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Scoping the scope: endoscopic evaluation of endoscope working channels with a new high-resolution inspection endoscope (with video)

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Abstract

Background—Outbreaks of transmission of infection related to endoscopy despite reported adherence to reprocessing guidelines, warrant scrutiny of all potential contributing factors. Recent reports from ambulatory surgery centers indicated widespread significant occult damage within endoscope working channels, raising concerns regarding the potential detrimental impact of this damage on the adequacy of endoscope reprocessing.

Methods—We inspected working channels of all 68 endoscopes at our academic institution using a novel flexible inspection endoscope. Inspections were recorded and videos reviewed by three investigators to evaluate and rate channel damage/debris. Working channel rinsates were obtained from all endoscopes and ATP bioluminescence measured.

Results—Overall endoscope working channel damage was rated as minimal/mild and consistent with expected “wear and tear” (median 1.59 on our 5-point scale), with predominant findings including superficial scratches (98.5%), and scratches with adherent peel (76.5%). No channel perforations, stains or burns were detected. Extent of damage was not predicted by endoscope age. Minor punctate debris was common and a few small drops of fluid were noted in 42.6% endoscopes after reprocessing and drying. The presence of residual fluid predicted higher ATP bioluminescence values. Presence of visualized working channel damage or debris was not associated with elevated ATP bioluminescence values.

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A video has been submitted along with this manuscript

Author Contributions:

MTB, RJH, SB and MG were involved in conception and design of the study as well as collection, analysis and interpretation of the data; MTB, RJH and SB were involved in drafting and critical revision of the article for important intellectual content; SB granted final approval of the article.

Conclusions—The flexible inspection endoscope enables high-resolution imaging of endoscope working channels and offers endoscopy units an additional modality for endoscope surveillance, potentially complementing bacterial cultures and ATP. Our study, conducted in a busy academic endoscopy unit, indicated predominately mild damage to endoscope working channels, which did not correlate with elevated ATP values.

Graphical abstract

Keywords

Endoscope; Adenosine Triphosphate; Flexible Inspection Endoscope

INTRODUCTION

Transmission of infection related to endoscopy was previously thought to be extremely infrequent, with an estimated transmission rate of 1 in 1.8 million endoscopic procedures,¹ and most reported cases were assumed to be related to either defective equipment or to breaches in following reprocessing protocols.^{2, 3} Several recent outbreaks of infection with multi-drug resistant organisms related to duodenoscopy use,^{4–7} suggest that the risk of infection-transmission during endoscopy may have been previously underestimated. Some of these outbreaks occurred despite reported adherence to reprocessing guidelines,^{4, 8} and were attributed to difficulties in cleaning the elevator mechanism.^{7–13} Transmission of infection despite reported adherence to reprocessing guidelines has also been reported with endoscopes lacking an elevator channel, including gastroscopes,¹⁴ and colonoscopes.^{15, 16}

Although European and Australian guidelines recommend periodic culture of endoscopes for bacteriological surveillance,^{17, 18, 19} these are expensive, require microbiology laboratory infrastructure and quarantine of endoscopes while awaiting culture results. Testing for adenosine triphosphate (ATP), which is present in microorganisms as well as human cells, offers a rapid, low-cost alternative for microbial surveillance.

Occult internal damage within the working channels of endoscopes may offer one explanation for transmission of infection despite reprocessing. Two previous ambulatory surgery center studies evaluated endoscope working channels with a borescope and reported widespread channel damage and debris,^{20, 21} with a cumulative increase in the amount of adherent debris over a 7-month observation period.²⁰ These concerning findings necessitated sending the majority of endoscopes at the facility for repairs. Although these single site studies have raised many concerns, it is unclear whether the extensive working channel damage and residue reported by these investigators is site-specific and dependent on local endoscope use and reprocessing patterns, or whether this is a widespread phenomenon. It is unclear whether such working channel damage, if present, affects the adequacy of reprocessing, although this has been hypothesized.²¹

In this study, we used a new ultra-slim flexible inspection endoscope to evaluate the working channels of all endoscopes in our busy endoscopy unit for channel damage and for the presence of residual debris despite HLD. We conceptualized a scoring system to categorize the presence and extent of damage and residue within all endoscope working channels and used an ATP bioluminescence assay to evaluate the impact of working channel damage and residue on the adequacy of reprocessing.

METHODS

Institution

This study was conducted in the endoscopy unit of a tertiary care academic medical center where >50 endoscopic procedures are performed daily. The study was approved by the Stanford University Medical Center Institutional Review Board (40603). No human subjects were involved and patient-specific data were not collected.

