Assessment of Endoscope Reprocessing in an Urban Pittsburgh Hospital Using Borescope Examinations and Microbial Cultures

by

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Abstract

Flexible endoscopes are highly versatile and useful medical instruments, and their proper reprocessing is critical to patient health and safety. The value of routine visual inspections and surveillance of endoscopes in an urban hospital setting was assessed by performing borescope examinations and microbial cultures on respiratory, gastro-intestinal, and urological endoscopes. Only gram-positive colonies were identified in endoscopes that had microbial growth. Borescope examinations revealed multiple abnormalities and damage including channel shredding, filamentous debris, water retention, discoloration, dents, and red particles. The red particles found in and outside of the distal end of bronchoscopes were caused by tip protectors used in the hospital. The use of that type of tip protector was discontinued in the hospital based on this study's findings. Overall, borescope examination and microbial culturing used routinely as part of the reprocessing procedure is a highly effective way to identify endoscopes with damage, abnormalities, or harmful microbial growth that poses a risk to patient safety and public health.

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Preface

The author would like to acknowledge the Infection Prevention team, especially Taylor Keck, Heather Dixon, and Dr. Mohamed Yassin, for their support and mentorship. Also, the team in Central Sterile Processing for their support, interest, and willingness to assist in this project.

1.0 Introduction

Flexible endoscopes are complex and highly effective medical devices used for minimally invasive diagnostics, surgery, and other medical procedures (De Groen, 2017). However, their complex design, high cost, and narrow channels all pose challenges for proper reprocessing. The effectiveness of reprocessing procedures and upkeep of endoscopes has been a highly debated, and extensively studied, topic in recent years (Ofstead et al., 2020).

Endoscopes that are not reprocessed effectively pose a risk of transmission of pathogens to patients (Muscarella, 2014). Internal channel damage in endoscopes can protect biofilms from high-level disinfection, further increasing the risk of patient-to-patient transmission of pathogens (Primo et al., 2021). The ramifications of improperly reprocessed and contaminated endoscopes is exemplified by outbreaks of *Pseudomonas aeruginosa*, carbapenem-resistant *Enterobacteriaceae*, and others that resulted not only in morbidity associated with transmission, but also in the death of several patients (Chang et al., 2013; DiazGranados et al., 2009; Epstein et al., 2014; Shimono et al., 2008; Srinivasan et al., 2003). Due to these challenges and risks to patients, infection prevention personnel, along with reprocessing technicians, in hospitals are tasked with continual assessment of the hospital's endoscopes, as well as implementation of the most up-to-date endoscope reprocessing practices. Due to the implications to patient safety, this study aimed to reduce the risk of infection from improperly reprocessed endoscopes in this hospital by identifying damaged and contaminated endoscopes through borescope examinations and microbial cultures.

1.1 High-Level Disinfection & Sterilization of Endoscopes

The type of an endoscope, and what it is used for, determines whether it will undergo high-level disinfection or sterilization (Kaplan, 1968). The Spaulding Classification system serves as a basis for determining the classification (critical, semi-critical, and non-critical) of medical devices and their associated level of reprocessing (sterilization, high-level disinfection, or low-level disinfection) (*Table 3.3.3, Spaulding Classification of Equipment Decontamination*, 2018). Flexible endoscopes are listed as semi-critical devices because they have contact with mucous membranes and thus should undergo high-level disinfection. Critical instruments that enter a sterile area of the body require sterilization. In this study, gastro-intestinal endoscopes (including gastroscopes, video duodenoscopes, and colonoscopes), respiratory (bronchoscopes), and urological endoscopes (cystoscopes and ureteroscopes) are evaluated. The hospital study location used high-level disinfection to reprocess the gastro-intestinal endoscopes and bronchoscopes, and vaporized hydrogen peroxide sterilization for urological scopes.

While both processes have commonalities, high-level disinfection and sterilization have important distinctions. Sterilization kills all life forms, including all spores and in general requires more time than high-level disinfection (Miner, 2013). Successful high-level disinfection will kill all bacteria, viruses, fungi, and mycobacteria but can leave behind small numbers of bacterial spores (Rutala, n.d.).

1.1.1 Reprocessing Procedures

Endoscope reprocessing begins at the patient bedside after the procedure is completed. The pre-cleaning phase involves wiping down the outside of the endoscope and flushes the channels

with a cleaning solution and is performed by a nurse or trained reprocessing technician (Lee & Park, 2013). This phase of cleaning removes a significant portion of the soil and bioburden produced by the procedure and must be done immediately post-procedure to keep the soil from drying and adhering to the channels. Once the endoscope has undergone pre-cleaning, it is transported to the reprocessing area of the hospital or clinic for the cleaning phase, which is carried out by a trained technician. A leak test is performed to ensure the endoscope is not damaged or compromised. Once passing the leak test, the endoscope is submerged in cleaning solution and scrubbed and brushed thoroughly. From there, the endoscope can be transported to an automated endoscope reprocessor (AER) which performs the high-level disinfection. The AER pumps the high-level disinfectant through the channels of the endoscope as well as performs a rinsing and drying cycle. Once the AER has completed its cycle, the endoscope is ready to be hung in a special endoscope cabinet to dry with a tip protector placed on the distal end of the endoscope to protect against scratches or other damage. Tip protectors vary in size and material, such as plastic or Styrofoam, and are made by several different companies. The large number of steps in the procedure for reprocessing, inadequate training (which leads to missed steps), staffing, and time between procedures can all contribute to inadequate reprocessing and has been reported in other studies (Ofstead et al., 2020).

1.2 Borescope Utilization & Importance

Numerous studies have cited the importance of using borescopes to examine endoscopes. Borescopes are small devices equipped with a camera and light on the distal end and used to visually inspect medical instruments. However, the frequency of use of borescopes is determined

by the hospital or endoscopy clinic, and is affected by staffing, scope inventory, frequency of use, as well as other factors. A study that used a borescope in addition to microbial culture and adenosine tri-phosphate (ATP) testing discovered that simethicone used during procedures by surgeons to reduce gas was still present in endoscopes after reprocessing (Ofstead et al., 2016). In another study done by Ofstead & Hopkins (2020) that explored the values of borescopes in detecting damage, abnormalities, and retained materials, the authors identified the necessity of collaboration with key partners (such as reprocessing technicians, infection control and prevention personnel, and endoscopists) within a hospital or clinic to assess how often borescope examinations should, and plausibly could, be done.

