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Challenges in achieving effective high-level disinfection in endoscope reprocessing

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Endoscope reprocessing is often ineffective, and microbes frequently remain on endoscopes after the use of high-level disinfectants (HLDs). Several factors impact reprocessing effectiveness, including non-adherence to guidelines, use of damaged endoscopes, use of insoluble products during endoscopy, insufficient cleaning, contaminated rinse water, and inadequate drying before storage. Our team suspected that issues with HLD chemistries and monitoring could also contribute to reprocessing failures. We conducted a mixed-methods analysis of published literature, our interviews with frontline personnel, and evidence from our previous studies. The evidence showed that reusable HLDs commonly failed tests for minimum effective concentration (MEC) before their maximum usage periods. MEC tests also detected failures associated with single-use HLDs that did not fully deploy. These failures were due to product issues, process complexities, and personnel non-adherence with guidelines and manufacturer instructions. HLDs will likely continue to be used for the foreseeable future. More research is needed to assess real-world practice patterns related to the high-level disinfection step and MEC testing and to establish more realistic usage periods for reusable HLD chemistries. Manufacturers and researchers should evaluate the ability of technological solutions and engineered safeguards to overcome human error. Recognition of the need for quality improvement is growing, and infection preventionists should take action to build on this momentum and collaborate with manufacturers, endoscopists, and reprocessing personnel to improve the effectiveness of high-level disinfection.

Over the past 10 years, evidence has mounted that endoscope reprocessing is frequently not effective. Studies have documented microbial growth rates of 16%,[1] 35%,[2] 41%,[3] 47%,[4] 58%,[5] 60%,[6-8] 64%,[9] and 71%[10] in samples from flexible endoscopes following the use of high-level disinfectants (HLDs). Even when double high-level disinfection was performed per recommendations from the US Food and Drug Administration (FDA)[11] and experts,[12,13] culturable aerobic bacteria were present 5%-40% of the time.[1,8,14,15]

Reprocessing failures can have dire consequences for patients, and infections have been associated with ureteroscopes,[3,16,17] cystoscopes,[18,19] bronchoscopes,[20-22] colonoscopes,[23] gastroscopes,[24] and duodenoscopes.[25-30] Attack rates have been high, ranging from 6% for bronchoscopes[21] to 35% for duodenoscopes[25] and ureteroscopes.[16] Post-endoscopy infections remain common (>3%) even when patients receive prophylactic antimicrobials.[3,16,17]

Our team has studied endoscope reprocessing effectiveness since 2007, and we have assessed reprocessing practices and outcomes for more than 900 endoscopes across the Unites States. We identified several factors that contribute to reprocessing failures, and other studies have echoed our findings. These factors include the following:

1. Human factors contributing to non-adherence with guidelines, standards, and manufacturer instructions for use (IFU)[5,10,16,23,25,31-34]
2. Clinical use of endoscopes with visible damage[4,5,7,10,26,29,34-36]

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3. Use of products that may interfere with reprocessing (simethicone, lubricants, and tissue glue)[37-40]
4. Presence of residual soil after manual cleaning[4,5,7,9,20,25,41]
5. Rinse-water quality issues[5,6,10,42]
6. Retained moisture in fully reprocessed endoscopes.[5,7,10,36,40]

In this context, reprocessing failures would not be unexpected. However, reprocessing failures have also been documented when no breaches were apparent.[3,28,29,43]

The recent literature has not included evidence exploring problems with the high-level disinfection step itself. Our research team has observed improper high-level disinfection practices during site visits, including the use of expired products, improper HLD temperature, inadequate testing for the minimum effective concentration (MEC) of HLDs, and improper storage of MEC test strips. The purpose of this report is to describe the steps we took to evaluate the prevalence and nature of problems specific to HLD use and monitoring.

DATA SOURCES AND ANALYTIC METHODS

We performed a mixed-methods analysis involving a grounded theory approach to identify additional factors that might be contributing to high-level disinfection failures. Grounded theory is a method used to determine what is occurring in the field by interviewing participants, making qualitative observations, and identifying patterns from diverse data sources.[44,45]

Literature review

A literature search was conducted using PubMed. Search terms included endoscopes, high-level disinfection, minimum effective concentration, minimum recommended concentration, test strip, indicator strip, *ortho*-phthalaldehyde (OPA), glutaraldehyde, peracetic acid, hydrogen peroxide, and automated endoscope reprocessor (AER) manufacturers and models. Our team also reviewed manufacturer IFU and searched FDA and Centers for Medicare and Medicaid Services (CMS) databases for reports related to high-level disinfection practices.

Interviews with frontline personnel

Semi-structured interviews with 7 experienced infection prevention, sterile processing, and endoscopy staff from diverse geographies and institutions were conducted to learn more about their real-world experience with HLDs, AERs, and MEC testing. Interviewees described their AERs, HLDs, current practices, and perspectives on challenges with high-level disinfection. Interview notes were analyzed using grounded theory to identify themes and patterns in the responses.

Retrospective review of data from audits and site visits

During our previous studies,[5-7,9,10,31,34,37,38] we recorded results and incidental findings on checklists and audit forms. These archived records were reviewed using grounded theory analysis.