Study Design

The working channels of all endoscopes in use at our institution manufactured by both Olympus™ (Olympus America, Center Valley, Pa) and Pentax (Pentax of America, Montvale, NJ) were evaluated at variable intervals between 6 and 72 hours after HLD. Lifetime use history (a surrogate for endoscope age), reprocessing history and date of most recent reprocessing were collated for each endoscope. *Endoscope Reprocessing:* Manual cleaning and HLD of endoscopes was performed by our institution's centralized sterile processing department (SPD) in strict accordance with endoscope manufacturer's guidelines. HLD was undertaken using an automated endoscope reprocessor (Medivators Advantage Plus, Minntech, Minneapolis, Minn, USA) using the automated cleaning cycle with peracetic acid as the liquid chemical sterilant culminating in alcohol flushing followed by forced air drying for 10 minutes.

Endoscopic evaluation of working channels—After HLD, endoscopes were evaluated with an ultra-slim flexible inspection endoscope (SteriCam, Sanovas Inc, San Rafael, Calif). This moisture-resistant flexible inspection endoscope is 110 cm long, with an outer diameter of 2.3 mm, has a light source at its distal tip with adjustable brightness, and a lens that enables high resolution (800 × 800 pixels) video (Supplementary Figure 1). The

video is viewed on a Windows-based computer or tablet equipped with SteriView^T device software (Sanovas Inc, San Rafael, Calif), which allows capture of both video and still images.

Endoscope working channels were examined by manually advancing the SteriCam both in an antegrade fashion from the endoscope handle, and in a retrograde fashion, from the distal tip of the endoscope, to allow visualization of the entire length of the working channel. The SteriCam endoscope was reprocessed immediately before each use, as recommended by the manufacturer, with disinfectant wipes (PDI Super Sani Cloth Germicidal Wipes) for a full 2 minutes of contact time, followed by air-drying for 10 minutes.

To educate ourselves on the full range of working channel abnormalities that might be encountered (Figure 1, Table 1), we visited an endoscope manufacturer's national service center. We then developed a scoring system to categorize types and degree of working channel damage and residue (Table 1). This scoring system was developed by consensus between the investigators based on the entire range of possible endoscope working channel damage reviewed at our institution and during our visit to the endoscope manufacturer's national service center. Examinations were recorded in their entirety and reviewed in a blinded fashion by 3 endoscopists, who scored working channel damage and fluid residue/debris. A brief questionnaire was administered to each endoscopist participating in the study to rate perceived ease of use of the flexible inspection endoscope and software interface and the quality of video and captured images on a scale of 1 (very poor) to 5 (excellent).

Random re-inspections of selected endoscopes were performed after additional reprocessing to validate intra-observer consistency between inspections of the same endoscope. We also performed endoscopic re-inspection of selected endoscopes with subtle abnormalities after an additional cycle of HLD, to differentiate potentially transient findings (residual linear debris) from persistent findings (linear scratches). No changes were made based on endoscope re-inspections, which confirmed that abnormalities were correctly identified at the initial inspection.

Rinsate Collection and ATP Testing—The “flush-only” method was used to obtain rinsates from endoscope working channels after HLD and SteriCam inspection, as previously detailed.^{22, 23} ATP testing was performed on the rinsates using the CleanTrace Water/Swab ATP test (3M Company, Maplewood, Minn) and ATP relative light units (RLU) determined using a handheld luminometer.^{24, 25} Positive controls per the ATP validation kit (3M Company, Maplewood, Minn) and negative control (water <5 RLU) were also tested to ensure validity of the measurements. We also performed testing which confirmed that ATP bioluminescence values were not increased due to potential residual bacteriological contamination of the SteriCam, or decreased due to potential residual disinfectant on the surface of the SteriCam (data not shown).

Statistical Analysis—All analyses were conducted using SAS Enterprise Guide version 7.11 HF3 (SAS Institute Inc, Cary, NC). Ordinal data were described using median and interquartile ranges. Quantitative comparisons between ordinal data were conducted using the Wilcoxon rank-sum test. Interobserver agreement was assessed using the Pearson

correlation coefficient. Predictors for continuous variables were determined using both univariate and multivariable generalized linear models and robust (empirical) standard errors. Models were constructed with both assumption of independence between individual endoscopes, as well by clustering endoscopes by type to account for correlations between endoscope type and patterns of usage. All reported p-values are 2-sided, and all comparisons attained statistical significance at $p < 0.05$ after adjustment for multiple comparisons using the method on Bonferroni.