1.3 Study Goals

This study was performed at an urban hospital in Pittsburgh, PA. The objectives of this study were to use borescope examinations and microbial cultures to assess the current state of the hospital's endoscopes, as well as the effectiveness of the hospital's reprocessing procedures. Bronchoscopes, gastro-intestinal, and urological endoscopes that were in use by the hospital were assessed.

2.0 Methods

A total of 42 endoscopes were cultured, and 36 endoscopes underwent a borescope examination. The cultures and borescope exams were completed on separate occasions to ensure accuracy of results. The endoscopes were separated into three groups, gastrointestinal (GI) endoscopes, bronchoscopes, and urological endoscopes (flexible cystoscopes and ureteroscopes).

Investigators were provided with endoscopes by personnel in the sterile processing department for examination. The type of endoscopes examined or cultured were based on which endoscopes were available at the time. Investigators ensured that the number of endoscopes examined at one time would not interfere with the hospital staff's time and availability to reprocess the endoscopes prior to being needed for a patient procedure.

2.1 Culturing

Culture procedure steps were followed as outlined in the hospital's standard operating procedures from their Division of Microbiology and Infection Control. A total of 42 endoscopes were cultured, with 14 being bronchoscopes, 18 gastro-intestinal endoscopes, and 10 urological endoscopes.

2.1.1 Collection

All endoscopes were cultured using the flush-brush-flush method (*Duodenoscope Surveillance Sampling & Culturing*, 2018). Approximately 30mL of sterile water was flushed through the endoscope's insertion tube at the proximal end while holding the endoscope vertically. The sterile water was deposited into a sterile screw-cap container. Next, a sterile endoscope channel cleaning brush was inserted at the proximal end and moved antegrade towards the distal end of the endoscope, scrubbing vigorously. Once the tip of the brush passed through the distal end, the brush was cut using sterile scissors into the sterile screw-cap container with the original 30mL of sterile water. Finally, an additional 30mL of sterile water was flushed through the flexible cable and deposited into the original sterile screw-top container. Every endoscope was marked for reprocessing after being cultured.

2.1.2 Processing and Incubation

The screw-top container containing the flushed water and brush tip was vortexed for approximately 15-20 seconds. Then, the vortexed water was poured into a 0.45 μm Nalgene™ Analytical Filter where the water was suctioned through the filter. The brush tip was left in the original screw-top collection container. The membrane was transferred using sterile forceps onto a blood agar plate where it was incubated at 37°C for 48 hours (Figure 9). All culture results were read and reported by a hospital microbiologist, who also performed Gram staining on any colonies seen.

2.2 Borescope Examination

A total of 36 endoscopes underwent a borescope examination with 13 being gastro-intestinal endoscopes, 12 being bronchoscopes, and 11 being urological endoscopes. A Steris IMS VerifEye® 1.9-meter borescope (Figure 8A) with a 1.6mm diameter was used to perform borescope examinations. A Microsoft® Surface Go tablet (Figure 8B) was connected to the VerifEye® borescope to project the live-stream video feed. The borescope examination was done in an antegrade and retrograde approach by feeding the borescope through the distal end of the endoscope up to the channel tip. All significant findings (i.e., channel shredding, filamentous debris, water retention, etc.) were recorded and documented through photographs. After borescope examination, each endoscope was marked for reprocessing prior to being used on a patient. The borescope was wiped between uses using a Clorox® Healthcare Bleach Germicidal wipe. Figure 8 illustrates the set-up of the VerifEye® borescope. Endoscopes that had evidence of severe damage or unknown substances were marked and the appropriate personnel from the hospital's sterile processing center were informed so that the scope could be sent out for repair.

3.0 Results

3.1 Cultures

A total of 42 endoscopes were cultured. Of the 42 endoscopes cultured, 14 were bronchoscopes, 18 were gastro-intestinal endoscopes, and 10 were urological endoscopes (either flexible cystoscopes or flexible ureteroscopes). Culture results were read and interpreted by a hospital microbiologist. Colony forming units (CFU) were used to quantify growth seen on the plates and Gram staining and examination was done on all colonies seen by the microbiologist. Of the 14 bronchoscopes cultured, 4 (28.5%) were positive for microbial growth (Table 1). All Gram stains were positive and either Bacillus or Staphylococcus species were seen. In gastro-intestinal endoscopes, 4 (22.2%) were positive for microbial growth that was Gram positive and either Bacillus or Staphylococcus species. Finally, urological endoscopes had 3 out of 10 (30%) positive results with all being Gram positive colonies of either Bacillus or Staphylococcus species.

Table 1. Microbial Culture Results

Scope ID	Scope Model	Microbial Growth (CFU)	Gram stain (Pos. or Neg.)	Species
R – 1	BF-H190	NG	NA	NA
R – 2	BF-H190	3	Positive	Bacillus & Staphylococcus sp.
R – 3	BF-H190	1	Positive	Bacillus sp.
R – 4	BF-H190	NG	NA	NA
R – 5	BF-H190	NG	NA	NA
R – 6	BF-H190	1	Positive	Bacillus sp.
R – 7	BF-1TH190	NG	NA	NA
R – 8	BF-H190	NG	NA	NA
R – 9	BF-P190	NG	NA	NA
R – 10	BF-XP190	NG	NA	NA
R – 11	LF-DP	NG	NA	NA
R – 12	LF-V	NG	NA	NA
R – 13	LF-GP	1	Positive	Bacillus sp.
R – 14	LF-V	NG	NA	NA
GI – 1	CF-H180AL	NG	NA	NA
GI – 2	GIF-HQ190	NG	NA	NA
GI – 3	GF-UCT180	NG	NA	NA
GI – 4	GIF-XP190N	NG	NA	NA
GI – 5	GIF-HQ190	1	Positive	Bacillus sp.
GI – 6	CF-HQ190L	NG	NA	NA
GI – 7	CF-HQ190L	4	Positive	Staphylococcus sp.
GI – 8	PCF H190 DL	NG	NA	NA
GI – 9	GIF-HQ190	NG	NA	NA
GI – 10	GIF-XP190N	2	Positive	Bacillus & Staphylococcus sp.
GI – 11	GIF-HQ190	NG	NA	NA
GI – 12	GIF-XP190N	NG	NA	NA
GI – 13	TJF-Q180V	NG	NA	NA
GI – 14	GIF-1TH190	NG	NA	NA
GI – 15	EUS GF-UCT180	NG	NA	NA
GI – 16	GIF-HQ190	NG	NA	NA
GI – 17	PCF H190 DL	NG	NA	NA
GI – 18	EUS GF-UE160-AL5	1	Positive	Staphylococcus sp.
U – 1	SN (Ureteroscope)	NG	NA	NA
U – 2	SN (Ureteroscope)	NG	NA	NA
U – 3	SN (Cystoscope)	NG	NA	NA

