features of the original grip were the 45mm outer diameter and intended interior grip of 12.7mm (1/2 inch) diameter endoscope. Additionally, there are raised bumps on the exterior of the grip to allow for better grip between the physician's hand and the surface of the device.

## **2.3 Interior Grip Angle Changes (Generation 1)**

The aspect of the grip we inspected was the interior grip angle of the device. The grip angle describes the The purpose of this was to increase the frictional force between the device and endoscope. The exact mechanics of which will be explained further in Chapter 3. During this iteration of the design process angles between 42.5 and 80 degrees were explored in increments of 7.5 degrees, additionally a special 0-degree grip angle design was created as a control group for the experiments.

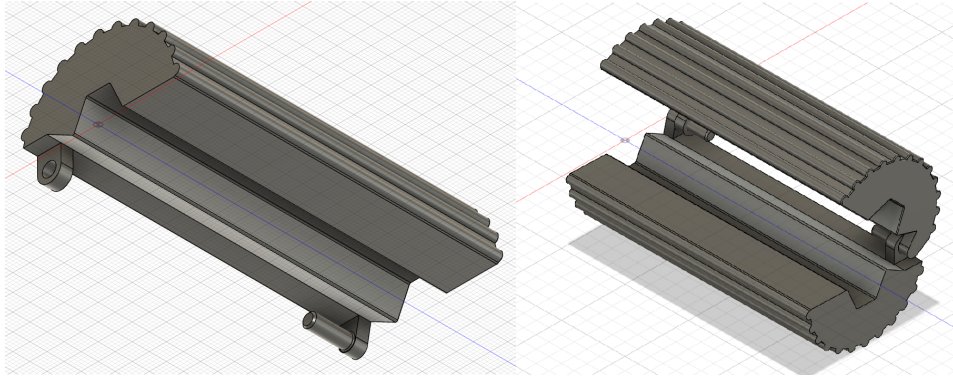


Figure 2.2: The working model of the EndoGrip at the beginning of this project.

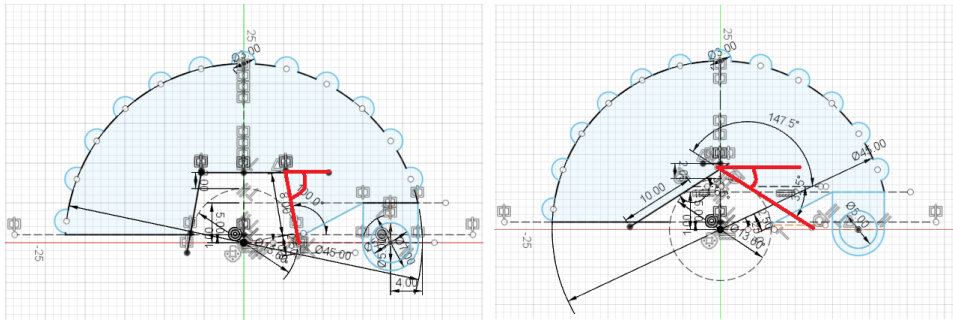


Figure 2.3: Two different interior grip angles highlighted in red: 80 degrees (left) and 42.5 degrees (right).

## 2.4 Springs and Removable Pins (Generation 2)

After the first round of physician shadowing the next generation of grips utilized springs to create a “default” position for the EndoGrip. The tested default positions were “default open”, “default closed”, and “no spring”. In order to add the springs to the interior of the EndoGrip, the axles that held the device together had to be redesigned. Instead of axles attached to each half of the device separate “pins” were made to insert into the two halves to allow for the springs to first be placed centrally and locked into place. An example is shown in figure 2.4.

Upon receiving physician feedback for this design, it was decided that the “default closed” position be used in further generations it allowed the grip to stay on the endo-

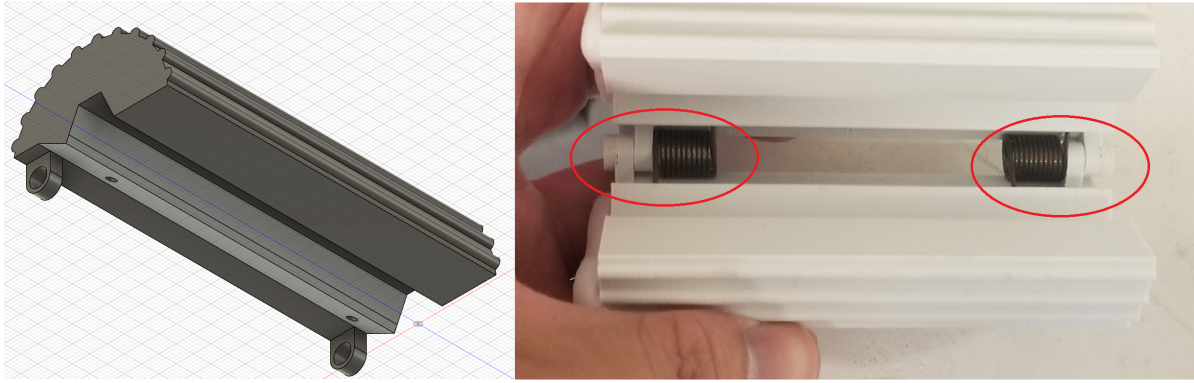


Figure 2.4: Generation of the EndoGrips which first introduced the interior springs and removable pins. Fusion 360 file (left) and assembled grip (right) both shown to illustrate the assembly of the device.

scope while the endoscopist removed their right hand from the EndoGrip to assist their left hand on the controls. The benefit of the static positioning was that the endoscopist could keep their eyes on the screen displaying the camera feed rather than looking down at their hands. This contrasted from a "default open" or "no spring" design as both of these designs were unable to maintain their position on the endoscope without an external force.

## 2.5 Exterior Design (Generation 3)

After the previous generations focused on the internal geometry and functionality of the EndoGrip, the next set of changes aimed to alter the external surface of the grip. This surface is crucial to the usability of the device as they are the surfaces that directly contacts the physician's right hand. This generation of devices also explored several different methods of opening the device. The opening method is important since the introduction of the "default closed" position requires the more force to open compared to the devices without springs.