Survey of sterile processing technicians and managers

In 2018, our team performed statistical analysis on data derived from an extensive online survey on endoscope reprocessing we conducted in collaboration with the International Association of Healthcare Central Service Materiel Management (IAHCSMM).[33] Completed surveys were submitted by 2,334 members from the United States and 11 other countries. The dataset did not include any personal identifiers and provided a cross-sectional view of current reprocessing practices and perspectives among respondents who were largely certified sterile processing professionals and worked in hospitals.[33]

HLD AND MEC TESTING GUIDELINES AND IFU

The survey found that the most commonly used HLDs were OPA, hydrogen peroxide, peracetic acid, and glutaraldehyde.[33] Our review of IFU uncovered substantial variation in HLD concentrations, exposure times, temperatures, and allowable use periods (Table 1). Several interviewees reported using HLDs that were kept in large reservoirs, reused for various periods of time, and then discarded and replaced (reusable HLDs). Others reported using concentrated solutions that are dispensed from large jugs during each cycle (single-shot HLDs) or small single-use containers of HLD that are diluted for each high-level disinfection cycle and discarded afterward (single-use HLDs).

According to the IFU, each HLD has a manufacturer-labeled expiration date indicating its shelf life. There is an additional expiration date that technicians record on each container when it has been opened, as well as a maximum reuse period that defines how long the solution can be used repeatedly (Table 1). For example, the manufacturer instructions for Acecide-C peracetic acid state that the HLD

Table 1
HLD characteristics for automated reprocessing

Chemistry	Product	Type*	Concentration	MEC	Exposure time (min)	Exposure temperature	Maximum reuse period (d)
OPA	ASP Cidex OPA[46]	Reusable	0.55%	0.3%	5	25°C	14
	ASP Cidex OPA-C Concentrate[47]	Single-shot	5.75%	0.055%	5	50°C	NA†
	Metrex MetriCide OPA Plus[48]	Reusable	0.6%	0.3%	5	25°C	14
	Medivators Rapicide OPA/28[49]	Reusable	0.575%	0.35%	5	20°C	28
PA	Medivators Rapicide PA 30°C[50]	Single-shot	0.105 g	0.085%	5	30°C	NA‡
	Steris S40[51]	Single-use	35%	0.182%	6	45.5-60°C	NA
	Olympus Acecide-C[52,53]	Reusable	0.31-0.34%	0.2%	7	20°C	5
Glutaraldehyde	ASP Cidex Activated Glutaraldehyde[54]	Reusable	2.4%	1.5%	45	25°C	14
	Medivators Rapicide[55]	Reusable	2.5%	1.5%	5	35°C	28
	Metrex MetriCide[56,57]	Reusable	2.6%	1.5%	45	25°C	14
	Metrex MetriCide 28[58,59]	Reusable	2.5%	1.8%	90	25°C	28
	Olympus Aldahol 1.8[60]	Reusable	3.4%	1.8%	10	20°C	14
H_2O_2	Steris Revital-Ox RESERT[61]	Reusable	2%	1.5%	8	20°C	21

H_2O_2, hydrogen peroxide; *HLD*, high-level disinfectant; *MEC*, minimum effective concentration; *NA*, not applicable; *OPA*, *ortho*-phthalaldehyde; *PA*, peracetic acid.
*Reusable HLD, a large amount of HLD is placed in a reservoir and reused for multiple cycles; single-use HLD, HLD concentrate in a single-use container is diluted for use and discarded following each cycle; single-shot HLD, a small amount of "fresh" concentrated HLD is taken from large jugs and diluted for each cycle and the bottle can be used within 21 or 80 days after opening.
†Single-shot HLD used within 80 days after opening.
‡Single-shot HLD used within 21 days after opening.

solution may be reused for up to 5 days or until the MEC test fails, whichever occurs first.

IFU state that MEC test strips should be immersed in the HLD for a specified dip time, and color changes should be interpreted after a certain amount of time (read time) (Table 2). Current guidelines[62,63] and IFU[64-70] recommend MEC testing during each reprocessing cycle to ensure that the HLD concentration exceeds the MEC, which is the level required to "achieve the claimed microbicidal activity."[62] Each HLD requires a different test strip that has particular IFU and pass/fail conditions, manufacturer-defined shelf life, open-container expiration date, and storage requirements (eg, keeping the container closed; maintaining a certain temperature, humidity, or light level).[64-71] Many test strips also require quality control checks on each newly opened bottle, which generally involves testing full-strength and diluted HLD to ensure that the test strips provide correct readings.[65,67-69,71-73]

HLD AND AER FAILURES

Our literature review uncovered several studies from the 1980s to the early 2000s that assessed the efficacy and other features of various HLDs for flexible endoscopes.[74-80] Two studies detected microbes after high-level disinfection.[75,76] Four articles assessed the dilution of reusable HLDs over time,[77-80] highlighting the necessity of MEC testing to ensure effectiveness.

To determine the extent of problems with HLD concentrations, we asked frontline staff about their experience with AER cycles and high-level disinfection failures identified through MEC testing. Two interviewees reported that MEC testing was critical because their HLDs generally did not reach the maximum use period. At one site, 28-day glutaraldehyde consistently failed within 21 days. A site with 14-day glutaraldehyde had to change the HLD every week instead of every 2 weeks. One manager speculated that early HLD failures were due to dirty or wet endoscopes being put into the AER, which could dilute the glutaraldehyde.

