# Redesigning the Endoscope With a Smaller, Lighter, and Ergonomic Wireless Controller

Industrial Engineering 170: Industrial Design and Human Factors Project

Team #1: Intestinnovations

Alyssa Nguyen, Ariel Qian, David Lu, Nikhil Simhambhatla, and Victor Cornejo

## Part I. Abstraction

### Purpose Driven Design

In the past few decades, endoscopes have greatly improved as a result of advancements in imaging and medical technologies, with newer flexible tubes, better suction channels, and more precise image guides. Nevertheless, there have not been parallel advancements in the design of the endoscope from the gastroenterologist's perspective. In fact, gastroenterologists and those who conduct endoscopies are at a particularly high risk of repetitive strain injuries due to the nonoptimal design of the endoscope, which requires gastroenterologists to hold their bodies in awkward positions when utilizing. To use, gastroenterologists must manipulate a complex system of dials and buttons with just their left hand while also pushing and pulling the insertion tube of the endoscope into the patient with their right hand. This series of movements places high strain on all upper body parts, but particularly on the gastroenterologist's hands, wrists, fingers, forearms, and shoulders due to the repeated motions and application of high force. As such, gastroenterologists face numerous injuries that require seeking treatment, needing surgeries, or retiring from medical practice entirely (Kamami & Kalwar, 2021). Our goal is to help gastroenterologists practice endoscopy safely and with minimal injury to themselves.

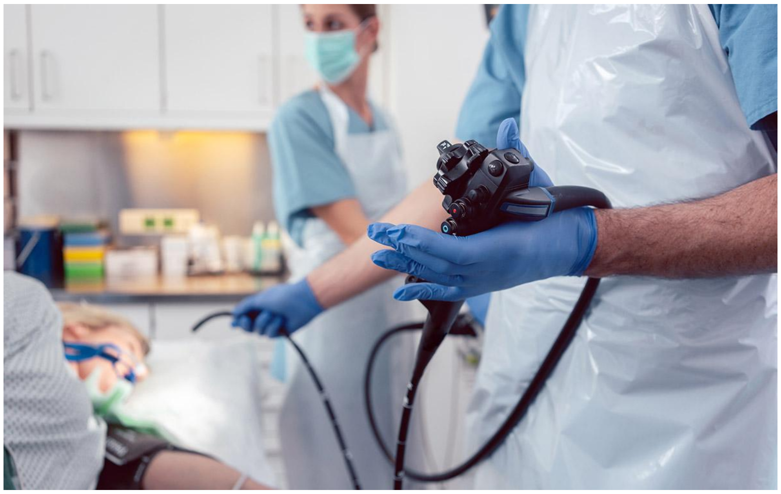
The following injuries are particularly common across gastroenterologists:

| | |
|---|---|
| Colonoscopist's Thumb | A wrist tendonitis at the first extensor compartment attributed to left thumb strain because of repeated turning of dials of the control section of the endoscope |
| Thumb Osteoarthritis | A relatively common condition (women more than men) that may be exacerbated by thumb abduction for turning of outer dial and pincer movements |
| Shoulder Injuries | Bursitis, impingement, frozen shoulder and rotator cuff issues caused |
| Biliary Endoscopist Knuckle | Injury to metacarpophalangeal joint from forceful pinch grip and advancement of stents and catheters. |
| Upper Extremity | Tendonitis, "tennis elbow," ulnar and radial nerve entrapment, carpal tunnel syndrome |
| Lumbosacral Strain | Caused by standing for long periods of time or lifting and moving of patients |

As can be seen, the majority of common injuries seen in gastroenterologists as a result from conducting endoscopies occurs in the hands, fingers, wrists, forearms, and shoulders. In fact, a study conducted on gastroenterology fellows by doctors at the John H. Stroger Jr. Hospital of Cook County revealed that the most common musculoskeletal injuries that result from practicing endoscopies occur in the right wrist (53% of injuries) and left thumb (42% of injuries) (Villa et al., 2019).

Furthermore, the current design of the endoscope features poor control ergonomics - as seen by the frequency of thumb osteoarthritis in women versus men, the size of the gastroenterologist's hand heavily influences the proficiency and fatigue associated with using the endoscope (Shergill, 2020). This, in turn, can affect the efficiency of the endoscopy conducted as fatigue can often lead to misdiagnosis or increased patient risk. As such, the need to provide a more ergonomic design of the endoscope control system for gastroenterologist usage is paramount to ensuring that gastroenterologists are able to safely practice endoscopy while minimizing hand injuries.

**Definition of the Task**



The job is called endoscopy which is defined to be "a procedure that uses an endoscope [the above device] to examine the inside of the body" (NCI). Even though there are multiple different endoscopes on the market, the most common ones used by most doctors are the classic mechanical endoscopes which look like the picture above. It exhibits various types of dangers to its users as mentioned earlier.

Hierarchical Relationships

Usually endoscopy requires four main tasks: (1) set up the endoscope, (2) prepare patients, (3) operate the endoscope as part of the procedure, and (4) end the operation and cleanup. Our group will focus mainly on the task "operate the endoscope." Operating the endoscope requires practitioners to perform many tasks. First, they must feed the insertion tube into the body via the mouth (this is an important step as the practitioners need great cautiousness in order not to hurt the patients). The endoscope usually contains a water/air button which is used to clear the pathway. Then, they manipulate the endoscope through the body through dialing control knobs and buttons (this task is achieved through using the left thumb to reach out to the knobs and buttons located on the controller held in the left hand and is also very important as it helps turn the insertion tube around after being inserted) and through using their right hand to continue feeding and guiding the insertion tube. Operating the endoscope usually lasts around 20 - 30 minutes, and during the operating process the practitioner has to hold both the endoscope and the insertion tube the entire time, which can contribute significantly to their injuries. The reason for operating the endoscope is to provide the practitioner the ability to see inside the gastrointestinal tract of the patient, helping with the diagnosing of disease and ailments. Further actions like biopsy can also be conducted through attachments on the device.