One major point of feedback from several previous designs was that the raised bumps on the exterior of the grip did allow for less slippage between the hand and device, but when the physician applied more force on the device, the bumps became physically uncomfortable as they would press into the physician's hand. Therefore, the raised

bumps were removed from the design of the device in favor of a smooth, rounded surface as shown in Figure 2.5.

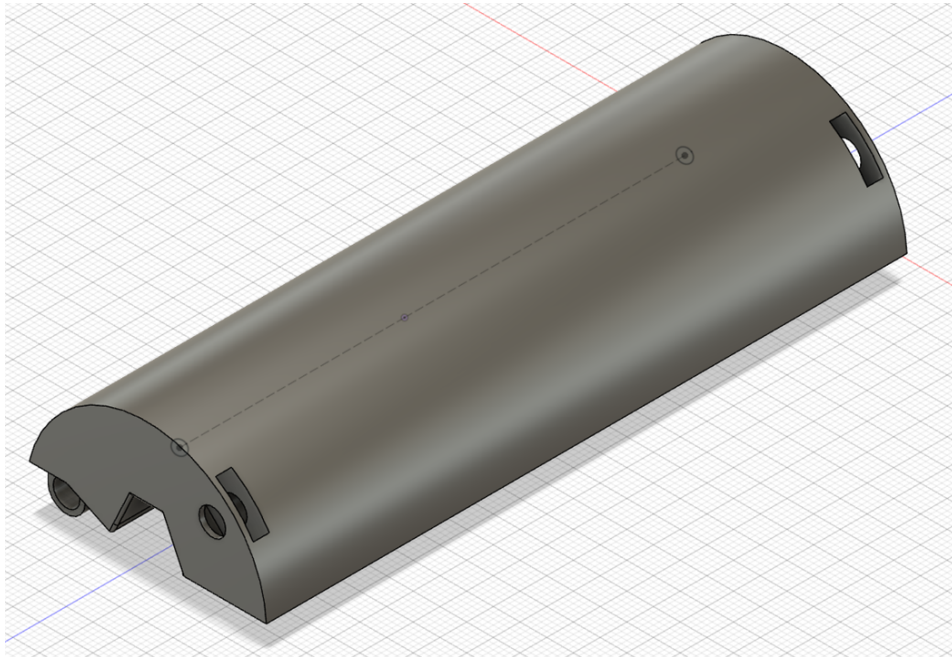


Figure 2.5: Example Generation 3 design of the EndoGrip

The other major design element of this generation was the introduction of opening methods. Functionally, these allowed for the physicians to comfortably transfer the force of their hand opening more comfortably onto the grip. This is important as during a colonoscopy the tip and shaft of the endoscope is advanced and retreated into the patient's bowel, requiring constant repositioning of the hand on the location of the scope. Therefore, being able to quickly open the device and reposition on the scope is incredibly important. Three methods for this were prototyped: a ridge on the exterior of the surface of the grip that fit the tips of the user's fingers ("Finger Ridges"), a silicone strap that attached securely to the sides of the grip and created a hole for the user's fingers ("Straps"), and a thermoplastic mold that created a rigid body for the fingers to press against ("Finger Loops"). All these Designs are illustrated in Figure 2.6. These features each took several centimeters of length on each end of the grip, and therefore the grip length was extended 1.5 centimeters on each side to allow for a hand to still fit comfortably on the grip.

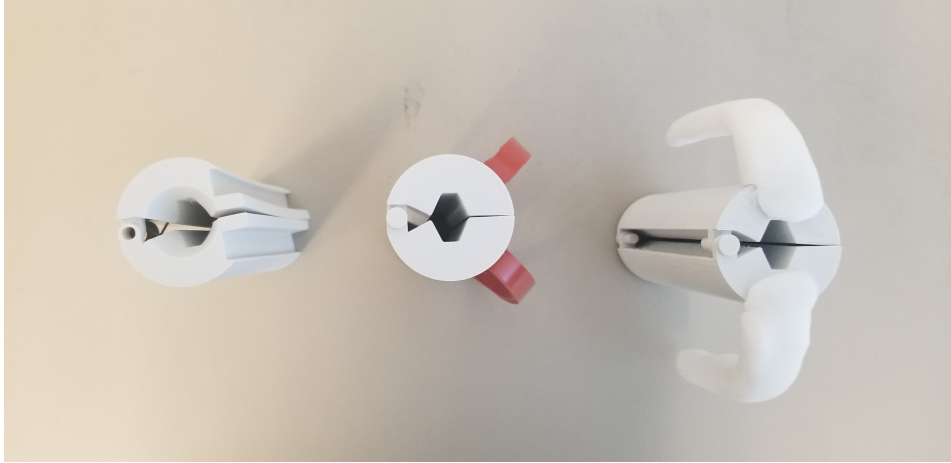


Figure 2.6: Example designs of opening methods. (From left to right) "Finger Ridges", "Straps", and "Finger Loops".

After receiving physician feedback, the "Straps" design was chosen as it was able to accommodate a wider variety of hand shapes and sizes. In contrast, the rigid thermo-plastic "Finger Loops" were not able to fit larger hands while the small "Finger Ridges" required too much finger strength from the user.

## 2.6 Interior Funnel Shape (Generation 4)

Following the increased device length, a new issue was discovered in a physician feedback session. During feedback on working with an actual endoscope, it was discovered that the flexible and curved nature of the endoscope made it difficult to close the recently lengthened EndoGrip on the endoscope if the endoscope had too much curvature. To solve this problem an interior funnel design was added to push the endoscope towards the main channel of the EndoGrip upon the user closing the grip. An example funnel is shown in Figure 2.7.