RESULTS

A total of 85 inspections were performed on all 68 endoscopes in use at our endoscopy unit, including 23 gastroscopes (4 therapeutic), 33 colonoscopes (17 pediatric), 7 duodenoscopes and 5 linear echoendoscopes. Endoscopes were inspected a median of 2 days after reprocessing. Median lifetime use history for all endoscopes was 676 (range 6 to 1919), and 45.6% of endoscopes had >1000 lifetime uses. Median lifetime uses varied by endoscope as follows: gastroscopes 1043 (Interquartile range (IQR): 131-1149), colonoscopes 714 (IQR: 358-1340), echoendoscopes 660 (IQR: 165-692) and duodenoscopes 244 (IQR:175-249).

Endoscope evaluation

Typical endoscopes have 3 distinct working channel segments: the inlet region where the biopsy port in the endoscope handpiece joins the working channel within the endoscope shaft, the uniform cylindrical channel segment within the endoscope shaft characterized by a white or grey/green lining with a metallic sheen and the channel segment at the distal bending tip characterized by circular rings (Figure 2, [video](#)).

Scratch Abundance & Severity—Scratches were visualized in 98.5% of endoscopes (67/68). The overall mean scratch abundance rating in all endoscopes was 1.26 (SD 0.39) and severity was 1.37 (SD 0.42). Median ratings and ranges for each type of endoscope are included in Table 2 and depicted in Figure 3. *Scratches with Adherent Peel*: Scratches associated with peeling of small strips of the inner lining of the endoscope working channel were visualized in 76.5% of all endoscopes (52/68). The overall mean rating of scratches with adherent peel was 1.24 (SD 0.94). Median ratings and ranges for each type of endoscope are included in Table 2 and depicted in Figure 3. The overall rating reached significance on comparison of standard and therapeutic gastroscopes (1.7 vs 0.5, $p=0.03$), but did not reach significance for comparison between any other types of endoscopes.

Channel Buckling—Channel buckling was present in 2 of 68 (2.9%) of endoscopes, both of which were standard gastroscopes. This channel buckling was characterized by buckling and indentation of the normally smooth tubular working channel. These abnormalities were localized within the distal segment of one gastroscope and within both distal and proximal segments in the second.

Overall Damage—Some form of endoscope working channel damage, even if only minimal, was present in all inspected endoscopes. The overall mean damage rating for all endoscopes was 1.59 (SD 0.52). Median ratings and ranges for each type of endoscopes are included in Table 2 and depicted in Figure 3.

Severe working channel damage—Deep scratches, burns, and channel perforations, all severe types of damage that usually require endoscope repair, were not visualized within working channels of inspected endoscopes.

Fluid residue—Small drops of residual fluid were visualized in the working channels of 29 of 68 endoscopes (42.6%). These were predominantly clear and occasionally opaque. The overall mean rating for residual fluid in all endoscopes was 0.62 (SD 0.95). Median ratings and ranges for individual types of endoscopes are included in Table 2 and depicted in Figure 3. Colonoscopes were significantly more likely than duodenoscopes to exhibit residual fluid within their working channels (0.7 [0.0–1.0] vs 0.0, $p=0.01$). Residual fluid was not visualized in the working channels of any therapeutic gastroscope or duodenoscope. Endoscope length did not predict residual fluid. Each millimeter increase in channel diameter conferred a -0.49 (IQR: -0.96 – 0.02 , $p=0.04$) change in fluid residue score. Although this was significant in the univariate analysis, it did not reach significance in the multi-variate analysis -0.41 (IQR: -0.94 – 0.13), $p=0.13$ (Table 3).

Debris—Small foci of minor debris were visualized in the working channels of 95.6% of endoscopes (65/68). Most of this debris consisted of localized small linear black or white particulate matter. Biofilms were not evident in any endoscope working channel. The overall mean rating for residual debris in all endoscopes was 1.31 (SD 0.58). Median ratings and ranges for each type of endoscope are included in Table 2 and depicted in Figure 3.

Interobserver Variability—We evaluated interobserver agreement in rating working channel characteristics and residue. Comparison of ratings from the 3 endoscopists who reviewed endoscope channel inspection videos and rated channel damage/debris resulted in R mean values ranging from 0.39 for scratch ratings to 0.89 for residual fluid ratings (Table 4).