Information Flow

People who use endoscopists are usually professionals with certificates and medical degrees. Some examples include the following:

- Gastroenterologists use endoscopes to examine the inside of the digestive tract, including the esophagus, stomach, and intestines. Endoscopes can help diagnose conditions such as ulcers, tumors, and inflammatory bowel disease.
- Pulmonologists use endoscopes to examine the inside of the respiratory system, including the trachea and bronchi. Endoscopes can help diagnose conditions such as lung cancer and tuberculosis.
- Otolaryngologists use endoscopes to examine the inside of the nose, throat, and ears. Endoscopes can help diagnose conditions such as sinusitis, ear infections, and vocal cord disorders.

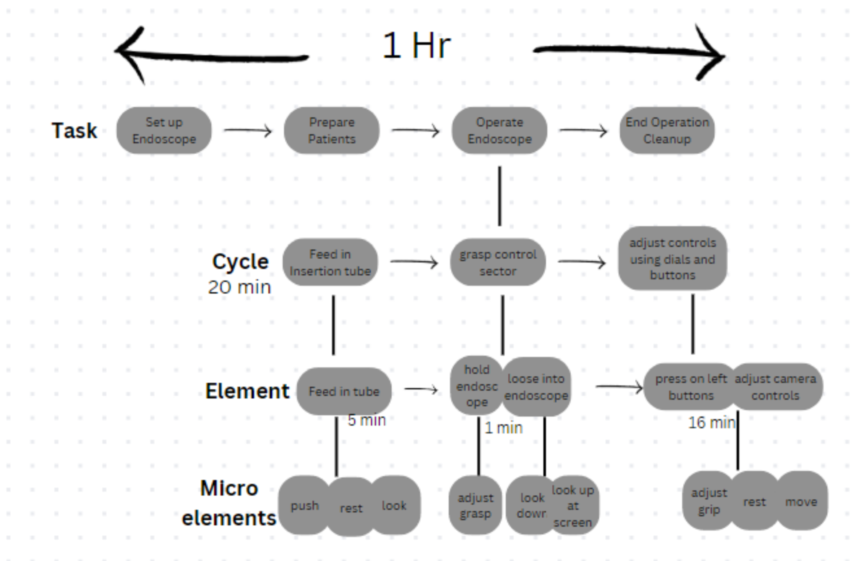
Practitioners' ages usually range from 20s - 60s and the average age is 42. However it is not uncommon for endoscopists to continue practicing well into their 60s and 70s (ETDS, 2022). 81.1% of gastroenterologists are men, however this number is rapidly decreasing as more women enter the field (Rotundo and Gaidos, 2022). Gastroenterologists perform endoscopy when patients experience symptoms like nausea, bleeding, and vomiting that represent issues to do with the gastrointestinal tract. If the cause can not be determined from outward inspection, they will choose to perform an endoscopy to gain an internal view of the situation. When performing an endoscopy, gastroenterologists will use the camera at the tip of the insertion tube to look around the tract. When they find what seems to be the cause of the issue, they will use that feedback to cease the operation. They may also use these visual cues to continue down the tract if they believe an issue lies further ahead. Biopsy might also be required from visual cues.

While indications and feedback are different depending on the types of endoscopy, endoscopists engage in multiple movements defined earlier with the following indications:

1) Hand movements (duration, power, frequency)
2) Upper body movements (bending over angle)
3) Finger movements (hyperflexion angle)
4) Neck Movements (duration, angle)

The feedback of the classic endoscope is mostly negative. The feedback gathered puts an emphasis on discomfort in the neck, shoulder, back and hand movements. Recent studies have reported prevalence of musculoskeletal pain or injuries from 29% to 89%. Moreover, studies have also shown that “frequent injuries or pain reported include low back pain (6% to 27%), thumb pain (5% to 19%), shoulder pain (9% to 32%), elbow pain (8% to 15%), hand pain (9% to 17%), neck pain (9% to 28%), and hand numbness (12%)” (Harvin, 2014). Another study has even shown that the effect is much more severe than most people thought. “In a survey of musculoskeletal complaints of Korean endoscopists, 89% reported musculoskeletal pain in at least 1 site with 47% reporting severe musculoskeletal pain”(Harvin, 2014). This feedback implies that musculoskeletal disorders are indeed very common among endoscopists.

Sequence & Timing




An endoscopy usually lasts for a whole hour with four main tasks. The most important task in operating the endoscope usually lasts for 20 minutes while the rest of the tasks each last for around 13.3 minutes. The sequence of the task begins with setting up the endoscope, which includes equipment cleaning and examinations to ensure that the endoscope and insertion tube are clean and safe to use for the patients to avoid infections and injuries. The next step is to prepare the patients, which involves turning the patients to the right angle (perpendicular to the bed) for smooth insertion to avoid injuries. Next is operating the endoscope which involves three subtasks. First, feed in the insertion tube (5minutes). Then grasp the control section (1min). Lastly, adjust using dials and buttons to operate the head of the insertion tube and use the right hand to guide (14min). Finally, the last task is cleanup, which focuses mainly on the cleaning of the insertion tube.

<u>Location & Environment</u>

Endoscopies are usually performed in procedure rooms. Procedure rooms should include at least the following: patient trolley, video monitor, piped oxygen supply, ancillary equipment, diathermy equipment, and computers used to generate endoscopy results. Moreover, the system should make sure that the temperature should be within the range of 68 to 73 fahrenheit degrees at any time and 30% - 60% relative humidity (Control Guidance, 2023). In addition to these physical conditions, some social environmental cues need to be considered. Patients are usually scared of endoscopy and patients' privacy is extremely important. Patients' cultural and religious beliefs need to be respected too (some cultures or religions may have specific beliefs or practices that may impact a person's willingness to undergo endoscopy or other medical procedures).