The exact dimensions of the funnel had to be tested through another round of physician feedback as a funnel that was too small would not achieve the purpose of guiding the endoscope while a funnel that was too big forced the axles of the device closer to the center, creating instability in the pivot. Therefore, a trade off between the ability to easily move up and down the endoscope and the smoothness of the device opening had



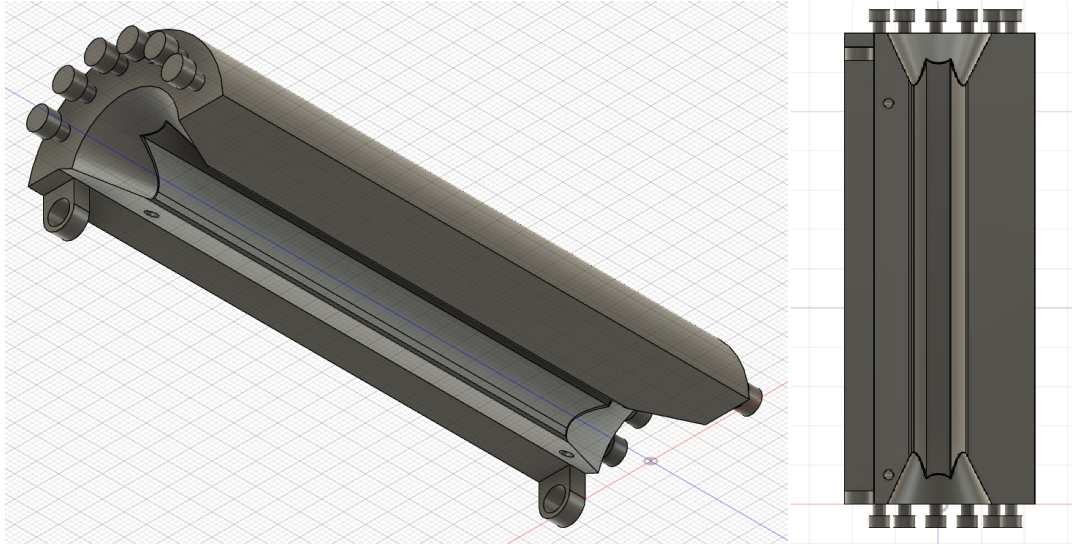


Figure 2.7: Isometric view (left) and Interior view (right) of the funneled ends of the grip. The structures on each end of the grip allowed for easy strap replacement and repositioning during prototyping.

to be made.

## 2.7 Final Design (Generation 5)

During the penultimate round of physician feedback, the EndoGrip was tested on a colonoscopy simulator. This process simulated a more realistic clinical environment than a loose endoscope. In this process, it was found that the physicians tended to only hold the bottom half of the grip, letting their hand partially contact the endoscope while still holding the EndoGrip. This left more than half of the length of the EndoGrip untouched.

To remedy this, the length of this generation of the EndoGrip was shortened to 60 mm (50% of the previous generation). Additionally, an external chamfer was added to one end of the grip to allow for a more natural slope from the wider diameter EndoGrip to the smaller diameter of the endoscope. This changed the overall intent of the design from sitting between the endoscope and the whole hand to acting as an assistance device that only provides a mechanical advantage to several fingers. The Final Fusion 360 file is shown in Figure 2.8.

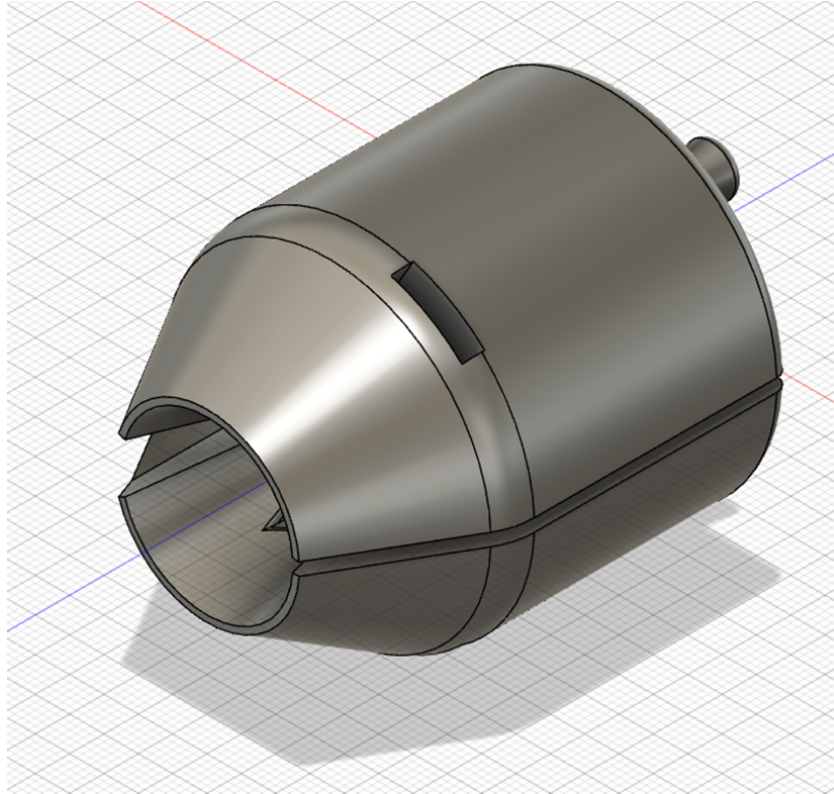


Figure 2.8: Final Design of the EndoGrip.

## 2.8 Further Work

Physician feedback on the final version of the EndoGrip is generally positive, though there still requires some work on device before it could be product ready. Most importantly, the grip material should be changed to a material that is softer than hard and slippery PLA. This is important as the hard PLA would be rough on the joints of the hand while it's slippery nature would make it difficult to manipulate the endoscope while it has endoscope lube or other fluids on it.

Another area to further study is the exact positioning of the straps. This would be further researched while examining the best grip position for the user. Currently, the device was designed to have the index and middle fingers on the device while the ring finger and pinky could sit on the endoscope or slope. But some physicians have found other preferences when gripping the device, many of which are shown in Figure 2.9.

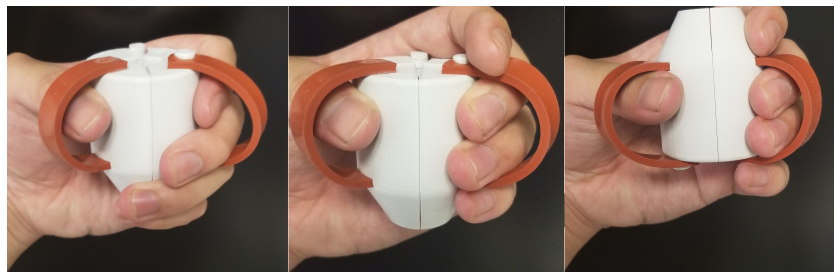


Figure 2.9: Intended hand position (Left). Other positions preferred by physicians (Center and Right)

# Chapter 3

## Mechanical Experiments

### 3.1 Background

Given the high rate of physician injury previously described the main purpose of the EndoGrip device is to increase the mechanical advantage of the physician on the shaft of the endoscope. Mechanical advantage is important to reduce the stress, and therefore the potential for injury on the physician's body. Our device, which focuses on reducing the right hand, wrist, and arm of the user has two different methods of creating mechanical advantage.