Device Questionnaire—Based on the questionnaire administered to endoscopists in this study, consensus among endoscopists was a 5/5 rating for ease of use of the inspection endoscope, a 4/5 rating for quality of images, and a 3.5/5 rating for user-friendliness of the software interface.

ATP bioluminescence readings

ATP bioluminescence values were obtained after HLD for all endoscopes. These values ranged from 3 to 87, with a median value of 10.

Predictors of ATP bioluminescence—We conducted independent and clustered multi-variate analyses to assess the impact of each type of working channel damage, and presence of debris and fluid residue, on ATP bioluminescence values (Table 3). Residual fluid predicted higher ATP values ($p<0.0001$ independent, $p=0.03$ clustered), as did latency from reprocessing ($p<0.0001$ for both independent and clustered). Neither endoscope channel diameter nor endoscope length predicted ATP bioluminescence values. The number of lifetime endoscope uses did not predict increased ATP bioluminescence values, working channel damage, residual fluid or residual debris.

Predictors of Residual Fluid—Because the presence of residual fluid predicts elevated ATP bioluminescence readings, we conducted additional independent and clustered multi-variate analyses to determine whether a specific type of working channel damage or presence of debris would predict the presence of residual fluid (Table 3). The presence of debris within the working channel of endoscopes predicted the presence of residual fluid ($p<0.0001$ for both independent and clustered analyses). Latency from reprocessing inversely predicted residual fluid ($p=0.02$ independent, $p<0.0001$ clustered), with a shorter interval from reprocessing predicting an increased amount of residual fluid within the endoscope working channel.

DISCUSSION

Flexible endoscopes are typically reprocessed by manual cleaning and HLD after use.^{26,17, 27} Recent outbreaks of infection associated with endoscopy, despite reported adherence to current endoscope reprocessing guidelines,²⁸ suggest that endoscope-specific factors may impact adequacy of reprocessing. In addition to the now-established difficulties in cleaning the elevator mechanism of duodenoscopes,⁹ concern has recently been raised regarding the potentially widespread prevalence of significant occult internal damage within the working channels of endoscopes and the negative impact of this damage on the adequacy of HLD.^{20, 21}

Our study of all endoscopes in a busy academic endoscopy unit, reassuringly indicated that endoscope working channels typically had only minor damage. It is the opinion of the investigators that this minor damage is consistent with expected “wear and tear.” Additionally, the presence of this minor channel damage was not associated with elevated ATP bioluminescence readings, a surrogate measure for the adequacy of manual cleaning and HLD. Mild localized channel buckling, which may result from withdrawal of incompletely deflated dilation balloons through the working channel, or from exposure to excessive temperatures, was only seen in 2 gastroscopes. Deep scratches and burns were not detected in our study. Similarly, working channel perforations and associated stains due to seepage of fluid through the channel, were not observed. These latter types of severe working channel compromise should be detected on routine leak testing, and should prompt endoscope repair with replacement of the working channel.

Our most common findings were mild scratches and scratches with adherent peel. Superficial scratches at the inlet were ubiquitous, and presumably reflect normal “wear and tear” of endoscopes. This type of mild working channel damage was not predicted by endoscope age and was evident even in new endoscopes with as few as 6 lifetime uses, indicating that these findings appear early in the life cycle of endoscopes, presumably related to the advancement of accessory devices and cleaning brushes. The majority of identified scratches were located either in the inlet region of the endoscope, or at the bending segment at the distal tip of endoscopes, sites where advancing devices must negotiate sharper bends.

Scratches may be more likely to occur with the advancement of sharp/large bore accessories used for therapeutic procedures and during procedures performed by less-skilled

endoscopists, who are more likely to advance accessory devices through endoscopes that are severely looped, torqued or have their tips sharply deflected. However, our evaluation of endoscopes used in a broader range of procedures including therapeutic procedures, and by endoscopists with a wider range of skills including trainees and low-volume research-focused endoscopists, indicated mainly mild “wear and tear” effects in the working channels of all our endoscopes.

In contrast, 2 studies from the same investigators reported extensive working channel damage within endoscopes at an ASC,^{20, 21} which is unexpected, as typically in this setting, a limited range of largely diagnostic and screening procedures are performed by high-volume endoscopists. Endoscopes evaluated in the initial ASC study had a higher lifetime usage relative to ours,²¹ which could potentially explain the more-extensive damage noted. However, the second ASC study included gastroscopes and colonoscopes with relatively lower lifetime usage in comparison with ours, and evaluation of these ASC endoscopes also revealed extensive, severe damage, including critical channel defects which necessitated repair of many endoscopes.²⁰ One might postulate that, as most ASC procedures include anesthesia support, less attention may be given to loop reduction during colonoscopy,^{29, 30} which may predispose to working channel damage during advancement of accessories. It is also possible that manual cleaning and HLD practices differed between the ASC and our academic endoscopy unit, where dedicated competency-tested SPD personnel perform HLD. Finally, it is possible that these studies reflect center-specific findings and may not be broadly representative of ASCs and teaching hospitals.