Assumptions & Constraints

The endoscopy is performed by a physician (gastroenterologist) in a procedure room at a hospital or medical facility with strict health and safety requirements as well as sufficient medical supplies. The endoscopy should be performed under 68 - 73 fahrenheit degrees with a humidity of around 30% - 60%. Privacy is a big factor to be implemented, posing a cost and space constraint. The new endoscope must be made from lightweight materials (plastic), should be no more expensive than the current mechanical endoscope, and must be compatible with medical systems.

**Task Collection Process**

We chose the following two Youtube videos that show how an endoscopy is performed as the basis for the task collection process: video #1 and video #2. In addition to these videos, we have recordings and pictures to reference from visiting the Human Factors & Ergonomics Program Laboratory at Richmond Field Station where we were able to handle an endoscope, replicating some of the actions seen in the videos to gain first-hand experience with the device. Visiting the lab also gave us the opportunity to talk to researchers and engineers knowledgeable on the ergonomics associated with the task in order to gain additional insight.

Since our focus is on upper extremities, we decided to use the Revised Strain Index (RSI) as the quantitative basis for our task collection. From our lab visit, we further learned that neck and back posture issues often stemmed from unergonomic controller issues, so we additionally used the REBA assessment to understand the full-body requirements of the current endoscope keeping in mind the ability to reduce some of these issues as a secondary consequence of fixing issues to do with the hands and wrists. Below are our RSI and REBA calculations for an average endoscopy, with the former being 18.39 suggesting high risk of MSD and the latter 7 suggesting medium risk that requires change soon. This was done through combining the insight we gained from the Youtube procedures in conjunction with our lab experience.

- RSI calculation

  IM = 3.71 as %MVC is 30

  EM = 7.60 as there are roughly 30 exertions per minute

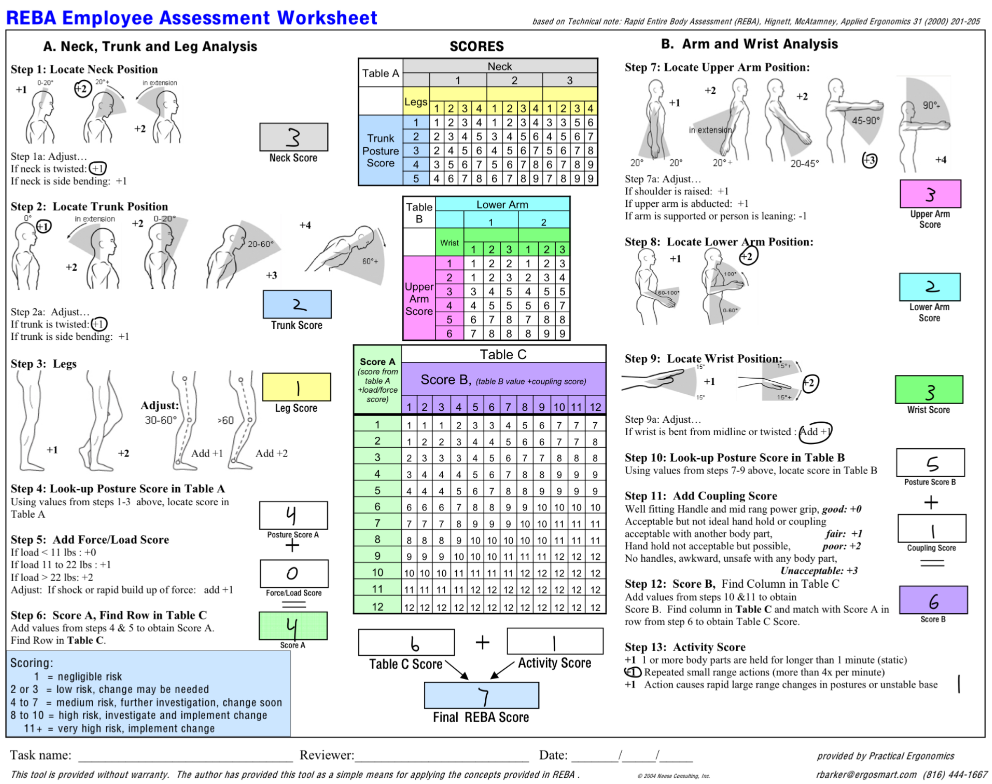
DM = 0.68 as duration per exertion in seconds is 0.75

PM = 1.37 as there is 30° wrist flexion

HM = 0.7 as  worst days feature 4 hours of endoscopy

IM*EM*DM*PM*HM = 18.39

- REBA



**REBA Employee Assessment Worksheet**

*based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205*

**A. Neck, Trunk and Leg Analysis**

**Step 1: Locate Neck Position**

+1 0-20° | +2 20°+ | +2 in extension

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score: 3

**Step 2: Locate Trunk Position**

+1 0° | +2 in extension | +2 0-20° | +3 20-60° | +4 60°+

Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score: 2

**Step 3: Legs**

+1 | +2 | Adjust: 30-60° Add +1 | >60 Add +2

Leg Score: 1

**Step 4: Look-up Posture Score in Table A**
Using values from steps 1-3 above, locate score in Table A

Posture Score A: 4

**Step 5: Add Force/Load Score**
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score: 0

**Step 6: Score A, Find Row in Table C**
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A: 4

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

**SCORES**

| Table A | Neck 1 | | | | Neck 2 | | | | Neck 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Legs | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Trunk Posture Score 1 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 3 | 3 | 5 | 6 |
| 2 | 2 | 3 | 4 | 5 | 3 | 4 | 5 | 6 | 4 | 5 | 6 | 7 |
| 3 | 2 | 4 | 5 | 6 | 4 | 5 | 6 | 7 | 5 | 6 | 7 | 8 |
| 4 | 3 | 5 | 6 | 7 | 5 | 6 | 7 | 8 | 6 | 7 | 8 | 9 |
| 5 | 4 | 6 | 7 | 8 | 6 | 7 | 8 | 9 | 7 | 8 | 9 | 9 |

| Table B | Lower Arm 1 | | | Lower Arm 2 | | |
|---|---|---|---|---|---|---|
| Wrist | 1 | 2 | 3 | 1 | 2 | 3 |
| Upper Arm Score 1 | 1 | 2 | 2 | 1 | 2 | 3 |
| 2 | 1 | 2 | 3 | 2 | 3 | 4 |
| 3 | 3 | 4 | 5 | 4 | 5 | 5 |
| 4 | 4 | 5 | 5 | 5 | 6 | 7 |
| 5 | 6 | 7 | 8 | 7 | 8 | 8 |
| 6 | 7 | 8 | 8 | 8 | 9 | 9 |