#### 3.1.1 Interior Grip Angle (Wedge Design)

The first major design feature that creates mechanical advantage is the introduction of the interior grip angle, which creates the “wedged shape” on the interior of the EndoGrip. The design process of the interior wedge angle of the grip was previously described in Chapter 2.3 of this thesis, but the reasoning behind choosing the dimensions of the wedge have a physical basis. The theoretical basis of the mechanical advantage of the wedge grip design is created by the idea that the wedge shape increases the normal force between the interior surface of the device and the endoscope. Mathematically, this is illustrated in the Free Body Diagram shown in Figure 3.1 and mathematical analysis in the following equations.

Analysis for wedge grip

$$\text{Equation 1: Frictional Force} = 2\mu rN$$

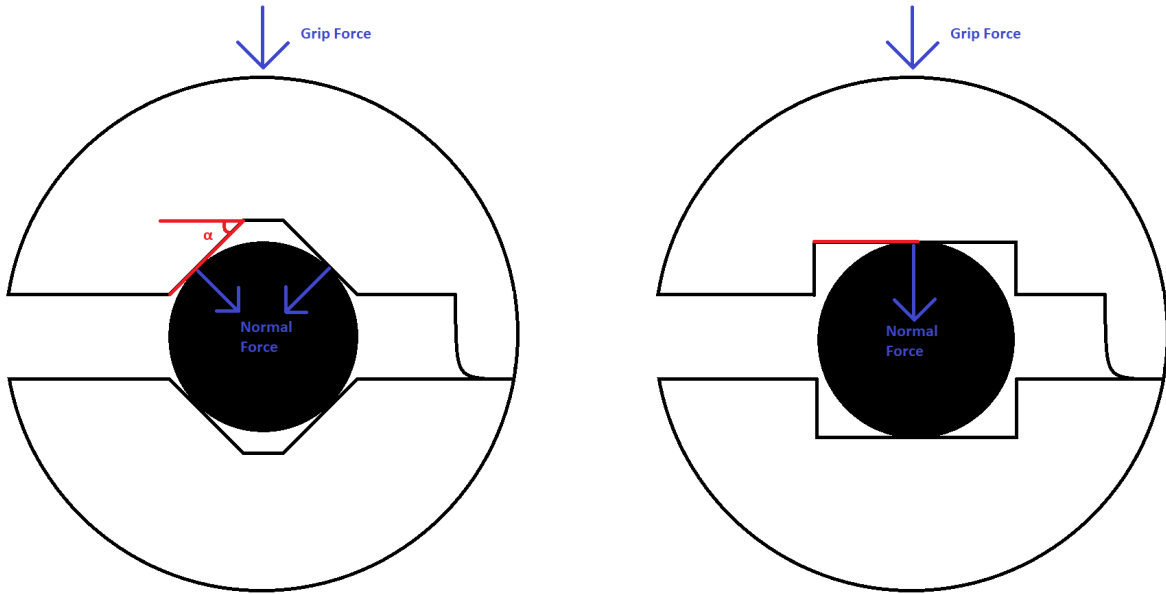


Figure 3.1: Free body diagram of the forces (blue) involved in the interactions between an EndoGrip (white) and Endoscope (black). Wedge grip design (left) vs traditional grip (right).

Since:  $\Sigma F_y = 0$ , Therefore:  $\text{Grip Force} = 2N \sin(90 - \alpha)$

Rearranged:  $N = \text{Grip Force} / (2 \sin(90 - \alpha))$

Substituting Equation 2 into Equation 1:  $\text{Frictional Force} = \text{Grip Force} * \mu r / \sin(90 - \alpha)$

Performing a similar analysis on the traditional grip results in:

$$N = \text{GripForce} * \mu r$$

Then creating the ratio between the frictional force  
of the wedge grip and traditional grip:

$$\text{Wedge Grip} / \text{Traditional Grip} = 1 / \sin(90 - \alpha)$$

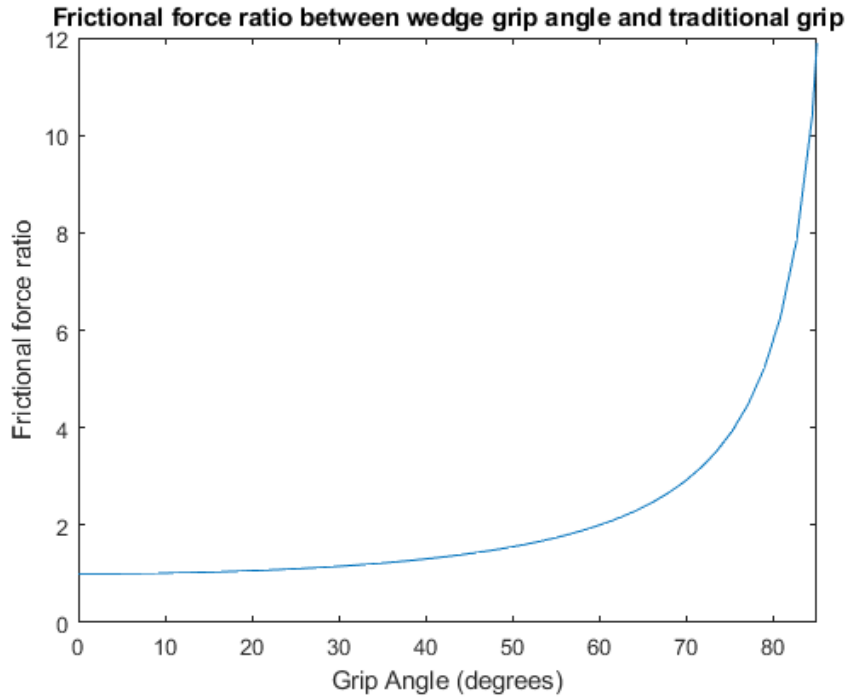


Figure 3.2: Graph of the theoretical increase in frictional force between the wedge grip and traditional grip.