Direct endoscopic visualization of residual fluid in endoscope working channels after HLD has only been described in 2 prior studies, one of which reported fluid residue in 95% of endoscope working channels at 24 hours after HLD.^{20, 21} Although some residual fluid was evident in 42% of endoscopes in our study, this was limited to a few small drops only, with a mean fluid residue score of 0.62. The relative infrequency of residual fluid in our study in comparison with the previous reports may be attributable to the 10-minute forced air drying protocol mandated at our institution compared with the shorter drying protocols used in these prior studies.^{20, 21} However, although, residual fluid in our study was most commonly noted within the first 24 hours after reprocessing, it was observed in some endoscopes for up to 72 hours after reprocessing. Residual fluid within endoscope channels is an undesirable finding as it may potentially promote bacterial proliferation, and the multi-society guidelines therefore stress that endoscope working channels be thoroughly dried before storage.³¹ Although hanging endoscopes vertically in drying/storage cabinets with “channel purge” devices to facilitate air circulation may lead to more effective drying,^{31,32} thorough drying of endoscope channels remains a problematic area worthy of further study.

The presence of residual fluid within endoscope working channels and longer latency between HLD and testing both predicted higher ATP values. We hypothesize that each of these factors may be associated with higher ATP levels for different reasons. Higher ATP levels associated with fluid may be due to the fluid harboring bacterial residue. Alternatively, it is possible that the presence of residual fluid may be a surrogate marker for lower overall attention to detail during manual cleaning and HLD. The increased duration of hang time in scopes with a longer latency to testing may have provided additional

opportunities for bacteria to proliferate within endoscope working channels. Additional studies are needed to further elucidate factors that may promote bacterial proliferation within endoscope channels after reprocessing.

Drops of residual fluid were more likely to be present in the longer colonoscope working channels compared to duodenoscopes, which have larger (4.2 mm) diameter working channels. Endoscope length did not predict the presence of residual fluid, but increased endoscope channel diameter predicted a stepwise reduction in fluid residue score. The larger working channel diameter may facilitate air drying after HLD. Visualized residual fluid was occasionally opaque, which may indicate the presence of residual HLD solution or simethicone, as was previously reported.³³ Because simethicone is widely used by many endoscopists, its retention and impact on the adequacy of HLD warrants further study. We do not add simethicone to the water bottle at our institution. Rather, it is used in a low dilution only as necessary and is directly injected using a syringe through the working channel of the endoscopes, typically followed by irrigation and suctioning of water through the channel.

Scratches with adherent peel were evaluated separately from simple scratches, as we were concerned that the peel might act as a nidus for retention of bacteria. However, neither the presence of superficial scratches nor scratches with adherent peel were associated with elevations in ATP bioluminescence. Future studies should evaluate the impact of more severe working channel damage on the propensity for retention of bacterial bioburden. The minor punctate and linear debris visualized within endoscope working channels was also not associated with elevations in ATP bioluminescence and did not appear to be biological residue. The pale punctate debris may potentially reflect particulate desquamation of normal working channel lining, residual HLD chemicals, or precipitated simethicone (dimethicone crystals), as were previously reported in the waterjet channel connector of colonoscopes.³⁴ Dark linear debris may represent sloughing of cleaning brush bristles.

Consensus among investigators was that the SteriCam, its associated software and images rated highly in terms of ease of use and quality. Image resolution was sufficient to distinguish and classify working channel damage. Interobserver correlation was highest in ratings for residual fluid and debris, for scratches with peeling and for channel buckling (R ranging from 0.78–0.89). Increased interobserver variability was seen for superficial scratches, which may reflect limitations in video resolution. Concordance for more severe working channel damage such as deep scratches and perforations was not determined as these findings were not encountered in our study, although one might hypothesize a high concordance for such unequivocal damage. The flexible inspection endoscope offers endoscopy units an additional modality for the surveillance of endoscopes, potentially complementing bacterial cultures and ATP bioluminescence. Routine surveillance inspections may potentially allow earlier detection of occult severe damage, allowing withdrawal of the affected endoscope from use, thereby minimizing the risk of transmission of infection. Additionally, surveillance inspections would enable endoscopy units the ability to track adequacy of their endoscope drying protocols; the development of protocols to ensure consistently adequate endoscope drying is an area particularly worthy of study.