Table C

| Score A (score from table A +load/force score) | Score B, (table B value +coupling score) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 6 | 7 | 7 | 7 |
| 2 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 6 | 6 | 7 | 7 | 8 |
| 3 | 2 | 3 | 3 | 3 | 4 | 5 | 6 | 7 | 7 | 8 | 8 | 8 |
| 4 | 3 | 4 | 4 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 9 | 9 |
| 5 | 4 | 4 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 9 | 9 | 9 |
| 6 | 6 | 6 | 6 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 10 | 10 |
| 7 | 7 | 7 | 7 | 8 | 9 | 9 | 9 | 10 | 10 | 11 | 11 | 11 |
| 8 | 8 | 8 | 8 | 9 | 10 | 10 | 10 | 10 | 10 | 11 | 11 | 11 |
| 9 | 9 | 9 | 9 | 10 | 10 | 10 | 11 | 11 | 11 | 12 | 12 | 12 |
| 10 | 10 | 10 | 10 | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 12 |
| 11 | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

Table C Score: 6 + Activity Score: 1

Final REBA Score: 7

**B. Arm and Wrist Analysis**

**Step 7: Locate Upper Arm Position:**

+1 20° 20° | +2 in extension 20°+ | +2 20-45° | +3 45-90° | +4 90°+

Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 3

**Step 8: Locate Lower Arm Position:**

+1 60-100° | +2 100° 0-60°

Lower Arm Score: 2

**Step 9: Locate Wrist Position:**

+1 15° 15° | +2 15°+ 15°+

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Wrist Score: 3

**Step 10: Look-up Posture Score in Table B**
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 5

**Step 11: Add Coupling Score**
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score: 1

**Step 12: Score B,** Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B: 6

**Step 13: Activity Score**
**+1** 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
**+1** Action causes rapid large range changes in postures or unstable base

1

Task name: ______________ Reviewer: ______________ Date: ____/____/____

*This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA .*



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<u>Observations</u>

Throughout our general research observing various endoscopy tutorials in video and diagram form as well as our own experiences with the device, we did notice some additional patterns important for the redesign process. Firstly, the endoscope itself is the base hardware for the endoscopy. Attachments for a number of tasks, such as biopsy, form an additional connection to the controller that may limit movement and add hardware that needs to be managed with respect to carrying and placement. These peripherals add to the already problematic physical demands of the endoscope. Setups also modulate physical demands. For example, some people use monitors that ease neck flexion whereas others look into the scope bending their head downwards. Inconsistent resources result in differentiated experiences. Lastly with respect to physical demands, the bulky, heavy design of the current endoscope coupled with the fact that the controller is tethered to the insertube means that the gastroenterologist cannot operate the controller with their left hand separately from operating the insertion tube with their right hand, requiring convoluted body movement at times to avoid entanglement and to manage the tether. Cognitively speaking, gastroenterologists seem to operate the endoscope as if it were an extension of their hands. There seems to be no attention paid to operating the device.

<u>Retrospective and Prospective Task Assessment</u>

There exists research and experiential documentation regarding issues to do with the usability, ergonomics, and one-size-fits-all approach to the current endoscope. The current endoscope, while having gone through vast amounts of technological innovation with respect to its functionality, has not experienced updates regarding its controls and their layout in over five decades, ignorance contextualizing the immense musculoskeletal disorders seen by practitioners (Khanicheh and Shergill, 2019). This problem culminates in the one-size-fits-all approach to the controller, where female gastroenterologists have complained that the same equipment is offered to them, who on average have smaller hands and lower hand strength, as is offered to their male counterparts at the opposite end of the spectrum, requiring them to assume awkward controller positions and having diminished force generation abilities (Shergill, 2020). So, retrospective task assessment confirms that there are significant controller issues.

Regarding prospective task assessment from the point of view of changing the task at hand potential solutions to come in the form of new technology. Medical robotics, for example the MONARCH Robotic Flexible Endoscopy Platform, features the potential to take out the need for physical exertion. However, new technology will bring in its own suit of problems as no product is correct the first time around, posing an issue in a medical context where lives are at stake. Furthermore, new systems require reteaching and relearning on the part of gastroenterologists, impacting their output and quality of work. There is, however, potential to deploy mature technology developed within this five decade gap that keeps the fundamentals of the current design but is able to fix some of the human factor issues currently posed.

<u>Surveys & Interviews</u>

The following set of survey questions combine to form both a structured and unstructured interview, with each bullet often requiring a definitive answer with room for expansion as the respondent sees fit. The fundamental group we are targeting with the survey are gastroenterologists that typically perform upper GI endoscopies. We will survey across all age groups. We also want to target all sexes in order to get a body of responses reflective of the group at large. The questions are as follows:

- In which regions of your body do you feel the pain as a result of using an endoscope?
- Do you require any rest or medical care as a result of using the current endoscope?
- Do you have an easy time using the controller of the current endoscope? If not, in what ways do you struggle in activating the controls?
- Is the weight of the current endoscope an issue for you? If so, what sort of weight adjustments would you like to see?
- Do you have issues gripping the controller of the current endoscope? If so, in what ways is gripping the controller an issue?
- Do you have issues operating the insertion tube? If so, in what ways do you struggle?
- Do you find yourself needing to contort your body in ways that feel awkward while using the current endoscope? If so, what causes you to go into those awkward positions?
- Does the current endoscope allow you to sufficiently explore the gastrointestinal tract? Are there certain actions that require complex sequences of current controls that you feel can be implemented as a standalone control?
- Would you like more recent technology incorporated into a new endoscope? If so, what types of technology do you see as being helpful? If not, what about new technology makes you hesitant?