U – 4	SN (Cystoscope)	NG	NA	NA
U – 5	SN (Ureteroscope)	NG	NA	NA
U – 6	SN (Cystoscope)	1	Positive	Bacillus sp.
U – 7	SN (Cystoscope)	1	Positive	Bacillus sp.
U – 8	SN (Ureteroscope)	1	Positive	Staphylococcus sp.
U – 9	SN (Video Ureteroscope)	NG	NA	NA
U – 10	SN (Ureteroscope)	NG	NA	NA

NG, no growth
NA, not applicable
CFU, colony forming unit

3.2 Borescope Examinations

All significant findings were recorded, and photographs taken for documentation. Overall findings include water retention, dents, filamentous debris, channel shredding, dried debris, red particles, gel-like substances, discoloration, and scratches (Table 2).

Table 2. Summary of Borescope Exam Findings*

	Bronchoscopes (n = 12)	Gastro-Intestinal Endoscopes (n = 13)	Urological Endoscopes (n = 11)
Water Retention	7	10	0
Channel Shredding	4	9	9
Filamentous Debris	0	5	2
Scratches	0	2	0
Dents	6	0	3
Dried Debris/Substances	2	1	5
Discoloration	0	0	8
Red Debris/Particles	5	0	0

**Please note that these results do not denote severity.*

3.2.1 Borescope Findings in Bronchoscopes

Water retention (58.3%) was the most common finding across the 12 bronchoscopes that had a borescope examination. Half (50%) of the bronchoscopes had dents in the inner channels. While none (0%) of the bronchoscopes had evidence of filamentous debris, a third of bronchoscopes (33.3%) had channel shredding. The dried debris, found in 16.7% of bronchoscopes, appeared to be dried water or other unidentifiable substances. Most notably, there was evidence of red particles on almost half (41.7%) of bronchoscopes. The red particles were evident both on the distal end, as well as inside the channel (Figure 6). The most probable source

of this red debris came from a red Styrofoam protective covering, the Endo-Boot™, for the distal end of the endoscope (Figure 7A). The protective coverings are put on the distal end of endoscopes after they have gone through high-level disinfection and Endo-Boot™ tip protectors were only found on the bronchoscopes at this hospital. The red debris was easily removable from the outside of the bronchoscopes, creating concern for the potential of deposition into a patient's lungs or airway. As a result of these findings the Styrofoam Endo-Boot™ tip protectors have been eliminated from use and replaced with plastic tip protectors for endoscope reprocessing (Figure 7B).

One of the bronchoscopes showed an unidentifiable red stain near the proximal end of the scope (Figure 10). It was difficult to assess whether the stain was on the inside or outside of the channel, but the stain was still apparent even after a second round of high-level disinfection. Due to the uncertainty of what was causing the red stain, the bronchoscope was taken out of circulation and sent to the manufacturer for repair.

3.2.2 Borescope Findings in Gastro-Intestinal Endoscopes

Water retention had the highest prevalence (76.9%) in gastro-intestinal (GI) endoscopes across all three groups. There was channel shredding found in 69.2% of the GI endoscopes, with 38.5% that had filamentous debris in the channel. Notably, 0% of the GI endoscopes had dents, discoloration, or red particles.

3.2.3 Borescope Findings in Urological Endoscopes

All urology endoscopes undergo vaporized hydrogen peroxide sterilization, and 0% of the endoscopes had water retention. Notably, there patches of what appeared to be dried substances in several of the urological endoscopes (45.4%). Almost all urological endoscopes that were examined (81.8%) had evidence of channel shredding, but only 18.2% had filamentous debris. Further, 27.3% of the urological endoscopes had dents in their channels. The most remarkable finding for the urological endoscopes was the presence and amount of discoloration (72.7%) found (Figure 6). These were the only endoscopes where this type of discoloration was observed.

Figure 1. Water Retention. Small droplets in bronchoscope (A) large and small droplets in bronchoscope (B) large droplets in GI scope (C)