Limitations of our study include the fact that it was conducted at a single institution. Our data contrast starkly with 2 previous reports,^{20, 21} which indicated widespread, severe occult endoscope working channel damage at an ambulatory endoscopy center, necessitating repair/replacement of 85% of endoscopes.²⁰ The reasons for this marked disparity are unclear and require further study to determine if these findings are site specific, reflect differences in endoscope lifetime use history or reflect broader patterns at hospital based endoscopy units and ASCs. A larger multicenter study would have been more effective in determining whether the previous reports of widespread working channel damage were site-specific or broadly representative of the true prevalence of occult endoscope channel damage. Our endoscope sample size was limited by the number and types of endoscopes in use in our facility. No endoscopes failed a leak test during this study period and potential channel perforations, which occur from time to time in any endoscopy unit, were not noted. Detection of biofilms within endoscope working channels may require advanced imaging techniques such as electron microscopy and visual inspection of endoscope working channels may potentially miss subtle biofilms.³⁵ We evaluated ATP bioluminescence to assess for microbial residue and did not obtain culture data on our endoscopes. ATP bioluminescence has been validated as a method for surveillance of flexible endoscopes after manual cleaning.^{23, 24} Our group and others have also described ATP bioluminescence for surveillance of flexible endoscopes after HLD.^{22, 36, 37} However, although low ATP values are reassuring, they do not reliably indicate absence of microbial residue within endoscope working channels.^{23, 25} Conventional microbial culture appears to be more sensitive than ATP bioluminescence.^{25, 36} Nevertheless, endoscope cultures for microbial surveillance also remain controversial and potentially prone to environmental contamination,³⁸ and have not been endorsed by the American Society for Microbiology or by the 2016 multi-society guidelines for endoscope reprocessing.³¹

Our findings should be reassuring to the larger endoscopy community. Although vigilance continues to be necessary to prevent endoscope-transmitted infections, our study conducted in a busy endoscopy unit in which a broad range of procedures are performed by endoscopists with varied skill levels, indicated predominantly minor damage to endoscopes, not associated with elevated ATP values. The flexible inspection endoscope used in this study enables direct visualization of channel damage, debris and fluid residue. This, along with our proposed rating system, may offer endoscopy units an additional modality for the surveillance of endoscopes, potentially complementing bacterial cultures and ATP bioluminescence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Acronyms

ATP	Adenosine triphosphate
HLD	High level disinfection
SPD	Sterile processing department
ASC	Ambulatory surgery center
IQR	Interquartile Range

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Figure 1.

Schematic depicting the full spectrum of working channel damage from mild to severe: superficial scratches and scratches with adherent peel are almost ubiquitous and consistent with normal “wear and tear.” The significance of deeper scratches and burns is uncertain and these findings should trigger discussion with the manufacturer. Channel buckling may compromise the channel lumen, may impair the ability to advance accessory devices and may impair manual cleaning; channel repair is indicated. Perforations and related stains usually fail leak testing; channel repair is indicated.

Figure 2.

Images depicting working channel damage and residue visualized in endoscopes, including (A) superficial scratches at the inlet region (left) and along the endoscope shaft (right), (B) scratches with adherent peel, perpendicular to circular rings of the endoscope bending segment (left) and along the endoscope shaft (right) (C) channel buckling of the endoscope shaft, (D) drops of residual fluid and (E) white punctate (left) and black linear (right) residual debris.

Figure 3.

Graphical boxplot representation of investigator ratings for scratch abundance and characteristics, scratches with adherent peel and residual fluid/debris. Boxes represent interquartile range. Horizontal lines within boxes represent median rating. Whiskers represent the lowest or highest data point still within a 1.5-multiple of the interquartile range. *Dots* represent outliers.