<u>Data Recording/Quantification</u>

Talking with individuals privy to the endoscopy practice, including gastroenterologists, technicians, and various individuals in research capacities, the following is insight we were able to gain:

- Regarding Pain
  - Most common regions of pain were as follows: thumb, wrist, fingers, neck, and back. Hand issues came from problems with the controller discussed below as well as the insertion tube. The insertion tube is slippery from lubricant and bodily fluid and requires a pinch grip while operating. Many say that there is no way to

avoid this, at least for now, as solutions take away control capabilities. Sitting down is not an option as this limits shoulder use operating the insertion tube even though lower body pain from standing is an issue.

- Regarding weight
  - Most respondents would like a lighter controller, especially considering the fact that peripherals are attached to it which can quickly become burdensome. On some days, respondents discussed feeling pain akin to having completed a tough work-out. There are no structural supports to help ease weight issues, nor is it practical to do as there are too many motions for a static support to be useful without getting in the way.
- Regarding gripping
  - Those with smaller hands describe the endoscope as difficult to grip. All employed a powergrip, but the need to access controls compromises this grip. Many lean the controller on the body for additional support or have to use their right hand to continually adjust the controller in their left hand. This overall results in a weak grip that turns into a pinch grip that constantly needs readjusting
- Regarding contortion of the body
  - Operating the insertion tube results in unavoidable contortion of the body. However, the fact that the controller is connected to the insertion tube results in a loss of flexibility that could ease some of the extreme angles experienced by practitioners as they try not to tangle to cord, for example.

We can summarize the above into a list of physical demands. The weight and size of the current controller pose major issues to practitioners. The weight is too heavy for the frequency at which endoscopy is operated and the controller is too bulky to effectively hold and operate. Furthermore, the connection between the controller and insertion tube adds a layer of operational friction. Interestingly, standing seems to pose strain but there is no will for a solution as it compromises one's ability to operate. Same with the insertion tube and the grip and environmental conditions involved. These issues can potentially be solved with just controller fixes due to added flexibility. The weight of the controller can be measured with a scale and can be compared with percentile calculations to do with carrying weight. Joint and posture angles with respect to the wrist and thumb can be measured through recordings and tools like Kinovea, after which we can compare these measures with neutral position requirements and see the deviation. We can measure grip strength and exertion required in operating the controller using the Borg-CR 10 scale as the convolution involved means that more empirical methods may not accurately reflect reality.

Regarding cognitive demands, the one part of the endoscope that doctors enjoy is the fact that it is not cognitively demanding. The knobs to turn the head of the insertion tube and the control buttons for camera and biopsy functions, for example, along with the locking controls are easy to learn and muscle memory is quickly acquired. In fact, many worry that changes in the design would result in losing this intuitive nature resulting in cognitive demands to do with the device on top of those required for the medical procedure.

## Functional Requirements and Design Parameters

Gastroenterology is a male dominated field. However, the rate at which women are entering the field is rapidly increasing (Rotundo and Gaidos, 2022). So as to not stunt the increasingly diversity trends, and to in general not to limit individuals, our design must support the 5th percentile of female population to 95th percentile of the male population regarding hand size and carrying weight. We define hand-size as the distance from the base of the palm to the tip of the middle finger. Carrying weight is defined as the amount of weight an individual can carry with their arms standing upright. Because gastroenterologists value the ease of operating the current endoscope from a muscle memory point of view, changes to the revised endoscope should maintain the same set of controls without major changes in the tactile phenomena for each so that skills are transferable. Furthermore, with respect to grip, the current controller is meant to be held with a power grip but its size prevents many from doing so. Ensuring a new controller design that maintains a power grip and such that one's fingers are curved toward their palm to maintain a neutral hand and wrist joint poster is key.

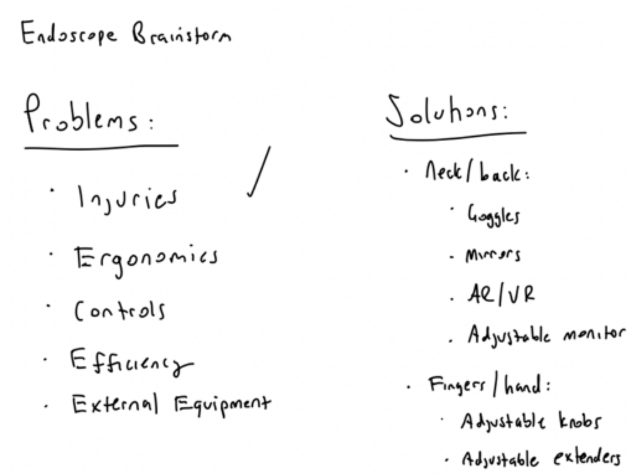
## Success Criteria

A successful redesign incorporates fixes to the problems discussed above while maintaining the good of the current design. Our success criteria involves reducing the RSI to do with operating the controller to be < 6.1 so that the risk of musculoskeletal disorder is low. Ideally, the REBA score is reduced as much as possible, preferably to be < 3 so that risk of full-body musculoskeletal disorder is low. However, this might not be possible due to the physical demands of the taks, but decoupling the controller and insertion tube is a good first start allowing for more flexibility. Furthermore, the weight of the controller must be reduced to be compatible with the 5th percentile of the female population with respect to carrying weight. Wrist position should be kept neutral as one holds the controller (no flexion or extension) and fingers, especially the thumb, should be neutral too (curved slightly towards the palm).

**Part II. Conceptualization**

Possible Solutions

The most common problems associated with the current design of the endoscope, we found that the colonoscopist's thumb, endoscopist's neck, and shoulder injuries were the most common ones. Based on these problems, we set ourselves to find a new design in our endoscope that would reduce the injury rate while maximizing efficiency.