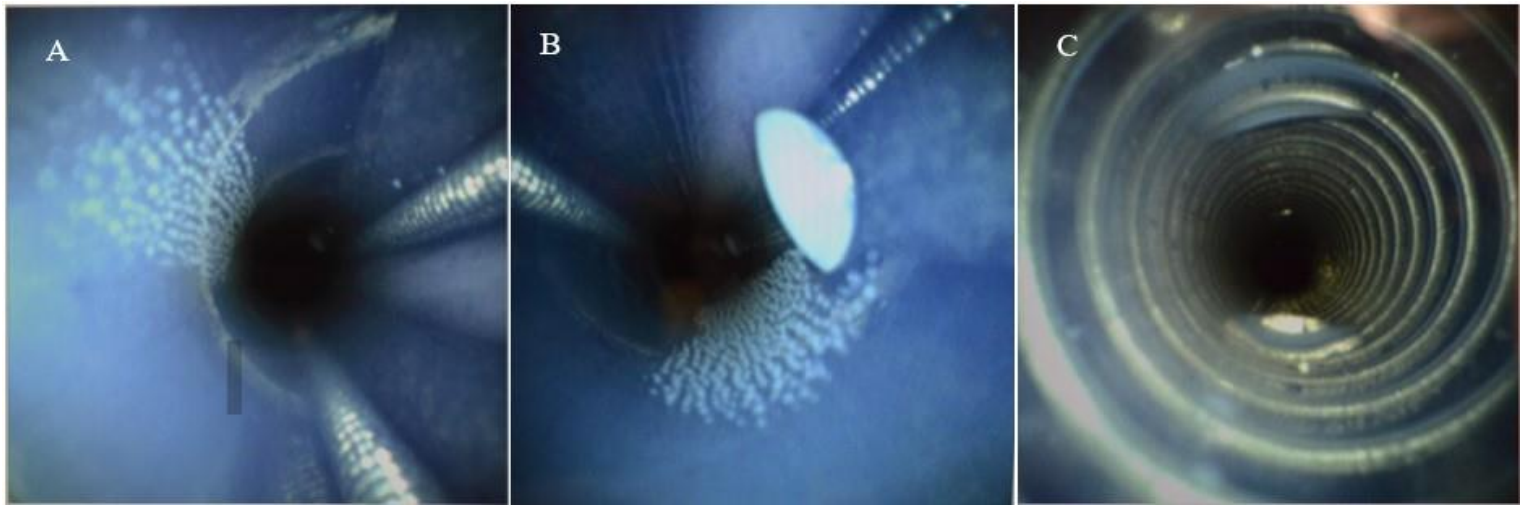


Figure 2. Channel shredding in a bronchoscope (A), GI endoscope (B), and cystoscope (C)

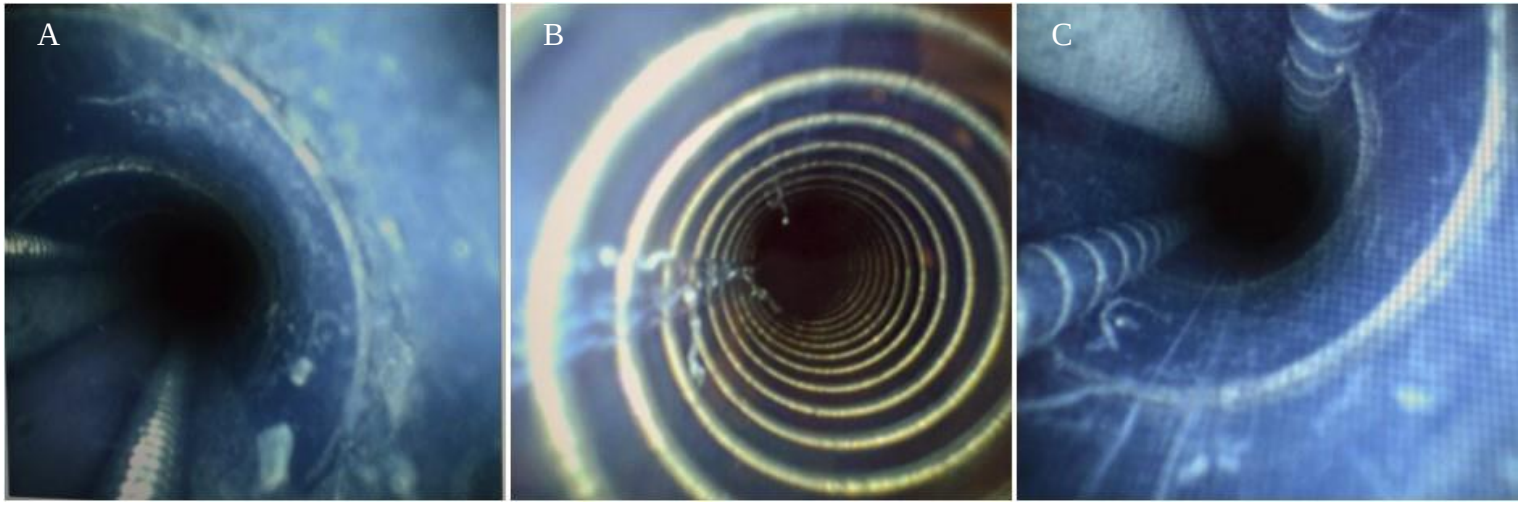


Figure 3. Filamentous debris in GI scopes (A-B) and a cystoscope (C)

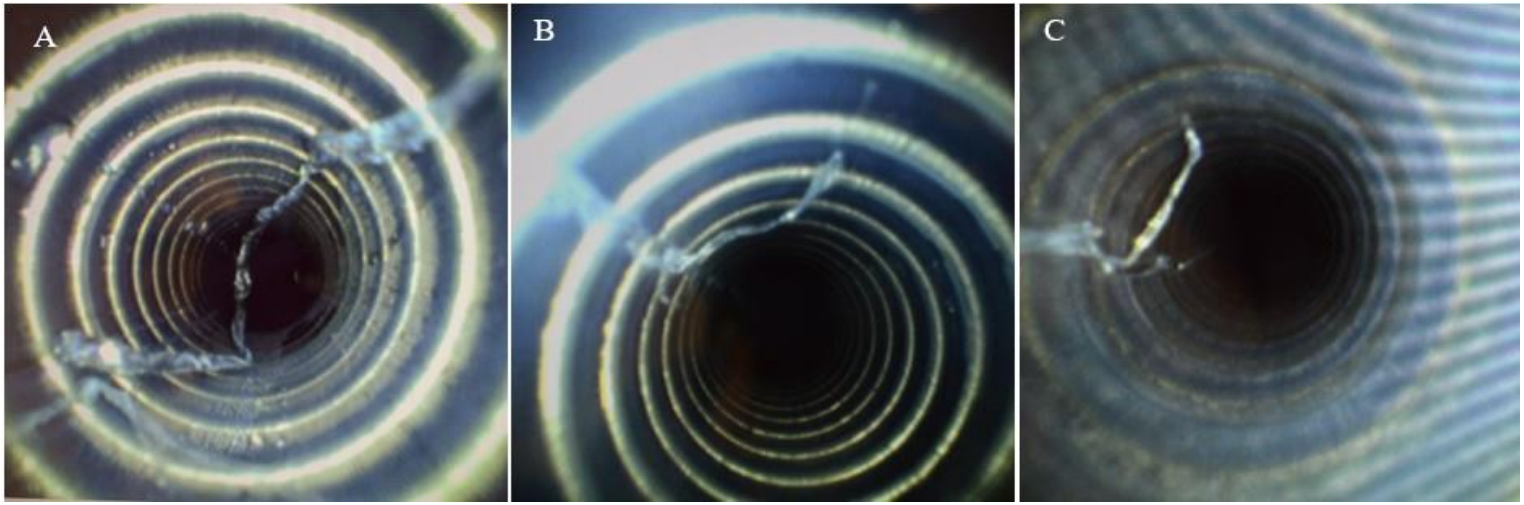


Figure 4. Dents in respiratory scope channel (A-B) and cystoscope channel (C)