This equation can then be graphed as a function of the interior grip angle as shown in Figure 3.2.

As shown in the equations and Figure 3.2, when the contact point between the device and the endoscope becomes more vertical, the normal force between the grip and device increases given the same exterior grip force. This can be rationalized as the y-component of the normal force is directly tied to the force applied by the user, the x-component increases and is balanced on the other contact point of the grip on the endoscope.

Given the sharp increase frictional force multiplier at high interior grip angles, it makes sense to increase the grip angle as much as possible. However, there is a major drawback of increasing the grip angle too much as the higher the grip angle, the more risk there is of the grip completely closing or being unable to close properly if the size of the endoscope varies. Given the variation of the diameter of endoscopes, an upper bound of the grip angle was chosen at 65 degrees for the purposes of this project.

### 3.1.2 Exterior Outer Diameter

The other source of mechanical advantage in this device is the increased external radius of device compared to the radius of the bare endoscope. Mechanically, the radius of the device acts as a lever arm to increase the torque applied on the endoscope given a constant exterior force. Therefore to apply the same torque on the endoscope with the EndoGrip compared to a bare hand, much less force must be applied. The difference in the lever arm lengths is shown in Figure 3.3.

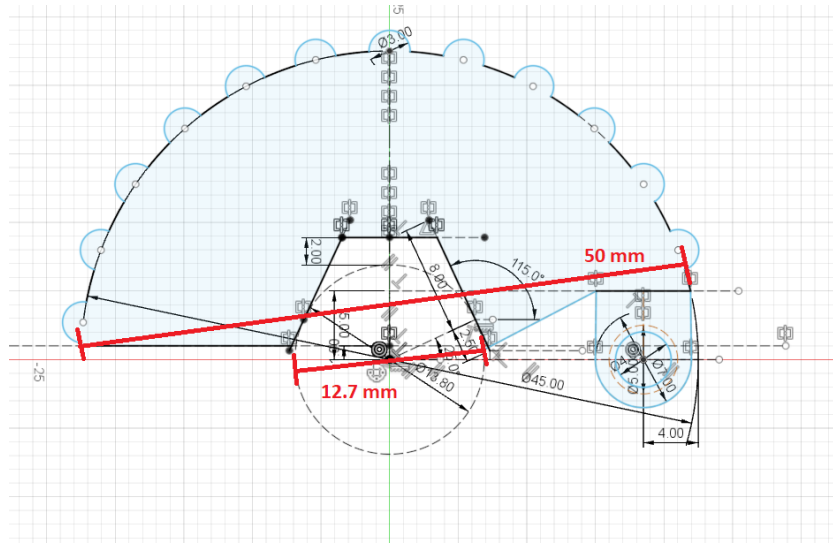


Figure 3.3: Illustration between the diameter of the grip (50mm) and the diameter of the endoscope (12.7mm)

## 3.2 Experimental Design

### 3.2.1 Interior Grip Angle

To verify the theoretical model of the interior grip angle, a mechanical testbed (Figure 3.4) was designed to apply a variable mechanical torque on the EndoGrip while the device is clamped to a stationary mock-endoscope with a constant, known force (to emulate a grip force). Then various interior grip angles were tested in the testbed to determine the effect of the interior grip angle on the point at which the EndoGrip slips on the endoscope.