Interviewees also reported HLD concentration issues with single-use peracetic acid cups. AER cycles failed when the powdered buffer and concentrated peracetic acid in the cup did not fully deploy and left thick residue in the cup or AER basin. They reported that shipping and storage conditions may have affected HLD usability.

These anecdotal reports were reinforced by IAHCSMM survey responses. Nearly half (46%) of respondents experienced AER cycle failures in the previous month, and 16% documented more than 3 failures during that time frame.[33] Reasons for AER failures included running out of chemicals and issues with temperature control, water filters, fluid flow rates, channel blockage, and leak test failures. These factors can impact HLD effectiveness.

NON-ADHERENCE TO HLD GUIDELINES AND STANDARDS

We have observed widespread non-adherence to minimum standards for HLD use and MEC testing at many sites. In one study, steps were skipped or done incorrectly for 99% of the endoscopes,[31] and substandard high-level disinfection practices were among the errors made. Our literature review identified several early studies that described suboptimal MEC testing practices. Two 1992 studies revealed that MEC testing was not performed in 73%[81] to 76%[82] of sites. A 2003 study found that test strips were not user friendly and endoscopy staff interpreted them incorrectly >12% of the time.[74] Researchers in 2010 evaluated reprocessing practices at 20 Brazilian facilities and found that 80% of endoscopes were not exposed to HLDs for the proper amount of time, and MEC testing was performed in only 15% of reprocessing cycles.[83] We were unable to identify recent prospective studies on real-world high-level disinfection practices or MEC testing. Most (79%) respondents to our IAHCSMM survey indicated that MEC tests were performed every cycle, but 17% reported testing MEC less often, and 4% tested less than once per day or never performed MEC tests at all. Only 51% reported documenting MEC results.[33]

Our review of FDA and CMS reports revealed that manufacturers and surveyors have also identified non-compliance with high-level disinfection practices and MEC testing (Table 3). These errors have negatively impacted patient outcomes. One FDA outbreak report described 2 cystoscopy patients who developed *Klebsiella pneumoniae* infections that required intravenous antibiotics.[93] Investigators reported that leak testing was not done, and MEC was tested only once every 2 weeks. A CMS report described a situation where an infection preventionist discovered that expired HLDs had been used to reprocess endoscopes.[94] Surveyors cited the institution for using endoscopes reprocessed with expired HLDs on 45 patients, including one with a history of hepatitis. They concluded that the facility's failure to adequately investigate the incidents "potentially jeopardized the health and safety of the patients involved." Given the lengthy period of time during which the high-level disinfection practices may not have been appropriate, 3,400 patients were notified about their potential exposure to bloodborne pathogens.[95]

WHY IS NON-ADHERENCE SO PREVALENT?

Complex IFU and inadequate training

One common barrier described by frontline staff was reprocessing IFU complexity. Most IAHCSMM survey respondents (84%) had read IFU for flexible endoscopes, but one-third of them reported that the IFU were not understandable or feasible.[33] Recent FDA post-market

Table 2
MEC testing instructions for various manufacturers

Chemistry	Brand	Dip time (s)	Read time (s)	Pass	Fail
OPA	Medivators Rapicide OPA/28[64]	3	90	Green	Blue
	ASP Cidex OPA[67]	1	90	Purple	Any blue
	Metrex MetriCide OPA Plus[72]	2	60	Magenta	Any yellow
PA	Medivators Rapicide PA[71]	1	30-60	Black	Any other color
	Steris Verify[66,*]	360	0-1,800	Pink	Blue, gray/beige or not clearly pink
	Olympus Acecide-C Test[70]	3	10[†]	Black	Any white
Glutaraldehyde	ASP Cidex Solution[68]	3	75	Purple	Any orange
	Metrex MetriTest 1.8% and 1.5%[73]	2	60	Purple	Any yellow
	Olympus Aldechek[69]	2	60	Purple	Any yellow
H_2O_2	Steris RevitalOx RESERT R60[65]	2	60	Blue or purple	Any pink

H_2O_2, hydrogen peroxide; *MEC*, minimum effective concentration; *OPA*, *ortho*-phthalaldehyde; *PA*, peracetic acid
*The test strip is placed in the automated endoscope reprocessor for the duration of the cycle and should be read immediately or within 30 min (1,800 s) of cycle completion.
†The 10-s read time consists of removal of excess fluid within 3 s and reading the strip 7 s after removal of excess fluid.

Table 3
CMS and FDA reports of MEC or HLD non-compliance

Report ID	Year	Expired MEC strips	Expired HLD	MEC bottle stored open	Improper HLD practices	Improper MEC testing	Missing records
CMS 15079[84]	2017		✓		✓	✓	✓
CMS 14533[85]	2017			✓			✓
CMS 24631[86]	2018					✓	✓
CMS 21220[87]	2018	✓			✓		✓
FDA 7182901[88]	2017					✓	
FDA 8072138[89]	2018		✓				
FDA 7558700[90]	2018					✓	
FDA 7833925[91]	2018		✓		✓		
FDA 7639885[92]	2018	✓					✓
FDA 8364744[93]	2019					✓	

CMS, Centers for Medicare and Medicaid Services; *FDA*, Food & Drug Administration; *HLD*, high-level disinfectant; *MEC*, minimum effective concentration.

surveillance studies into human factors that impact duodenoscope reprocessing effectiveness found that IFU are "difficult for reprocessing staff to comprehend and follow."[96] Concerns about IFU complexity are amplified by insufficient training. Most survey respondents (70%) received a week or less of training before beginning to reprocess endoscopes independently.[33] Only 46% received model-specific training that covered unique steps required for reprocessing each type of endoscope used in their facilities. Multiple types of AERs were in use at 17% of facilities, and the use of multiple systems increased the number of IFU that technicians must understand and remember. This also raises the possibility of using the wrong combination of HLD chemistries and MEC testing materials.