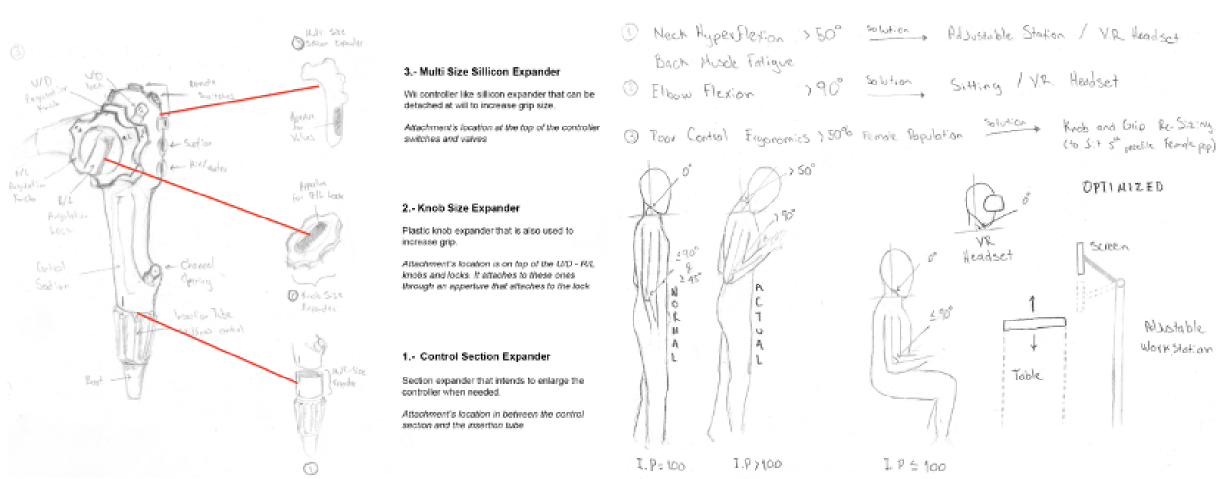

Hand injuries are the most prevalent ones, and that is because of the long periods that endoscopists have to undergo, the heavy weight of the controller, the stiffness of the knobs, and the poor ergonomic design around them. We focused on conceptualizing a design that would reduce the injuries of most endoscopists; therefore, we decided to re-size our endoscope controller to fit the 95th percentile of the female population. This is because women have smaller grips than men, and the standard controller is more significant than the grip of the average man.

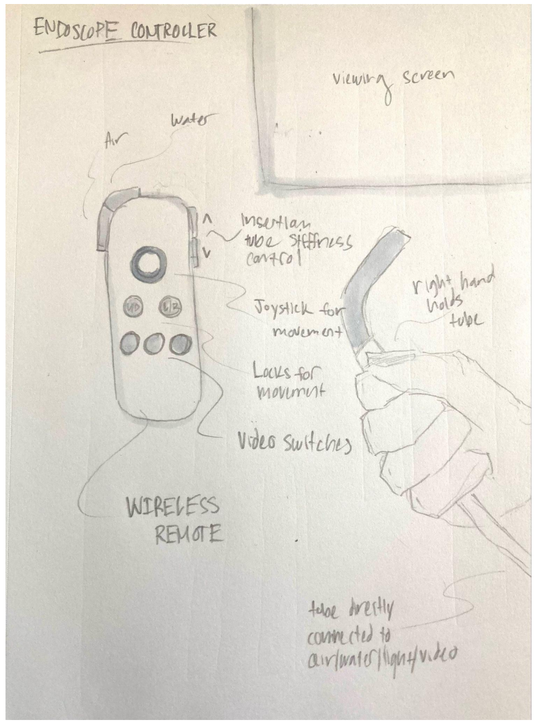
As for the neck and back injuries, these are associated with the posture that endoscopists have to recur when working in settings where there is no screen, and they have to rely on a visor on the endoscope controller. This endoscope design is more austere, as the addition of screens and displays can heavily change the affordability of the controller. However, the controller's price should have been considered during our design process.

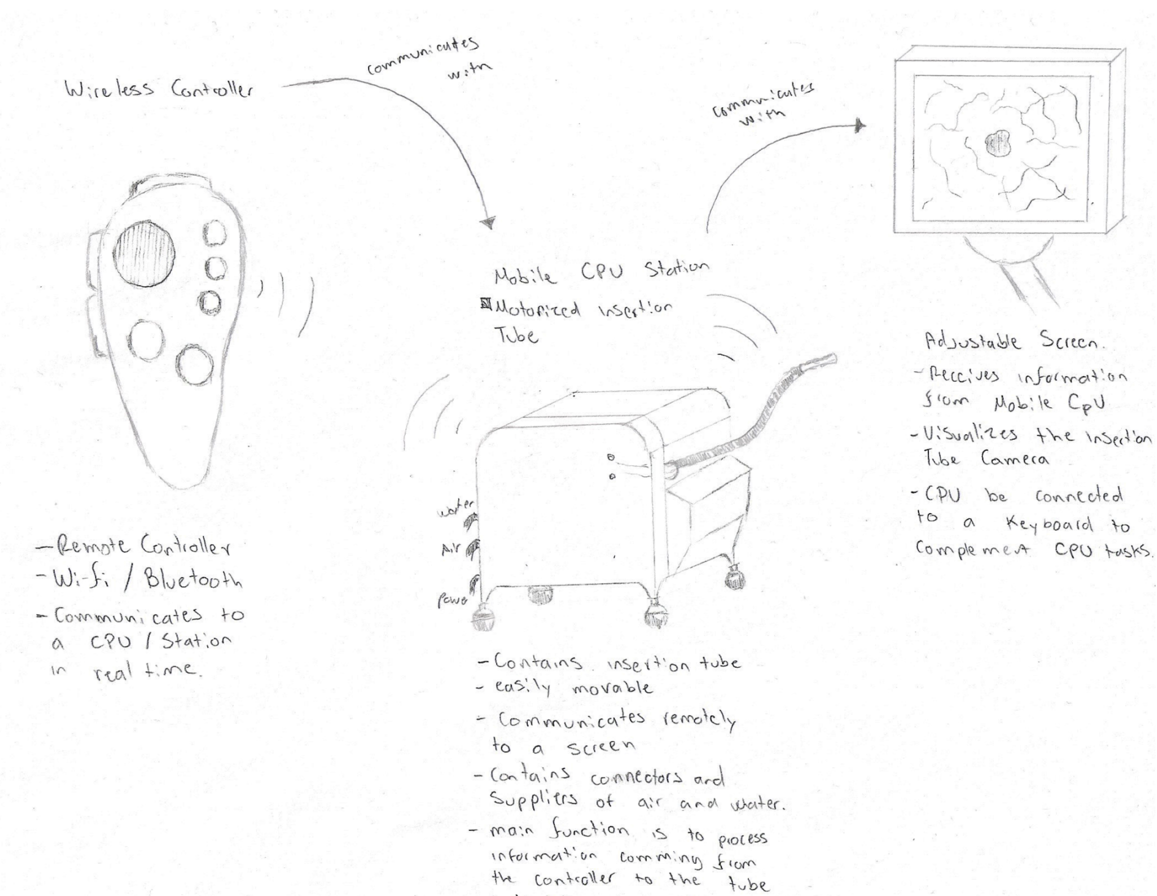
We then imagined an endoscope controller that would be small but potentially increase height with the help of section and knob expanders. We thought that adding silicon expanders that wrapped around the knobs would compensate for the cases in which the grip was too small. And the same concept was applied to the control buttons and the section expander, except that the section expander would be a stiff insert that would be used only when the endoscopist's reach is far beyond the knob section.