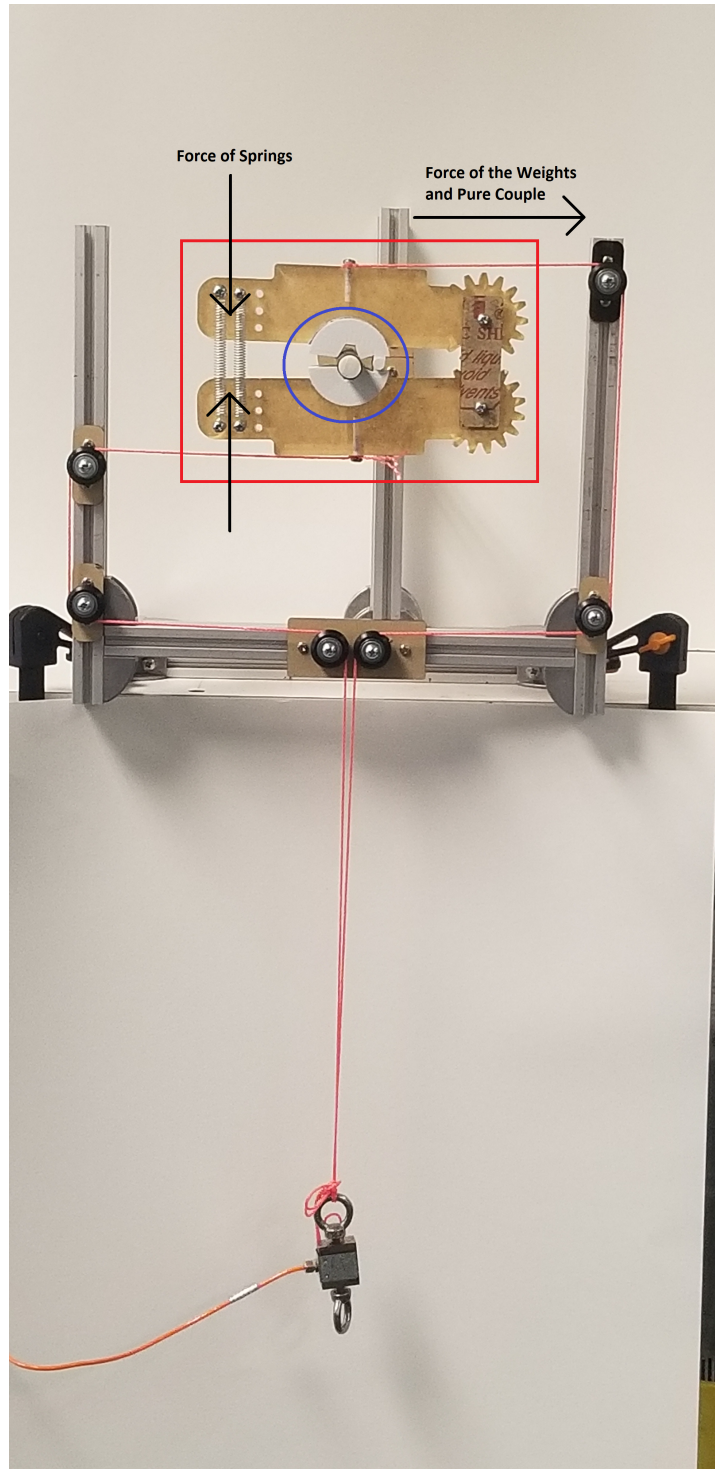


Figure 3.4: Picture of the testbed used to conduct the mechanical tests. The red square outlines the force clamp and springs while the blue circle denotes the EndoGrip and stationary-mock endoscope.



The test bed is primarily comprised of two components, the stationary mock-endoscope and pure couple, and the force clamp. The stationary mock-endoscope is made using a 12.7mm (1/2 inch) diameter Delrin rod wrapped in electrical shrink wrap. The structure of the mechanically pure couple and testbed is made using 20-80 aluminium rods and bearings mounted using laser cut acrylic.

The force clamp was designed using AutoCAD and cut out in 1/2 inch acrylic using a LaserCAMM laser cutter. The force was applied to the clamp using springs, which spring's constant were known by calibration of known weights.

The force clamp was then mounted on an Endogrip device, which was then placed on the stationary mock-endoscope. Afterwards, the pure couple was attached to the top and bottom of the force clamp using a loop of string. This method allowed for equal forces to be applied at orthogonally to the top and bottom of the force clamp.

To obtain the torque at which the grip slipped of the stationary endoscope, known weights were hung on the same string that created the pure couple. At the point of slippage between the EndoGrip and the stationary mock-endoscope, the mass of the known weights were recorded. This process was repeated 3 times for each of the selected grip angles (0, 25, 45, and 65 degrees), shown in Figure 3.5.

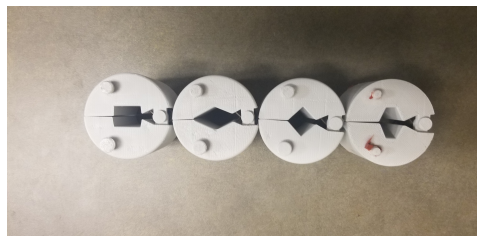


Figure 3.5: The grip angles used to test the theoretical model. (left to right) 0 degrees, 25 degrees, 45 degrees, and 65 degrees.

### 3.2.2 Exterior Outer Diameter

The outer grip diameter is incredibly important to ergonomics as the ability of the user to apply squeezing and torquing force on an object is very dependant on the outer diameter of that object [7]. This concept is called the power grip position, and in general, the best position for exerting as much grip strength and torque is an object where the

circumference is close to the length of the hand and thumb [7]. This would result in a complete surround of the object without overlap from the hand and thumb.

To determine if the EndoGrip’s increase in diameter truly does result in an increase in the torque applied to the endoscope, a simple mechanical test was used. A string was attached to both the exterior of the bare endoscope and the EndoGrip attached to a rotatable mock endoscope (Figure 3.6).

Upon one end of the endoscope was a known pendulum weight with an inclinometer attached. Using the known mass of the pendulum and the rotation of the rotatable endoscope, the torque on the endoscope could be measured. Then, variable weights were then attached to the end of the string and the relative rotation of the pendulum was recorded.

The rate of increase in torque can then be calculated by comparing the angle of the pendulum with the bare hand compared to the EndoGrip by the following formula:

$$\begin{aligned} \text{Torque on the mock endoscope} &= mgsin(\alpha) \\ \frac{\text{Torque with the EndoGrip}}{\text{Torque with the bare hand}} &= \frac{sin(\alpha_{\text{EndoGrip}})}{sin(\alpha_{\text{Bare}})} \end{aligned}$$

### 3.3 Results and Discussion

#### 3.3.1 Interior Grip Angle

The results (Table 3.1) of the experiment show a distinct difference in the slip torque when comparing the different grip angles. Given the very consistent nature of the data received, the experiment was only repeated 3 times before statistical significance was achieved between the four different Interior Grip Angles tested. The results show a general increase in the frictional force between the grip and the stationary mock endoscope as the grip angle increased. Most notably, there is a 45% increase between the 65 degree grip and the 0 degree grip.

Table 3.1: Results of the interior grip angle mechanical tests

Grip Angle	0 Degree	25 Degree	45 Degree	65 Degree
Average weight at slip (kg)	.502	.515	.702	.730
Torque (Nm)	.246	.253	.344	.358



Figure 3.6: Rotatable Mock Endoscope

While this is a rather large increase in the frictional force, it is not the calculated theoretical increase of 137% ( $1/\sin(90 \text{ degrees} - 65 \text{ degrees})$ ). This is likely due to the non-ridged nature of both the mock endoscope and the causing the frictional interactions between the mock endoscope and EndoGrip. This may be caused by two interactions: either of the bodies elastically deforming slightly which causes the geometry to be imperfect or the frictional coefficient of either of the bodies being reduced due to the stress on the material. Both these reasons would result in diminishing returns in increasing the frictional force at higher interior grip angles. This would explain the shape of the bar graph of the torques (Figure 3.7) where despite having an exponential-like growing theoretical normal force, the torque at slippage levels off past 45 degrees.

Notably both the mentioned effects are incredibly material dependent, and since future versions of the EndoGrip will likely use a material that has a higher frictional coefficient than the 3D printer PLA. Therefore, despite the 65 degree interior grip angle EndoGrips having an 45% increase over the 0 degree interior grip angle devices, it is unlikely that this increase in mechanical will be standard across all materials. Despite this, the geometry of the device should confer some amount mechanical advantage.