Time pressure and workflow

Most survey respondents (70%) reported feeling pressured to reprocess endoscopes more quickly, and 26% reported one of their biggest challenges was not having enough time for reprocessing.[33] Our studies have found that proper endoscope reprocessing requires well over 1 hour per endoscope[32,97]; yet, frontline staff reported being expected to turn endoscopes around much more rapidly. In addition, 17% of respondents reported skipping steps or doing them more quickly than they should due to time pressure. Two interviewees reported that manufacturer sales representatives had recommended shortening or disabling AER cleaning and rinsing cycles in order to save time and improve turnaround. During previous studies, we discovered that AER manufacturers' representatives had disabled AER cleaning cycles in 2 other hospitals.[5,10] Incidents where AERs were disabled or cycles were improperly programmed have also been reported to the FDA.[98-100]

Our review of IFU determined that MEC testing requires substantial time (1 to 8+ minutes) (Table 2). Performing MEC tests was perceived as a "hassle" by 170 survey respondents, and 280 disliked changing HLDs. Interviewees said that responding to failed MEC tests was time intensive, as technicians had to interrupt their workflow to dispose of the used HLD and container, refill and reprogram the AER, and possibly rerun the cycle. Failures of single-use HLD cups were also disruptive, and technicians reported having to clean concentrated peracetic acid out of AER basins before the cycle could be rerun. Every MEC test failure requires documentation before technicians can continue with other duties. For these reasons, interviewees indicated that technicians disliked discovering failed MEC tests. Interviewees also reported that technicians commonly had difficulties interpreting test strip color changes and making pass/fail determinations. One interviewee said, "Dipsticks are hard to read—the results aren't black and white and that's a huge problem." In addition, institutions must ensure that all personnel responsible for tasks that require color interpretation are able to discern the colors.[101] According to interviewees, when a colorblind staff member is on duty, other personnel have to interpret MEC tests, which is distracting and takes additional time.

Occupational health concerns

Concerns about chemical exposure were frequently cited as a reason why technicians might not adhere to HLD guidelines. The IAHCSMM survey found that 47% of respondents were bothered by odors in the reprocessing area.[33] When technicians change the HLD, they may be exposed to vapors from highly concentrated chemistries. Safety data sheets state that glutaraldehyde and peracetic acid can cause respiratory issues.[102,103] During site visits, we frequently noticed strong HLD odors in reprocessing areas even when the HLD was not being changed, possibly due to insufficient air changes or poor ventilation mechanisms.

HLDs can cause burns[104] and skin[105] and lung[106] irritation, and FDA reports describe injuries related to HLD exposure. Some interviewees stated that some technicians are afraid of peracetic acid and therefore dislike working with it, and others disregard safety concerns and fail to wear proper personal protective equipment when working with HLDs. One infection preventionist described a technician who neglected to wear a face shield and sustained permanent eye damage due to a peracetic acid splash.

One interviewee said that changing HLD was a grueling process because each AER held 8 gallons of 14-day glutaraldehyde that generally had to be changed weekly due to failed MEC tests. Technicians and the safety management team were uncomfortable with the occupational health risks associated with this regimen, and the site was switching to peracetic acid. In the IAHCSMM survey, 459 respondents reported that changing chemical solutions caused them pain, and 26% reported pain that was significant or so extreme that they could not complete the task.[33]

WHERE DO WE GO FROM HERE?

We are troubled by mounting evidence demonstrating that HLD effectiveness is suboptimal in real-world settings.[1-10,14,15] Previous research has established that multiple factors contribute to reprocessing failures.[16,20,26,40,42] Our first endoscope reprocessing study (2008-2009) found that 27 of 36 participants (75%) had been pressured to work quickly, and a technician admitted skipping steps.[31] Occupational health problems were common, with respiratory issues reported by 18% and physical discomfort by 50%. These health problems were so severe that 25% missed work, and 30% reported the symptoms interfered with their ability to function at work and/or at home. Since then, little progress has been made, and we have repeatedly observed the same problems at study sites and on audits.

Clearly, these long-standing barriers to adherence and overall reprocessing effectiveness must be addressed; however, the groundbreaking research described in this manuscript identified additional

problems specific to the high-level disinfection step and MEC testing that ensures the chemistries are strong enough to reliably eliminate microbes. As Rutala and Weber[13] stated, the margin for error with high-level disinfection is simply not large enough to tolerate any deviations from optimal practices. They have recommended a shift toward sterilization, and we agree that sterilization may be necessary for improving patient safety. In the meantime, high-level disinfection will continue to be used by many institutions, and it is essential to address the quality issues described in this paper.