TABLE 1**Damage, debris, and fluid ranking scale**

Working channel findings	Endoscope inspection ratings
Damage *	
Scratch characteristics	0 (None) - No scratches visualized
	1 (Mild) - Superficial, with regular margins, <1 image field in length
	2 (Moderate) - Deeper, with irregular margins or >1 image field in length
	3 (Severe) - Deep with irregular margins
Scratch severity	0 (None) - No scratches visualized
	1 (Mild) - <10 scratches visualized
	2 (Moderate) - 10–20 scratches visualized
	3 (Severe) - >20 scratches visualized
Adherent peel	0 (None) - No adherent peel visualized
	1 (Mild) - Localized to 1 small (<1 cm) site
	2 (Moderate) - Present in 2–3 locations or 1 1-2-cm site
	3 (Severe) - Present in >3 locations or single >2 cm site
Burns *	0 (None) - No burns visualized
	1 (Mild) - Single localized burn
	2 (Moderate) - Burns visualized in >1 site
	3 (Severe) - Burn with associated channel perforation
Channel buckling *	0 (None) - No channel buckling visualized
	1 (Mild) - Mild channel buckling present in 1 area
	2 (Moderate) - Channel buckling with associated moderate narrowing of channel lumen
	3 (Severe) - Channel buckling with associated channel perforation
Stains *	0 (None) - No stains visualized
	1 (Mild) - Single localized stain
	2 (Moderate) - Stain visualized in >1 site
	3 (Severe) - Stain with associated channel perforation
Perforation *	0 (None) - No perforation visualized
	1 (Mild) - Single discrete site of perforation visualized
	2 (Moderate) - Perforation associated with buckling, burn, or stain
	3 (Severe) - Larger or multiple sites of perforation
Debris	
Dark colored debris	0 (None) - No dark colored debris
	1 (Mild) - Small dark particles or linear debris in up to 3 locations
	2 (Moderate) - Small dark particles or debris in >3 locations or larger debris in 1 location
	3 (Severe) - Larger dark particles or debris in >1 location
Light colored debris	0 (None) - No light colored/reflective debris
	1 (Mild) - Small light-colored/reflective particles or residue in up to 3 locations

Working channel findings	Endoscope inspection ratings
	2 (Moderate) - Small light-colored/reflective particles or residue in >3 locations, or larger debris/residue in 1 location
	3 (Severe) - Larger light-colored/reflective particles or debris in >1 location or present in continuous large patches
Other (ie, bristles, biologic residue)	
Fluid *	
Clear	0 (None) - No clear fluid
	1 (Mild) - Up to 5 individual drops of clear fluid within channel
	2 (Moderate) - 6 to 10 individual drops of clear fluid within channel
	3 (Severe) - Greater than 10 individual drops of clear fluid or pooling of fluid within channel
Opaque, may reflect simethicone in fluid	0 (None) - No opaque fluid
	1 (Mild) - Up to 5 individual drops of opaque fluid within channel
	2 (Moderate) - 6 to 10 individual drops of opaque fluid within channel
	3 (Severe) - Greater than 10 individual drops of opaque fluid or pooling of fluid within channel

* Findings associated with critical risk. The endoscope should be sent to the manufacturer for servicing and repair.

TABLE 2

Endoscope damage and residue

Endoscope type (no. evaluated), median (IQR)	Scratch abundance	Scratch characteristics	Scratches with adherent peel	Overall damage	Fluid residue	Residual debris	ATP values
Gastroscope (18)	1.0 (1.0–2.0)	1.3 (1.0–2.0)	1.7 (1.0–2.3)	2.0 (1.0–2.0)	0.0 (0.0–1.0)	1.3 (1.0–2.0)	11 (6–41)
Therapeutic gastroscope (4)	1.3 (1.0–2.0)	1.3 (1.0–2.0)	0.5 (0.0–1.0)	1.0 (1.0–2.3)	0.0 (0.0–0.0)	1.7 (1.0–2.0)	11 (5–52)
Colonoscope (16)	1.3 (1.0–13)	1.3 (1.0–1.7)	1.3 (0.3–2.0)	1.7 (1.0–2.0)	0.7 (0.0–1.0)	1.0 (1.0–2.0)	10 (8–13)
Pediatric colonoscope (17)	1.3 (1.0–1.3)	1.3 (1.0–1.3)	1.0 (0.3–2.0)	1.7 (1.0–2.0)	0.7 (0.0–0.7)	1.0 (1.0–2.0)	11 (8–13)
Duodenoscope (7)	1.0 (1.0–1.3)	1.0 (1.0–1.3)	1.0 (0.0–1.0)	1.0 (1.0–2.0)	0.0 (0.0–0.0)	1.0 (1.0–2.0)	9 (5–11)
Echoendoscope (5)	1.0 (1.0–1.0)	1.3 (1.0–1.7)	0.3 (0.3–1.0)	1.3 (1.0–1.3)	0.0 (0.0–2.7)	1.0 (1.0–1.0)	10 (10–14)
<i>P</i> values							
Gastroscope vs colonoscope	.65	.85	.68	.47	.36	.46	.25
Gastroscope vs duodenoscope	.98	.09	.21	.16	.08	.89	.25
Gastroscope vs echoendoscope	.59	.98	.07	.24	.75	.46	.99
Colonoscope vs duodenoscope	.71	.04	.39	.18	.01	.76	.59
Colonoscope vs echoendoscope	.42	.91	.18	.25	.93	.61	.28
Duodenoscope vs echoendoscope	.64	.23	.50	.86	.13	.57	.24
Therapeutic gastroscope vs gastroscope	.36	.19	.03	.29	.06	.38	.98
Pediatric colonoscope vs colonoscope	.51	.36	.41	.64	.72	.61	.48