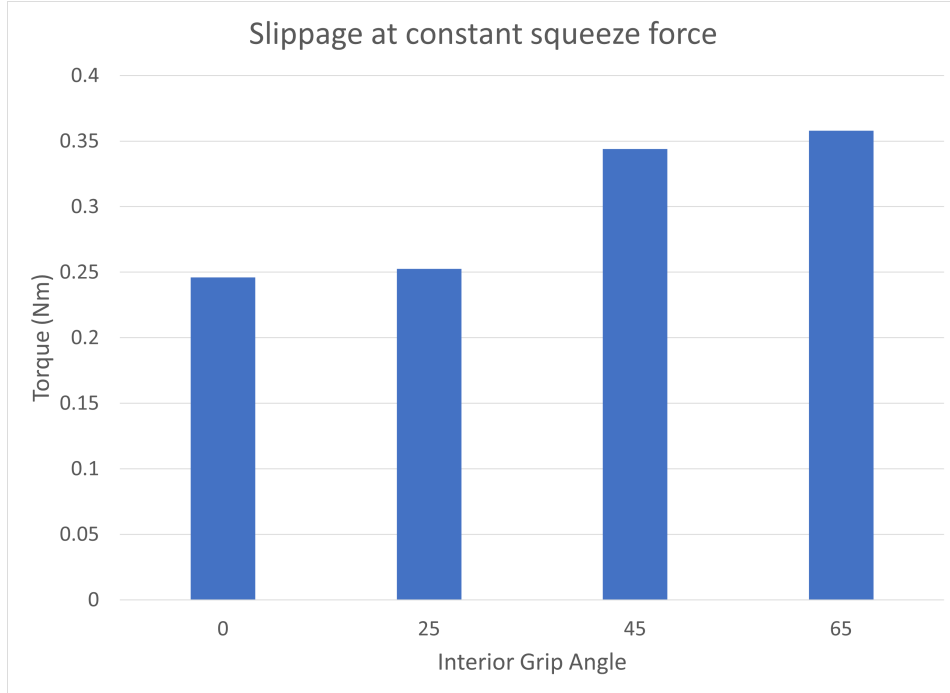


Figure 3.7: Figure showing the torques at slippage of the different interior grip angles.

### 3.3.2 Exterior Outer Diameter

The results (Table 3.1) of the outer diameter mechanical tests show nearly a 208% increase in the torque applied to the rotatable mock endoscope between the EndoGrip and the bare endoscope. This is very close to the theoretically calculated value of 254%. The difference can be accounted for in the twisting deformation of the rotatable mock endoscope when in contact with the hard 3D printed PLA device. This would result in less of an increase when the grip is applied.

Table 3.2: Results of the exterior outer diameter mechanical tests

Mass (kg)	EndoGrip Angle	Barehand Angle	$\sin(\text{EG angle})/\sin(\text{Bare angle})$
3.11	34.3	9.99	3.25
2.58	28.6	9.43	2.92
2.17	23.7	7.75	2.99
1.24	13.0	4.10	3.15

While the increased outer diameter increase the torque on the endoscope, the conservation of energy requires more distance to be turned compared to a bare endoscope.

Muscularly, this means that the stress is transferred from the wrist and hand to the arm and shoulder. Within the goal of improving the ergonomics of colonoscopies, shifting the stress from the smaller muscles and ligaments of the wrist and hand to the larger ones in the arm and shoulder.

### **3.4 Conclusions**

The results of the mechanical tests clearly show that both features intended to increase the mechanical advantage of the EndoGrip show statistically significant increases. However, while both features show an increase of mechanical advantage that should be helpful in reducing the stress and injury in physicians, they do not match the theoretical increases predicted by physical models. This is likely due to the lack of rigidity in both the mock endoscope and the EndoGrip device. As the end goal for the EndoGrip device is use in a clinical setting, a less rigid and more frictional material will be necessary. Therefore, further studies with more clinically relevant materials are necessary.

# Chapter 4

## EMG Experiments

### 4.1 Background

While the mechanical tests showed clear mechanical advantage when comparing the EndoGrip to the bare hand, the goal of the device is to reduce physician stress and injury. To do this, we used the American Conference of Government Industrial Hygienists' (ACGIH) standard Threshold Limit Value (TLV) curve as a measure of muscular fatigue. The ACGIH's TLV curve is commonly used as an academic method of measuring risk of muscle fatigue and risk of injury [5] [3].

This curve relies on measuring the muscle activation using a surface Electromyography machine (EMG). EMGs works on measuring the muscular depolarization of surface muscles, thereby measuring the frequency and amplitude of the muscular activation [2]. Surface EMG is able to do this by using highly conductive silver electrodes pressed tightly onto the skin as to be able to detect the changes in the surface muscles [2].

Ergonomic studies of colonoscopies are rare and mostly survey based [4], direct EMG measurements during colonoscopy are rare [1], and currently there are no studies examining devices to improve ergonomics in colonoscopies. However, there are many studies that examine the benefits of ergonomic devices on other activities [3]. These studies primarily use the TLV curve to quantify the Duty Cycle (DC) of the muscle and the % of the Maximum Voluntary Contraction (% MVC). This creates a curve that shows how often a muscle is activated on the x-axis compared to the strength of activation on the y-axis [3]. The ACGHI guidelines on TLV curves create a threshold of % MVC based on the DC, above which there is a high risk of injury [3]. The TLV data can then be plotted on an Fatigue Risk Value (FRV) which quantifies the distance between the

measured DC and % MVC and the injury threshold.

The purpose do the EndoGrip device is to reduce the muscular stress on the user by colonoscopy. Given the previously shown mechanical advantage (Section 3), we hypothesized that using gripping devices with greater mechanical advantage decreases the FRV on a set of mock colonoscopy activities.

## 4.2 Experimental Design

Being a pilot study, the experiment focused on the mechanics of one set of data from subject. The subject performed mock colonoscopy motions. The mock colonoscope motion involved using the same rotatable mock endoscope from section 3 (Figure 4.1). The EMG used to measure the muscle activity is a Tringo Lite system with two Tringo Duo sensors. The sensors were attached to the Abductor Pollicis Brevis (APB), First Dorsal Interosseous (FDI), and Flexor Carpi Radialis (FCR) (Figure 4.1). These muscles were chosen as the APB and FDI are both large surface muscles that are heavily involved in gripping while the FCR is the primary muscle used in torquing. The chosen muscles mirror the sections examined in the mechanical advantage study (Gripping - 3.2.1 and Torquing - 3.2.2).