Given our findings, we recommend that multisite studies and ongoing surveillance be conducted to assess real-world practice patterns and determine the nature and prevalence of breaches related to the high-level disinfection step and MEC testing. Research should also be done to establish realistic usage periods for reusable HLD chemistries in real-world settings. In addition, researchers should assess the ability of technological solutions such as automation and engineered safeguards (eg, AERs that shut down when anything does not meet manufacturer criteria) to overcome shortcomings that have been attributed to human error. For these technological innovations to be successful, it is essential that manufacturers and their representatives be partners in striving for excellence in the field. Neither company representatives nor customers should seek to deviate from IFU or to shorten automated cycles to save time. Before implementing time-saving or cost-cutting measures, infection prevention and reprocessing managers should review evidence provided by the manufacturer that reprocessing is still effective when these steps are skipped or processes are truncated. Ideally, manufacturers and facility personnel will provide mutual support and accountability for ensuring that practices align with guidelines and IFU.

We see a strong parallel between endoscopy and aviation in terms of high stakes for patients and passengers as well as complex protocols and procedures. Aviation has addressed these challenges by cultivating an environment of safety, accountability, and discipline. Aircraft manufacturers have the responsibility for building safe aircraft, and everyone from pilots to mechanics and support personnel undergo mandatory training, certification, and use checklists on every flight. However, adoption of similar measures in the medical field has lagged. One explanation for this difference may be that on-board airline personnel assume the same risk as passengers, whereas health care personnel do not bear the same risk from contaminated endoscopes as their patients.

Leaders in pulmonology and otolaryngology are beginning to recognize the risk of infection from improper reprocessing practices and call for comprehensive solutions.[107-109] As Gawande[110] stated, when quality improvements are not implemented, the cause is generally not laziness or unwillingness to change, but rather the "reason is more often that the necessary knowledge has not been translated into a simple, usable, and systematic form." Given the current situation, it is essential for infection preventionists to leverage this momentum and take the lead in coordinating efforts of endoscopists, reprocessing personnel, and others to implement robust quality management programs that address all of the factors that impact HLD effectiveness.

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References

1. Snyder GM, Wright SB, Smithey A, Mizrahi M, Sheppard M, Hirsch EB, et al. Randomized comparison of 3 high-level disinfection and sterilization procedures for duodenoscopes. Gastroenterology 2017;153:1018-25.
2. Saliou P, Le Bars H, Payan C, Narbonne V, Cholet F, Jezequel J, et al. Measures to improve microbial quality surveillance of gastrointestinal endoscopes. Endoscopy 2016;48:704-10.
3. Legemate JD, Kamphuis GM, Freund JE, Baard J, Oussoren HW, Spijkerman IJ, et al. Pre-use ureteroscope contamination after high-level disinfection: reprocessing effectiveness and the relation with cumulative ureteroscope use. J Urol 2019;201:1144-51.
4. Ofstead CL, Wetzler HP, Eiland JE, Heymann OL, Held SB, Shaw MJ. Assessing residual contamination and damage inside flexible endoscopes over time. Am J Infect Control 2016;44:1675-7.
5. Ofstead CL, Quick MR, Wetzler HP, Eiland JE, Heymann OL, Sonetti DA, et al. Effectiveness of reprocessing for flexible bronchoscopes and endobronchial ultrasound bronchoscopes. Chest 2018;154:1024-34.
6. Ofstead CL, Doyle EM, Eiland JE, Amelang MR, Wetzler HP, England DM, et al. Practical toolkit for monitoring endoscope reprocessing effectiveness: identification of viable bacteria on gastroscopes, colonoscopes, and bronchoscopes. Am J Infect Control 2016;44:815-9.