For the back and neck issues, we conceptualized a screen that would never have to leave the endoscopist's gaze, and we embodied such an idea in a VR headset. We intended this VR application to reduce the neck injuries associated with the endoscopist looking at the screen and the possibility of doing the procedure while sitting comfortably in a chair, reducing internal disk pressure. Immediately after our first design, we realized the way in which we conceptualized the controller was almost entirely wrong. That is so because the controller remained mechanical, which would make the knobs remain stiff and hard to maneuver, allowing for injuries after long periods. And the VR headset could turn out to be more of a complication in a critical scenario and most likely useful only in a training scenario.

Schematics and Sketches




ENDOSCOPE CONTROLLER
Viewing screen
Air
Water
Insertion tube stiffness control
right hand holds tube
Joystick for movement
Locks for movement
Video switches
WIRELESS REMOTE
tube directly connected to air/water/light/video


Wireless Controller
communicates with
communicates with
Mobile CPU Station
Motorized Insertion Tube
water
Air
Power
Adjustable Screen.
- Receives information from Mobile CPU
- Visualizes the insertion Tube Camera
- CPU be connected to a Keyboard to Complement CPU tasks.
- Remote Controller
- Wi-fi / Bluetooth
- Communicates to a CPU / Station in real time.
- Contains insertion tube
- easily movable
- Communicates remotely to a screen
- Contains connectors and Suppliers of air and water.
- main function is to process information comming from the controller to the tube

## Iterative Approach

We started off with a brainstorming session followed by a couple of sketches of possible designs based off of the research we did on different injuries endoscopists face and our knowledge of the procedure. But the biggest evolution in our design approach happened after visiting the lab. We did an overhaul of our previous design since we learned a lot of new things about the controller and how we might improve upon it. It was at this point where we decided to switch over to a redesign of the controller, and create a wireless and more easy to use controller design. Then we created different iterations of controllers via brainstorm and prototyping. By using clay as our material we were able to create and test multiple different controller shapes and see which one had optimal grip and button locations. There were a few iterations based off of the original wireless controller sketch. The main goal then was just going for simplicity, but after testing the new controller we aimed to find a more comfortable grip for multiple hand sizes rather than just the flat remote design. Similarly with the buttons, we looked for optimal positioning and changed the location of them to suit where the hand would find it easy to press. We based the shape of these iterations off of existing controllers meant exclusively for one handed use, and fit them to match what buttons we needed for our design.

## Design Selection Process

Initially, we had two pretty different ideas to reduce injuries. One aimed to reduce neck and back stress by having a VR headset, the other aimed to reduce arm and thumb stress by decreasing the size of the controller. But after visiting the lab it became clear that we should be focusing on the latter issue since we were informed that there isn't too much difference between looking at a screen and looking at through a headset. It was then a matter of figuring out how to reduce hand and thumb stress with the controller. It occurred to us that we could create a wireless controller instead of the mechanical one currently in production. This would reduce repeated hyperflexion and hyperextension of the thumb as well as allow a neutral hand and arm position leading to a firm power grip. This is an optimal holding position to prevent injuries as well as avoid awkward postures. When we visited the lab there were multiple awkward positions and difficulties in operating the controller especially for those of us with smaller hands.

We circled back to our functional requirements and success criteria and reevaluated them for our new design that would primarily focus on the controller. We continued to keep our design in mind for the 5th percentile of the female population to the 95th percentile of the male population with respect to controller dimensions (hand-size). But instead of our original design which was essentially a smaller version that was more suited for users with small hands, we decided that we could make even more improvements to it. Our success criteria became for the hand to remain in a power grip, to keep the revised strain index $> 0$ and $< 6.1$, and to reduce the REBA score to under 7. It did occur that doing an overhaul of the original controller could pose a possible barrier to doctors that already use the controller, so we kept in mind ways to replicate the mechanical sensations that the doctor would feel while using the controller. Adding haptic feedback would accomplish this for us, as many modern controllers use it to send feedback to the user.

The last part of our process involved discussion on button placements and grip type. Originally the new controller was a simple remote with a joystick and multiple buttons on the surface, but it wasn't a very comfortable grip for those of us with larger hands. By this point we had fulfilled our functional requirements and success criteria, but we still wanted to create a grip that would fit nicely in different hand sizes, and button placements that would be more intuitive to press. Instead of a flat remote we decided on one modeled after modern day game controllers since these controllers involve a lot of joystick movement and different button controls. Then we decided to put the air and water buttons on the back since it's a similar placement to the original controller, and easy to reach without needing to move the thumb. Top buttons were placed in accordance to where the thumb could naturally move on the remote, and the stiffness control adjustment has been altered to be similar to volume buttons that increase or lower the stiffness. This design fit comfortably in the hands of users with large hands and small hands, and didn't require any awkward postures or uncomfortable movement of the thumb when testing.