The subject was then instructed to obtain Maximum Voluntary Contractions (MVCs) as a reference for the experimental data. The MVCs for the APB and FDI were obtained by having the subject exert maximum effort in gripping the EndoGrip for 5 seconds. The MVC for the FCR was obtained by having the subject place their right arm in a neutral position and having the subject exert their hand against a non-flexible exercise band for 5 seconds. All MVC tests were repeated 3 times with 2-minute break periods.

The experimental test was comprised of 5 second active and 5 second rest periods for a total of 4 minutes. The active periods were comprised of rotating the mock-rotatable endoscope to 35 degrees while during the rest periods the subject rested their hand on the EndoGrip neutrally.

All EMG data was collected at 2148 Hz and all data was analyzed using MATLAB code. First data was filtered through a bandpass filter at a range for 20 Hz to 400 Hz. The data was then rectified and moving 1 second windows were obtained to smooth out the data. The experimental data was then compared to the MVC data for the corresponding muscle, if the experimental data reached 5% of the MVC the muscle was



Figure 4.1: Rotatable mock endoscope

considered active. And the % MVC of the active data was obtained by gathering the average Muscle activation when the muscle is considered active.

### 4.3 Results and Discussion

The results of the analysis (Figure 4.2) show a general decrease in the FRV as the interior grip angle increases for all muscles. Notably in the APB and FCR muscles bare hand trial has a higher FRV than all the EndoGrip variants, but this is the opposite in the FDI where the bare hand has a much lower FRV than any of the EndoGrip variants.

The muscles are split up into two groups: Gripping Muscles (FDI and APB) and Torquing Muscles (FCR). Therefore, the results show a definite decrease with the EndoGrip in the FRV in the torquing muscles while showing conflicting results in the gripping muscles.

However, the data supports opposite trends in FRVs between the barehand and EndoGrip trials for the gripping muscles. The FRV seemed to increase in the FDI when using the EndoGrip and decrease in the APB when using the EndoGrip. The increase in



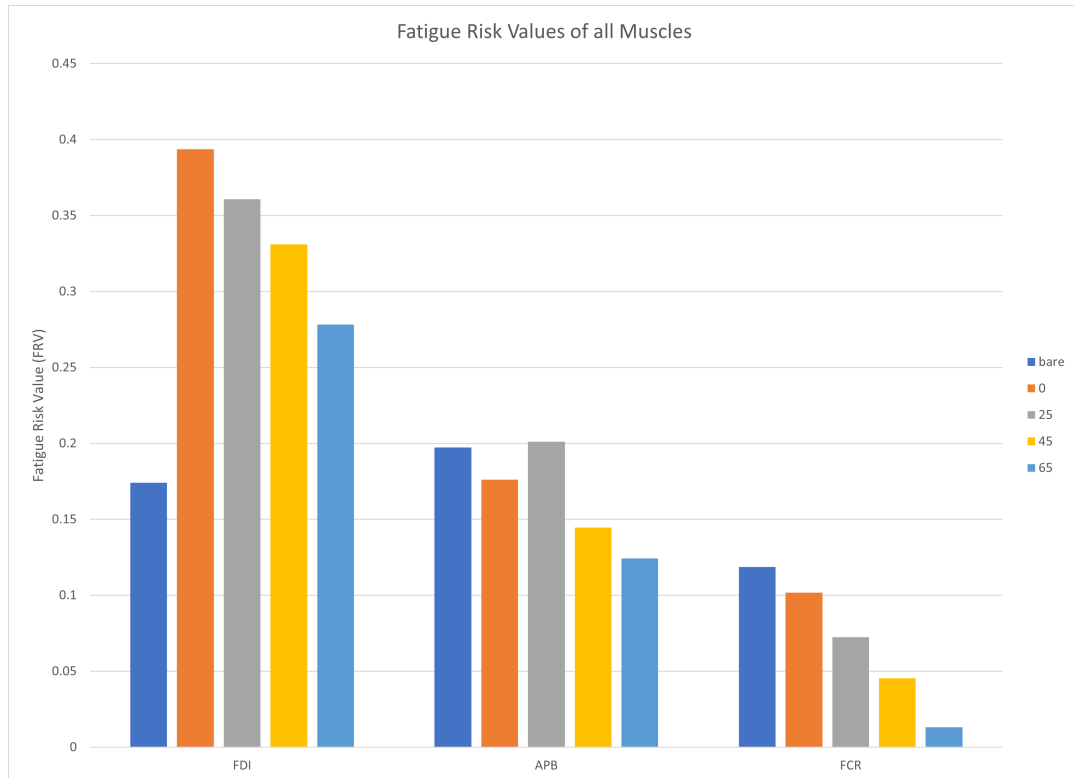


Figure 4.2: FRV's of the rotatable endoscope trials with the barehand and EndoGrips with varying interior grip angles. Different muscle groups shown First Dorsal Interoceous (FDI), Abductor Planar Brevis (APB), and Flexor Carpi Radialis (FCR).

the FDI's FRV may be due to the change in the coefficient of friction from the barehand to the EndoGrip. As stated before, the 3D printed PLA grips have a relatively low coefficient of friction with the endoscope (when compared to the bare hand). This has the opposite effect as the wedged grip shape of increasing the necessary clamping force to prevent the rotatable mock endoscope from slipping. While this theory may have been the cause of the inconsistency between the two gripping muscle groups, it is difficult to know without further testing on a much larger group of subjects.

The main results of this experiment exist in the trend between the EndoGrip interior grip angles. This trend confirms the mechanical tests of the previous section (Section 3). As the mechanical advantage of the grip increases as the interior grip angle increases. This results in less fatigue for the subject as the interior grip angle increases.

## 4.4 Conclusions

Overall, the results of the EMG study confirm that the mechanical advantages discussed in the previous section result in actual ergonomic benefits. Showing that an increased grip angle and larger grip diameter result in less wrist and hand stress. However, due to the single subject data set of the study it is difficult to make generalizations about the EndoGrip as a whole when compared to a bare hand. Both increasing the sample size and creating a more clinically (higher coefficient of friction) ready grip are both necessary next steps to take in showing clinical benefit of the EndoGrip Device.

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