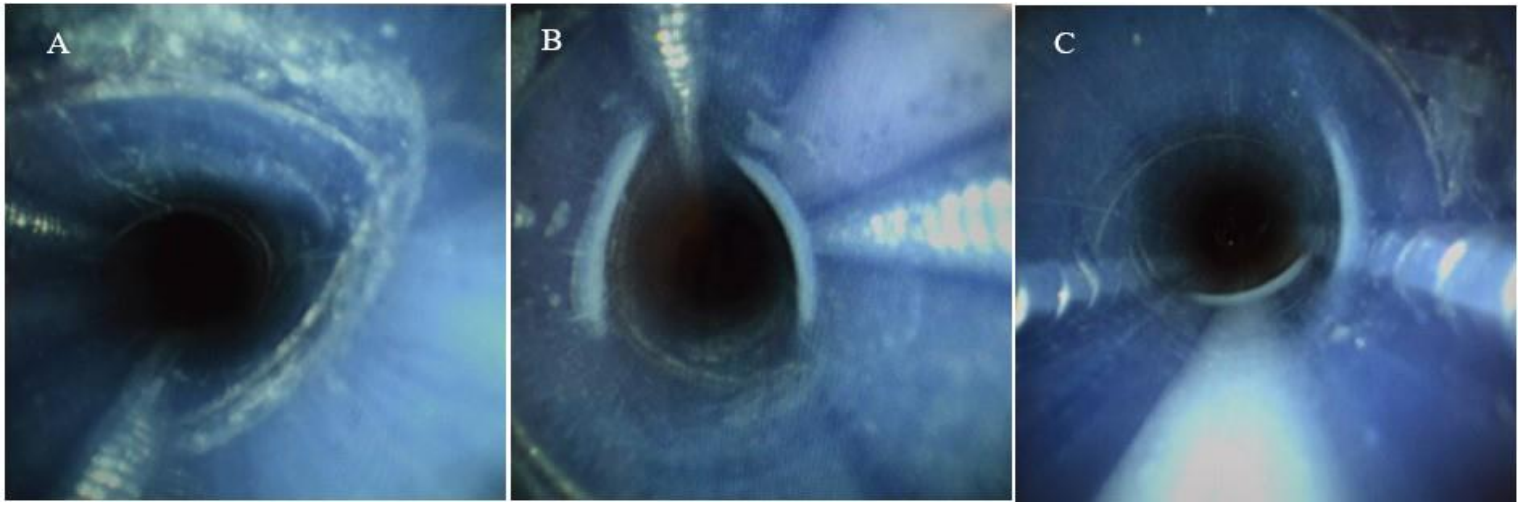


Figure 5. Red styrofoam particles seen on outside of distal end (A), inside side distal tip (B), and outside of tip (C)