IQR, Interquartile range; *ATP*, adenosine triphosphate.

TABLE 3

Predictors of channel ATP values

Predictor	Univariate estimate (95% CI)		Multivariate estimate including fluid, debris, and latency (95% CI)	
	Independent	Clustered	Independent	Clustered
Scratch abundance	-8.6 (-16.8, -0.3) $P = .04$	-8.9 (-20.3, 3.0) $P = .14$	–	–
Scratch characteristic	-1.6 (-9.6, 6.3) $P = .69$	-2.3 (-5.3, 0.7) $P = .13$	–	–
Adherent peel	2.6 (-0.9, 6.1) $P = .14$	2.4 (-0.1, 4.9) $P = .06$	–	–
Fluid	4.9 (1.5–8.2) $P = .004$	4.8 (2.3–7.2) $P = .0001$	6.3 (3.8–8.8) $P < .0001$	6.1 (2.1–10.1) $P = .003$
Debris	9.5 (4.2–14.9) $P = .0005$	9.7 (1.2–18.1) $P = .03$	0.1 (-4.2, 4.3) $P = .98$	0.5 (-1.9, 3.0) $P = .66$
Latency	5.1 (3.8–6.6) $P < .0001$	4.9 (4.9–5.0) $P < .0001$	5.6 (4.3–6.9) $P < .0001$	5.3 (4.9–5.7) $P < .0001$
Uses	-0.2 (-0.8, 0.5) $P = .60$	-0.2 (-0.7, 0.2) $P = .36$	–	–
Channel width	-4.5 (-11.8, 2.7) $P = .22$	–	–	–
Predictors of channel fluid				
Predictor	Univariate estimate (95% CI)		Multivariate estimate including fluid, debris and latency (95% CI)	
	Independent	Clustered	Independent	Clustered
Scratch abundance	0.02 (-0.54, 0.58) $P = .96$	0.02 (-0.62, 0.66) $P = .96$	–	–
Scratch characteristic	0.19 (-0.33, 0.72) $P = .48$	0.21 (-0.24, 0.67) $P = .36$	–	–
Adherent peel	0.14 (-0.09, 0.37) $P = .25$	0.14 (0.00, 0.28) $P = .048$	–	–
Debris	0.56 (0.20–0.92) $P = .002$	0.56 (0.28–0.84) $P < .0001$	0.75 (0.39–1.11) $P < .0001$	0.73 (0.54–0.93) $P < .0001$
Latency	-0.07 (-0.20, 0.05) $P = .24$	-0.07 (-0.08, -0.05) $P < .0001$	-0.14 (-0.26, -0.02) $P = .02$	-0.13 (-0.18, -0.08) $P < .0001$
Uses	0.03 (-0.01, 0.08) $P = .11$	0.04 (0.01, 0.06) $P = .012$	0.00 (-0.01, 0.01) $P = .88$	0.03 (-0.01, 0.06) $P = .11$
Channel width	-0.49 (-0.96, -0.02) $P = .04$	–	-0.41 (-0.94, 0.13) $P = .13$	–

ATP, Adenosine triphosphate; CI, confidence interval.

TABLE 4

Interobserver agreement

	Reviewer 1	Reviewer 2	Reviewer 3	R mean
Scratch abundance	0.32	0.52	0.4	0.41
Scratch character	0.25	0.64	0.3	0.39
Adherent peel	0.67	1	0.67	0.78
Damage	0.19	1	0.19	0.46
Fluid	0.84	1	0.84	0.89
Debris	0.67	1	0.67	0.78

R1 = interobserver agreement between Reviewer 1 and Reviewer 2.

R2 = interobserver agreement between Reviewer 1 and Reviewer 3.

R3 = interobserver agreement between Reviewer 2 and Reviewer 3.