## **Part III: Realization**

### Production Process

Evaluation Approach

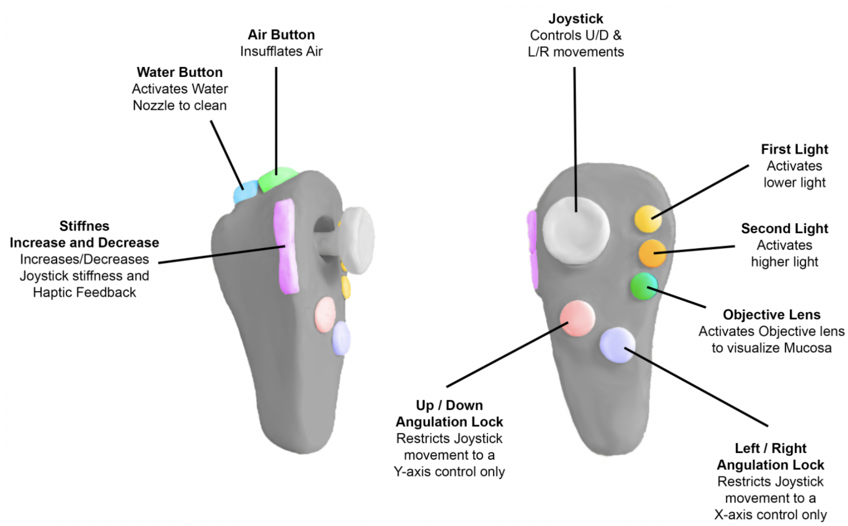
We will evaluate our design on the basis of a learnability and memorability as well as a set of objective and subjective measurements that test whether we have met our success criteria, guiding our future iterations.

Our design has all and only the inputs of the classic endoscope. There is no need for new control instructions if the user knows how to use the classic design, requiring new instructions only to do with the position of the new controls and connecting the wireless controller with the new processor box. Instead of knob-based movement controls, there is a joystick, which is the only operational input difference, but the tactile intuition is the same in that both involve swiping with your thumb. The locks are also different in that they have switched from switches and knobs to buttons. However, we believe this makes them easier to access as locking is switching from one binary event to another, so there is no need for rotational movement. We believe learning this new layout will be easy based on the fact that it is based on gaming controllers that people already use effectively. This ensures that the lack of cognitive demands present in the old endoscope remains a feature of the new endoscope.

A small study to test the cognitive and physical demands of our prototype involves randomly sampling a set of gastroenterologists and have them simulate a day in their life on a dummy patient, going through the series of procedures that they commonly perform.

In terms of physical measurements, we can do the following to analyze physical demands. We can measure strain using the Revised Strain Index across a variety of physicians as they use the new device, measure wrist and thumb extension and flexion through recordings by using tools like Kinovea, complete a REBA assessment to see if there are posture improvements by separating the controller from the insertion tube, and we can determine if fingers are curved to the palm in a powergrip-like position for joint neutrality and optimal grasp.

Cognitive demands can be done through surveys. To reiterate, the goal is for the new design to allow for muscle memory, and this involves proper feedback that queues the next action. Button placement and haptic feedback can be fine-tuned for ergonomics and memorability by asking practitioners for their opinion on the ease of use of the device as well as the correctness of input and feedback.




<u>Outcomes</u>

With our final design we are expecting our users to experience fewer MSDs especially hands and wrist pain due to hyperflexion and hyperextension. Moreover, our design should be able to reduce the REBA score to be under 7 in order for endoscopy to be sustainable. In addition, the Revised Strain Index should be smaller than 6.1 and greater than 0. Lastly, our design should be able to cover 5th percentile female and 95th percentile male in regard to hand sizes. Indeed, our design is able to achieve all of the previous expected outcomes. By changing the classic mechanical design of the endoscope to incorporate a detached electrical controller, we can mitigate the strain from repetitive turning of the mechanical dial by utilizing a joystick that has less resistance and more variability in action. Additionally, the shape of the controller is smaller and suitable for all hand sizes. The controller can also come in different sizes to incorporate a range of hands as the fundamental design scales. The main limitation is that our design might give different responses when the endoscope hits something inside the body and in order to fix this issue we will need more responses and help from doctors and we will then further revise our product based on their responses. The lack of real feedback is a major limitation until it can be calibrated as seen fit by gastroenterologists.

**Part IV: Reflection**

Redesigning the endoscope was quite a broad topic - having identified so many ergonomic issues with the endoscope, from the control section to the video interface, we struggled in the beginning to really narrow down our focus point and prioritize what was most pressing in terms of unergonomic design. Originally, we identified neck strain as the most serious issue that needed to be addressed, but as we referenced additional readings and journals as well as performed a visit to the lab, we realized that more injuries occurred in the hands, wrists, and fingers than those in the neck, and that these injuries not only happened more frequently, but also impacted gastroenterologists the most in terms of permanency and mobility. Once we were able to identify our main issue to address, the conceptualization process became a lot easier because we had a tangible problem to work towards.

Perhaps the most rewarding part of the entire design process was the prototyping portion - we went through a few sketches during conceptualization on how we wanted the new control section to look like, but actually building the physical prototype itself and then being able to test it in person was an incredible feeling. Being able to see something that was simply an idea become a physical item really emphasized the amount of work and time we had placed into this design project. Additionally, the team collaboration was also incredibly rewarding - having the group gather weekly to talk was crucial in the design process because with every discussion, each of us contributed something that made the design and thought processes better and better. Each iteration of the concept sketches came from collaborative thinking, and it feels incredible to compare our first ideas with our final prototype and realize how much our group has achieved by working together.

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