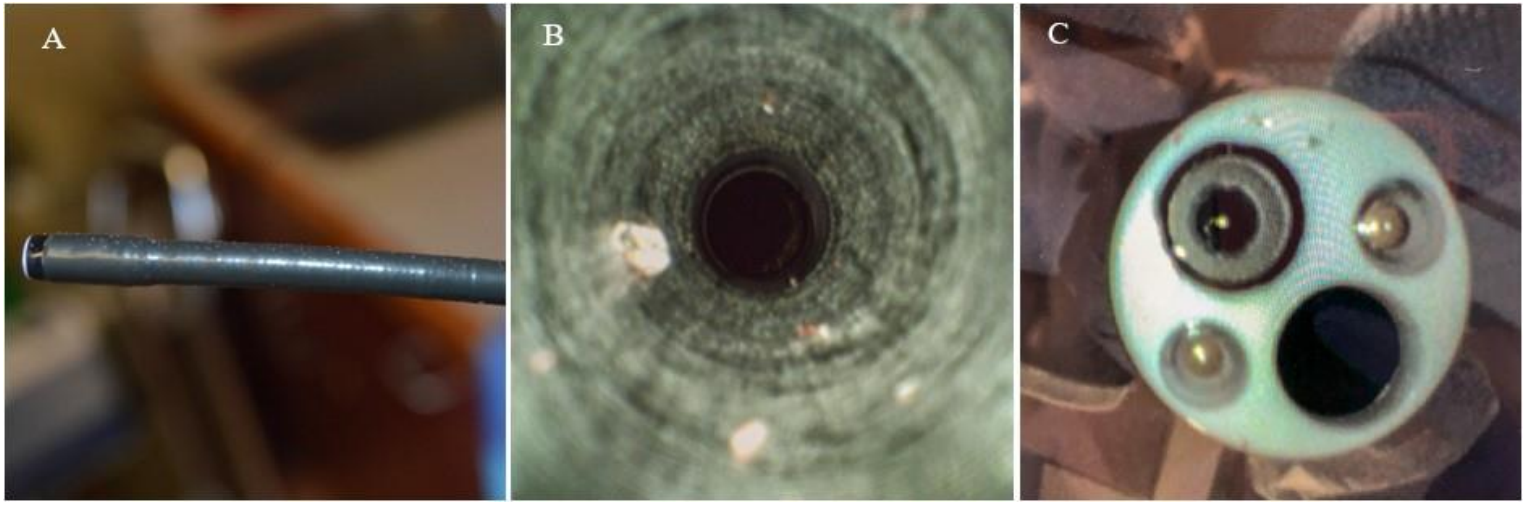


Figure 6. Discoloration in cystoscopes

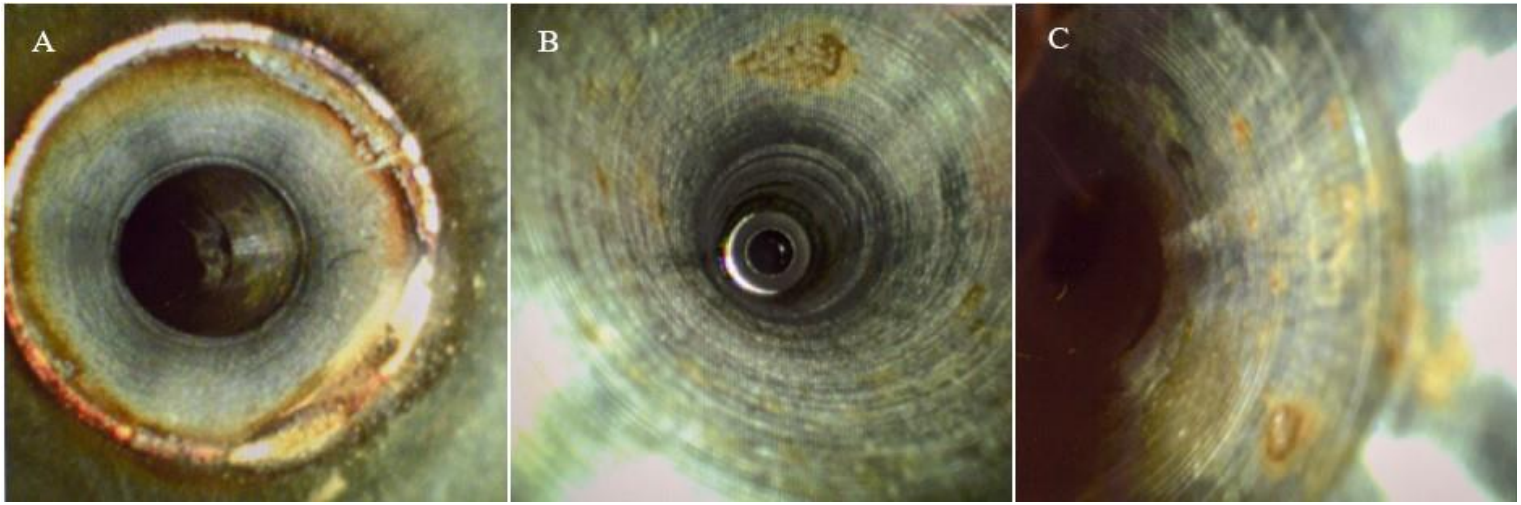
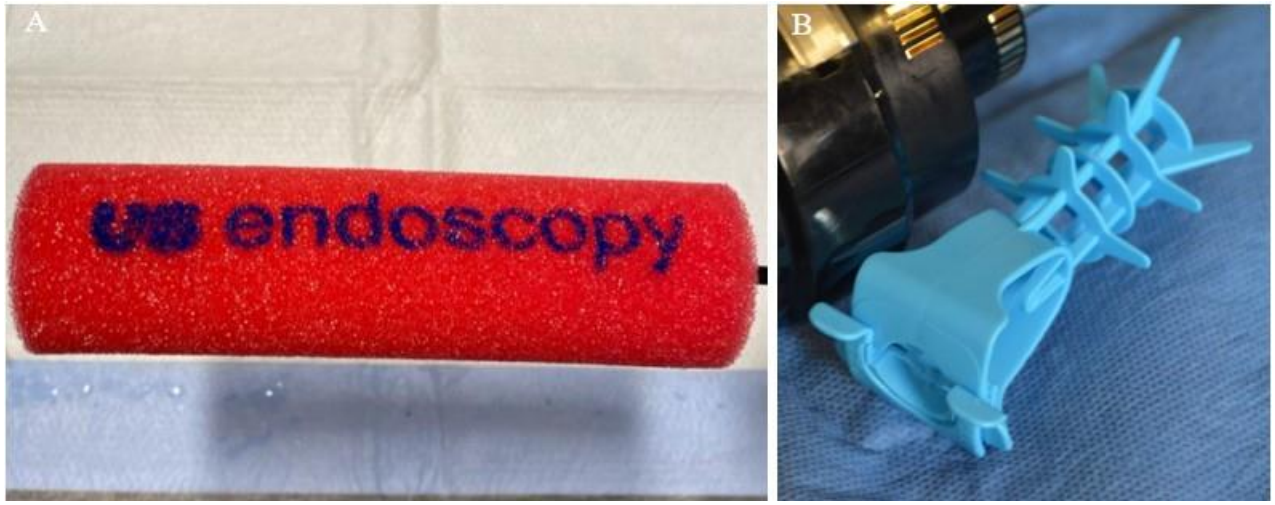


Figure 7. Endoscope Tip Protectors. Endo-Boot™ red styrofoam tip protector (A) plastic tip protector (B)



4.0 Discussion

Borescope examination and microbial cultures proved to be an invaluable tool in the assessment of endoscopes in an urban hospital in Pittsburgh, PA. The evidence gathered from the borescope examinations of both the extent and frequency of damage seen in gastro-intestinal, respiratory, and urological endoscopes supports the need for routine borescope examinations. Identifying damaged endoscopes can help prolong the life of the endoscope and reduce the risk of accidental patient infection during a procedure. The borescope was easy to set-up, and the examination was relatively quick to perform, increasing its suitability for everyday use.

Routine microbial culture of endoscopes is important in surveillance for multidrug-resistant organisms (MDROs) and other organisms of concern (Alfa & Singh, 2021). The microbial cultures were primarily looking for Gram negative species of bacteria, as those have historically been known to cause outbreaks from endoscopes, such as carbapenem-resistant *Enterobacteriaceae* (CRE) (Muscarella, 2014). Culturing is also a tool that can assist during outbreak investigations to help identify any contaminated endoscopes. According to the Food and Drug Administration (FDA), culturing of endoscopes is not intended to assess sterility of an endoscope, but to identify microorganisms of concern (*Duodenoscope Surveillance Sampling & Culturing*, 2018). The FDA still recommends culturing as a means of identifying potential problems early which lowers the risk of pathogen transmission.