7. Ofstead CL, Wetzler HP, Heymann OL, Johnson EA, Eiland JE, Shaw MJ. Longitudinal assessment of reprocessing effectiveness for colonoscopes and gastroscopes: results of visual inspections, biochemical markers, and microbial cultures. Am J Infect Control 2017;45:e26-33.
8. Visrodia K, Hanada Y, Pennington KM, Tosh PK, Topazian MD, Petersen BT. Duodenoscope reprocessing surveillance with adenosine triphosphate testing and terminal cultures: a clinical pilot study. Gastrointest Endosc 2017;86:180-6.
9. Ofstead CL, Wetzler HP, Doyle EM, Rocco CK, Visrodia KH, Baron TH, et al. Persistent contamination on colonoscopes and gastroscopes detected by biologic cultures and rapid indicators despite reprocessing performed in accordance with guidelines. Am J Infect Control 2015;43:794-801.
10. Ofstead CL, Heymann OL, Quick MR, Eiland JE, Wetzler HP. Residual moisture and waterborne pathogens inside flexible endoscopes: evidence from a multisite study of endoscope drying effectiveness. Am J Infect Control 2018;46:689-96.
11. Food and Drug Administration. Supplemental measures to enhance duodenoscope reprocessing: FDA safety communication. Available from: https://www.fdanews.com/ext/resources/files/08-15/081015-duodenoscopes-fda.pdf?1520541508. Accessed September 18, 2019.
12. Rutala WA, Weber D. ERCP scopes: what can we do to prevent infections? Infect Control Hosp Epidemiol 2015;36:643-8.
13. Rutala WA, Weber DJ. Reprocessing semicritical items: current issues and new technologies. Am J Infect Control 2016;44:e53-62.
14. Rex DK, Sieber M, Lehman GA, Webb D, Schmitt B, Kressel AB, et al. A double-reprocessing high-level disinfection protocol does not eliminate positive cultures from the elevators of duodenoscopes. Endoscopy 2017;50:588-96.
15. Bartles RL, Leggett JE, Hove S, Kashork CD, Wang L, Oethinger M, et al. A randomized trial of single versus double high-level disinfection of duodenoscopes and linear echoendoscopes using standard automated reprocessing. Gastrointest Endosc 2018;88:306-13.
16. Kumarage J, Khonyongwa K, Khan A, Desai N, Hoffman P, Taori SK. Transmission of multi-drug resistant *Pseudomonas aeruginosa* between two flexible ureteroscopes and an outbreak of urinary tract infection: The fragility of endoscope decontamination. J Hosp Infect 2019;102:89-94.
17. Greene DJ, Gill BC, Hinck B, Nyame YA, Almassi N, Krishnamurthi V, et al. American Urological Association antibiotic best practice statement and ureteroscopy: does antibiotic stewardship help? J Endourol 2018;32:283-8.
18. Wendelboe AM, Baumbach J, Blossom DB, Frank P, Srinivasan A, Sewell CM. Outbreak of cystoscopy related infections with *Pseudomonas aeruginosa*: New Mexico, 2007. J Urol 2008;180:588-92.
19. Jimeno A, Alcalde MM, Ortiz M, Rodriguez A, Alcaraz B, Vera F. Outbreak of urinary tract infections by *Salmonella* spp. after cystoscopic manipulation. Actas Urol Esp 2016;40:646-9.
20. Galdys AL, Marsh JW, Delgado E, Pasculle AW, Pacey M, Ayres AM, et al. Bronchoscope-associated clusters of multidrug-resistant *Pseudomonas aeruginosa* and carbapenem-resistant *Klebsiella pneumoniae*. Infect Control Hosp Epidemiol 2019;40:40-6.
21. Guy M, Vanhems P, Dananche C, Perraud M, Regard A, Hulin M, et al. Outbreak of pulmonary *Pseudomonas aeruginosa* and *Stenotrophomonas maltophilia* infections related to contaminated bronchoscope suction valves, Lyon, France, 2014. Euro Surveill 2016;21.
22. Jorgensen SB, Bojer MS, Boll EJ, Martin Y, Helmersen K, Skogstad M, et al. Heat-resistant, extended-spectrum beta-lactamase-producing *Klebsiella pneumoniae* in endoscope-mediated outbreak. J Hosp Infect 2016;93:57-62.
23. Reddick E. Investigation of salmonellosis outbreak following a hospital endoscopy: a public health case study. Can J Infect Control 2017;32:156-9.
24. Bajolet O, Ciocan D, Vallet C, de Champs C, Vernet-Garnier V, Guillard T, et al. Gastroscopy-associated transmission of extended-spectrum beta-lactamase-producing *Pseudomonas aeruginosa*. J Hosp Infect 2013;83:341-3.
25. Rauwers AW, Troelstra A, Fluit AC, Wissink C, Loeve AJ, Vleggaar FP, et al. Independent root cause analysis of contributing factors, including dismantling of 2 duodenoscopes, to an outbreak of multidrug-resistant *Klebsiella pneumoniae*. Gastrointest Endosc 2019;90:793-804.