Endoscopes with growth of a Gram-negative colony can be quarantined, reprocessed, and re-cultured, to reduce the risk of transmission to the next patient. Culturing can potentially assist in determining if endoscope reprocessing and high-level disinfection protocols are being properly followed, as a high percentage of endoscopes positive for microbial growth can signify leftover

bioburden from reprocessing. No endoscopes that were cultured in this study were positive for Gram negative bacteria. However, this does not imply that microbial cultures are not necessary to perform since the sensitivity of microbial cultures is hard to estimate. The FDA's recommendations for culturing endoscopes includes the use of a neutralizing broth which neutralizes any chemical disinfectants or alcohol leftover in the channel which can kill bacteria that have been mechanically removed from their biofilm environment (*Duodenoscope Surveillance Sampling & Culturing*, 2018). A neutralizing broth was not used in this study as per the hospital's standard operating procedure which has the potential to limit microbial growth and could have affected the results.

Results from the borescope examination of bronchoscopes that had a red, Styrofoam protective tip cover (Figure 7A) were important in altering tip protector products used on endoscopes in this hospital. Investigators hypothesized that the Styrofoam's brittleness caused small pieces to break off onto and inside of the endoscope due to the snug fit over the distal tip. There are several dangers to the foreign material found in and around the distal tip of bronchoscopes. One risk is the development of biofilms or other microbial growth (Ren-Pei et al., 2014). The most serious concern is the potential for the foreign particles to be deposited in a patient's lungs during a procedure since the small particles were easily removed by wiping a finger over the affected areas. Inflammation and infection are likely to result from foreign particles being introduced into a patient's lungs, especially considering that patients who undergo a bronchoscopy usually have an underlying health concern and potentially compromised lung health. The risk to patient safety caused the removal of this product from use in the hospital and the use of plastic tip protectors (Figure 7B).

Water retention (Figure 1) was a very common problem seen in both respiratory (46.7%) and gastro-intestinal (55.5%) endoscopes. The urological endoscopes did not have evidence of water retention because they undergo vaporized hydrogen peroxide sterilization. Maintaining dry channels is important in the prevention of microbial growth, especially of Gram negative waterborne pathogens (Nerandzic et al., 2021), yet it is very difficult to achieve in endoscopes. Water retention is often a problem with endoscopes that undergo high-level disinfection because the narrow diameter of the channels easily retains water. Flushing alcohol through the channels at the end of high-level disinfection followed by treatment with compressed air prior to storage has been associated with increased dryness in endoscopes and could be a future intervention to test in this hospital (Alvarado & Reichelderfer, 2000).

Structural damage, including channel shredding (Figure 2), filamentous debris (Figure 3), and dents (Figure 4) are concerning for several reasons. The most pressing concern for structural damage is the risk of biofilms to persist despite repeat high-level disinfection (Primo et al., 2021). A study done by Primo et al. (2021) found that structural damage provides protection for biofilms and makes it even more difficult for high-level disinfection to be successful. Another concern, particularly with filamentous debris, is the potential for the channel pieces to break off during a procedure and be deposited into a patient.

While this study demonstrates the effectiveness of borescope examination, determining the appropriate frequency of these examinations in this hospital is still unknown. Not all borescope findings have clear implications for the future longevity of the endoscope or risk to patients as novel findings can be difficult to interpret. Future studies at this hospital could include a longitudinal study where individual endoscopes are followed and examined with a borescope after each use to determine the average amount of uses before damage occurs.

4.1 Quality Management

Moving forward, the endoscope culturing standard operating procedure should be updated based on the FDA's current recommendations (*Duodenoscope Surveillance Sampling & Culturing*, 2018). The addition of a neutralizing broth to the sample collection water was not done during this study but should be considered in the future per the FDA's (2018) recommendations to neutralize leftover chemical disinfectant from the high-level disinfection process. To date, there is no written standard operating procedure for the operation of the borescope at this hospital. A protocol should be established for borescope examinations along with training of personnel in central sterile processing for the regular use of the borescope. For both microbial cultures and borescope examinations endoscope sampling frequency should be established depending on staffing, resources, and current literature.

The use of routine microbial cultures and borescope examinations to continually assess the effectiveness of endoscope reprocessing is an important component of infection prevention and patient safety. The borescope examinations and microbial cultures in endoscopes are essential tools in the prevention of patient-to-patient transmission of infection. Removal and repair of a damaged endoscope has the potential to prevent infection of a patient, but internal damage can go unnoticed unless a borescope examination is performed.

Training of reprocessing technicians is also essential to improving the safety of endoscopes and patient health. Reprocessing endoscopes involves many steps and requires specific knowledge on the anatomy and function of each type of endoscope, as well as the manufacturer instructions for use protocols (Ofstead et al., 2020). Manufacturer instructions for use protocols can be complex and lengthy, adding further complications to the reprocessing procedure. In addition to understanding how to handle the endoscopes, technicians must know how to properly use the

automated endoscope reprocessor machines. The study done by Ofstead et. al. (2020) identified other human factors that affect proper reprocessing, such as time and workflow, where low staffing and high reprocessing demand can lead to missed steps. Collaboration between infection prevention personnel and reprocessing technicians on proper reprocessing techniques, in addition to borescope examinations and microbial cultures, is key to improving patient safety.

Hands-on training should be done by an individual qualified in endoscope reprocessing either from the sterilization department or the hospital's training department. In the hospital in which this study was performed training was handled by senior reprocessing technicians and technician supervisors. Staff should be encouraged to obtain a certificate in endoscope reprocessing, such as the program offered by the International Association of Healthcare Central Service Material Management (IAHCSMM) which requires hands-on experience as well as a passing score on an exam that emphasizes proper endoscope handling and infection prevention (*CER - IAHCSMM.Org*, n.d.). In addition, continuing education is paramount in a field where standards and recommendations are frequently updated, and the IAHCSMM endoscope reprocessing certification requires continuing education credits to renew the certification each year. There should also be on-going verification of reprocessing technicians to assess competencies, which sterilization supervisors and infection preventionists can perform (*Flexible Endoscope Reprocessing | HICPAC | CDC*, 2018).