26. Ross AS, Baliga C, Verma P, Duchin J, Gluck M. A quarantine process for the resolution of duodenoscope-associated transmission of multidrug-resistant *Escherichia coli*. Gastrointest Endosc 2015;82:477-83.
27. Robertson P, Smith A, Anderson M, Stewart J, Hamilton K, McNamee S, et al. Transmission of *Salmonella enteritidis* after endoscopic retrograde cholangiopancreatography because of inadequate endoscope decontamination. Am J Infect Control 2017;45:440-2.
28. Humphries RM, Yang S, Kim S, Muthusamy VR, Russell D, Trout AM, et al. Duodenoscope-related outbreak of a carbapenem-resistant *Klebsiella pneumoniae* identified using advanced molecular diagnostics. Clin Infect Dis 2017;65:1159-66.
29. Shenoy ES, Pierce VM, Walters MS, Moulton-Meissner H, Lawsin A, Lonsway D, et al. Transmission of mobile colistin resistance (mcr-1) by duodenoscope. Clin Infect Dis 2018;68:1327-34.
30. Kim S, Russell D, Mohamadnejad M, Makker J, Sedarat A, Watson RR, et al. Risk factors associated with the transmission of carbapenem-resistant *Enterobacteriaceae* via contaminated duodenoscopes. Gastrointest Endosc 2016;83:1121-9.
31. Ofstead CL, Wetzler HP, Snyder AK, Horton RA. Endoscope reprocessing methods: a prospective study on the impact of human factors and automation. Gastroenterol Nurs 2010;33:304-11.
32. Ofstead CL, Hopkins KM, Eiland JE, Wetzler HP. Managing bronchoscope quality and cost: results of a real-world study. PROCESS 2019;March/April:63-71.
33. Ofstead CL, Hopkins KM, Eiland JE, Wetzler HP. Endoscope reprocessing: current practices and challenges in the field. PROCESS 2019;July/August:60-71.
34. Ofstead CL, Heymann OL, Quick MR, Johnson EA, Eiland JE, Wetzler HP. The effectiveness of sterilization for flexible ureteroscopes: a real-world study. Am J Infect Control 2017;45:888-95.
35. Barakat MT, Girotra M, Huang RJ, Banerjee S. Scoping the scope: endoscopic evaluation of endoscope working channels with a new high-resolution inspection endoscope (with video). Gastrointest Endosc 2018;88:601-11.
36. Thaker AM, Kim S, Sedarat A, Watson RR, Muthusamy VR. Inspection of endoscope instrument channels after reprocessing using a prototype borescope. Gastrointest Endosc 2018;88:612-9.
37. Ofstead CL, Wetzler HP, Johnson EA, Heymann OL, Maust TJ, Shaw MJ. Simethicone residue remains inside gastrointestinal endoscopes despite reprocessing. Am J Infect Control 2016;44:1237-40.
38. Ofstead CL, Hopkins KM, Eiland JE, Wetzler HP. Widespread clinical use of simethicone, insoluble lubricants, and tissue glue during endoscopy: a call to action for infection preventionists. Am J Infect Control 2019;47:666-70.
39. van Stiphout SH, Laros IF, van Wezel RA, Gilissen LP. Crystallization in the waterjet channel in colonoscopes due to simethicone. Endoscopy 2016;48:E394-5.
40. Barakat MT, Huang RJ, Banerjee S. Simethicone is retained in endoscopes despite reprocessing: Impact of its use on working channel fluid retention and adenosine triphosphate bioluminescence values (with video). Gastrointest Endosc 2010;89:115-23.
41. Visrodia KH, Ofstead CL, Yellin HL, Wetzler HP, Tosh PK, Baron TH. The use of rapid indicators for the detection of organic residues on clinically used gastrointestinal endoscopes with and without visually apparent debris. Infect Control Hosp Epidemiol 2014;35:987-94.
42. Seidelman JL, Wallace RJ, Iakhiaeva E, Vasireddy R, Brown-Elliott BA, McKnight C, et al. *Mycobacterium avium* pseudo-outbreak associated with an outpatient bronchoscopy clinic: lessons for reprocessing. Infect Control Hosp Epidemiol 2019;40:106-8.
43. Epstein L, Hunter JC, Arwady MA, Tsai V, Stein L, Gribogiannis M, et al. New Delhi metallo-beta-lactamase-producing carbapenem-resistant *Escherichia coli* associated with exposure to duodenoscopes. JAMA 2014;312:1447-55.
44. Rieger KL. Discriminating among grounded theory approaches. Nurs Inq 2019;26:e12261.
45. Singh S, Estefan A. Selecting a grounded theory approach for nursing research. Glob Qual Nurs Res 2018;5, 2333393618799571.
46. Advanced Sterilization Products. Cidex OPA instructions for use. Irvine (CA): Advanced Sterilization Products; 2016.
47. Advanced Sterilization Products. Cidex OPA concentrate instructions for Use. Irvine (CA): Advanced Sterilization Products; 2017.
48. Metrex Research Corp. Metricide OPA Plus Solution. Available from: https://www.metrex.com/sites/default/files/content/education-file/education-file-upload/metricide-opa-plus-wall-chart-77-1191.pdf. Accessed September 16, 2019.
49. Medivators. Medivators Rapicide OPA/28 high-level disinfectant instructions for use. Minneapolis (MN): Medivators; 2016.
50. Medivators. Medivators Rapicide PA high-level disinfectant directions for use. Minneapolis (MN): Medivators; 2015.
51. STERIS. S40 Sterilant concentrate package insert. Mentor (OH): STERIS Corporation; 2018.
52. Olympus. Acecide-C high-level disinfectant and sterilant instruction manual. Center Valley (PA): Olympus Corporation of the Americas; 2011.
53. Olympus. Acecide®-C high-level disinfectant. Available from: https://medical.olympusamerica.com/sites/default/files/pdf/Acecide-C_Product_Brochure.pdf. Accessed September 17, 2019.
54. Advanced Sterilization Products. Cidex activated dialdehyde solution (glutaraldehyde 2.4%) instructions for use. Irvine (CA): Advanced Sterilization Products; 2018.
55. Medivators. Medivators Rapicide [glutaraldehyde]: high-level disinfectant and sterilant. Minneapolis (MN): Medivators; 2013.
56. Metrex Research Corp. MetriCide technical bulletin. Available from: https://www.metrex.com/sites/default/files/content/education-file/education-file-upload/metricide-technical-bulletin-us-en.pdf. Accessed September 16, 2019.