The Centers for Disease Control and Prevention (2018) provides recommendations on elements of a reprocessing program for flexible endoscopes. In addition to education and training, the recommendations touch on other quality control measures such as documentation, risk assessment, and proper preparedness for breach of protocols and failures. Documentation includes maintaining a thorough and accurate inventory of all endoscopes present in the hospital or clinic.

Information that is recorded should include the endoscope's model and serial numbers, location, and procedures each endoscope was used for. This information is important in the event of an outbreak for tracing purposes. Risk assessments are key for the improvement of endoscope reprocessing safety and should be performed periodically by personnel in the sterilization department, including endoscope reprocessing technicians, supervisors, and director(s) of sterilization, along with infection preventionists, endoscopists, endoscopy nurses, and other key hospital partners. Elements that should be involved in risk assessment analysis include verification of staff competencies, proper reprocessing protocols as outlined in the manufacturer's instructions for use (IFU) are being followed, and all equipment used in reprocessing is being properly maintained. Finally, all teams involved in endoscope use and reprocessing should be prepared for situations where proper endoscope handling and/or reprocessing protocols has been breached. This should include an assessment to determine the risk of disease transmission and result in a plan to mitigate any risks to patients or staff.

Borescope examinations and microbial cultures will improve upon quality management for infection prevention by identifying endoscopes that have the potential to carry a higher risk to patient safety either from damage or contamination. In instances where many endoscopes are positive for microbial growth, especially Gram-negative bacteria, the risk assessment team can step in to evaluate current reprocessing procedures and equipment (such as an automated endoscope reprocessor) function at an early stage before patients are put at risk from a contaminated and/or damaged endoscope. Overall, there are many aspects involved in quality management of endoscope reprocessing procedures.

5.0 Conclusions

Flexible endoscopes are essential medical devices that provide minimally invasive diagnostic and medical procedures. However, these procedures continue to prove difficult to properly reprocess and maintain. The borescope examinations in this study identified frequent internal endoscope damage and as a result the hospital sent numerous endoscopes out for repair. Damaged and compromised endoscopes increase the risk of infection between patients. This study also found that a specific type of Styrofoam tip protector left particles on and inside of the distal end of bronchoscopes, creating a risk for these particles to be deposited inside a patient. As a result, the tip protectors were removed from use in this hospital and replaced with a plastic tip protector. While the microbial cultures did not reveal microorganisms of concern, they were still important in the surveillance of endoscopes and will be continued in the hospital.

Overall, the borescope examinations were able to reveal damage and other abnormalities that would otherwise be impossible to identify without taking the endoscope apart. Damage in endoscope channels have been shown to protect biofilms from high-level disinfection which increases the risk of patient-to-patient transmission of pathogens (Primo et al., 2021). Identification of damage through borescope examination led to the repair of multiple endoscopes in the hospital and thus improved patient safety. To properly assess the safety of endoscopes, multiple surveillance measures need to be implemented. Coupling microbial culture and borescope examination results, along with clinical patient findings, allows for assessment of multiple aspects of endoscope safety from microbial growth of microorganisms of concern to structural abnormalities, all of which improves patient safety.

Supplementary Figures

Figure 8. Borescope Set-Up. (A) Microsoft® Surface Go tablet with live stream video connected to (B) VerifEye® borescope apparatus

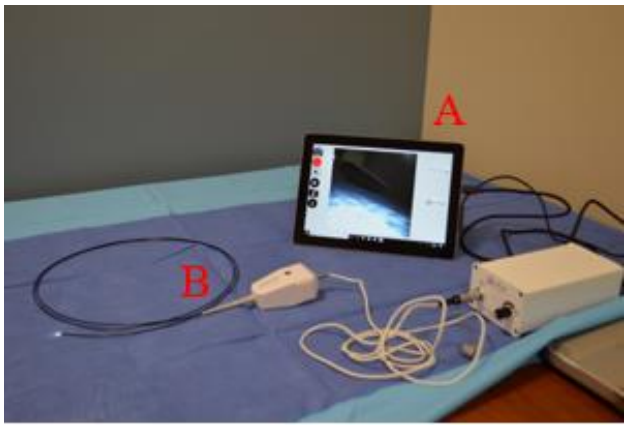


Figure 9. Filter membrane on blood agar plate

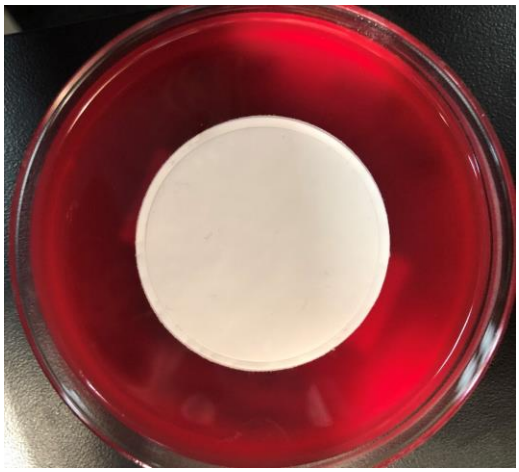
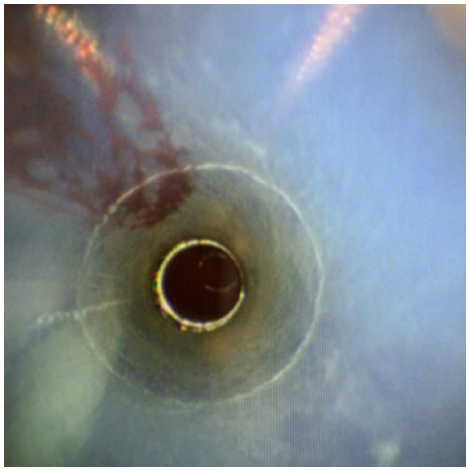


Figure 10. Unidentifiable red staining inside bronchoscope



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