57. Metrex Research Corp. MetriCide. Available from: www.metrex.com/en-us/products/high-level-disinfectants/metricide. Accessed September 18, 2019.
58. Metrex Research Corp. MetriCide™ 28 [glutaraldehyde]. Romulus (MI): Metrex Research Corp; 2010.
59. Metrex Research Corp. MetriCide 28. Available from: www.metrex.com/en-us/products/high-level-disinfectants/metricide-28. Accessed September 18, 2019.
60. Olympus. Aldahol 1.8: high-level disinfectant instruction manual. Center Valley (PA): Olympus Corporation of the Americas; 2013.
61. STERIS. Revital-Ox RESERT high-level disinfectant instructions for use. Mentor (OH): STERIS Corporation; 2011.
62. AAMI, ANSI. ANSI/AAMI ST91: 2015 flexible and semi-rigid endoscope processing in health care facilities. Arlington (VA): Association for the Advancement of Medical Instrumentation; 2015. p. 1-70.
63. Van Wicklin SA, Conner R, Spry C. Guideline for processing flexible endoscopes. Guidelines for perioperative practice. Denver (CO): Association of periOperative Registered Nurses; 2017. p. 1-84.
64. Medivators. Rapicide OPA/28 Test Strips instructions for use. Minneapolis (MN): Medivators; 2016.
65. STERIS. Revital-Ox RESERT R60 Solution Test Strip instructions for use. Mentor (OH): STERIS Corporation; 2015.
66. STERIS. Verify chemical indicator for S40 sterilant instructions for use. Mentor (OH): STERIS Corporation; 2012.
67. Advanced Sterilization Products. Cidex OPA solution test strips instructions for use. Irvine (CA): Advanced Sterilization Products; 2015.
68. Advanced Sterilization Products. Cidex [glutaraldehyde] solution test strips instructions for use. Irvine (CA): Advanced Sterilization Products; 2015.
69. Olympus. Aldechek ALDAHOL 1.8 glutaraldehyde indicator instructions for use. Center Valley (PA): Olympus Corporation of the Americas; 2013.
70. Olympus. Acecide peracetic acid test strips–quick reference. Center Valley (PA): Olympus Corporation of the Americas; 2011.
71. Medivators. Rapicide PA high-level disinfection test strip directions for use. Minneapolis (MN): Medivators; 2016.
72. Metrex Research Corp. Quick reference for using MetriCide® OPA Plus Solution Test Strips. Available from: https://www.metrex.com/sites/default/files/content/education-file/education-file-upload/guide-to-using-metricide-opa-plus-solution-test-strips-77-1401.pdf. Accessed July 15, 2019.
73. Metrex Research Corp. Quick reference for using MetriTest Test Strips. Available from:https://www.metrex.com/sites/default/files/content/education-file/education-file-upload/guide-to-using-metritest-test-strips-77-1400.pdf. Accessed September 18, 2019.
74. Cooke RP, Goddard SV, Whymant-Morris A, Sherwood J, Chatterly R. An evaluation of Cidex OPA (0.55% *ortho*-phthalaldehyde) as an alternative to 2% glutaraldehyde for high-level disinfection of endoscopes. J Hosp Infect 2003;54:226-31.
75. Vesley D, Melson J, Stanley P. Microbial bioburden in endoscope reprocessing and an in-use evaluation of the high-level disinfection capabilities of Cidex PA. Gastroenterol Nurs 1999;22:63-8.
76. Foliente RL, Kovacs BJ, Aprecio RM, Bains HJ, Kettering JD, Chen YK. Efficacy of high-level disinfectants for reprocessing GI endoscopes in simulated-use testing. Gastrointest Endosc 2001;53:456-62.
77. Hession SM. Endoscope disinfection by *ortho*-phthalaldehyde in a clinical setting: an evaluation of reprocessing time and costs compared with glutaraldehyde. Gastroenterol Nurs 2003;26:110-4.
78. Leong D, Dorsey C, Klapp M. Dilution of glutaraldehyde by automatic endoscope machine washers: the need for a quality control program. Am J Infect Control 1987;15:86.
79. Cooke RP, Goddard SV, Chatterley R, Whymant-Morris A, Cheale J. Monitoring glutaraldehyde dilution in automated washer/disinfectors. J Hosp Infect 2001;48:243-4.
80. Cox HM, Cheung K, Fletcher AJ, Whitby RM, Hickman PE. Glutaraldehyde concentration in the sterilization of endoscopes. Pathology 1995;27:362-4.
81. Kaczmarek RG, Moore RM Jr., McCrohan J, Goldmann DA, Reynolds C, Caquelin C, et al. Multi-state investigation of the actual disinfection/sterilization of endoscopes in health care facilities. Am J Med 1992;92:257-61.
82. Reynolds CD, Rhinehart E, Dreyer P, Goldmann DA. Variability in reprocessing policies and procedures for flexible fiberoptic endoscopes in Massachusetts hospitals. Am J Infect Control 1992;20:283-90.
83. Barbosa JM, Souza AC, Tipple AF, Pimenta FC, Leao LS, Silva SR. Endoscope reprocessing using glutaraldehyde in endoscopy services of Goiania, Brazil: a realidade em servicos de endoscopia de Goiania, GO. Arq Gastroenterol 2010;47:219-24.
84. Centers for Medicare and Medicaid Services. Yakima Valley Memorial Hospital, Yakima, WA: statement of deficiencies. Baltimore (MD): Centers for Medicare and Medicaid Services; 2018.
85. Centers for Medicare and Medicaid Services. Mary Greeley Medical Center, Ames, IA: statement of deficiencies. Baltimore (MD): Centers for Medicare and Medicaid Services; 2017.
86. Centers for Medicare and Medicaid Services. The Physicians' Hospital, Anadarko OK: statement of deficiencies. Baltimore (MD): Centers for Medicare and Medicaid Services; 2018.
87. Centers for Medicare and Medicaid Services. Wagoner Community Hospital, Wagoner OK: statement of deficiencies. Baltimore (MD): Centers for Medicare and Medicaid Services; 2018.

88. FDA. MAUDE adverse event report: Medivators Inc. DSD-201 Automated Endoscope Reprocessor 7182901. Silver Spring (MD): Food and Drug Administration; 2018.
89. FDA. MAUDE adverse event report: Advanced Sterilization Products Cidex OPA Solution Biocides Solutions 8072138. Silver Spring (MD): Food and Drug Administration; 2018.
90. FDA. MAUDE adverse event report: Advanced Sterilization Products US Cidex OPA Solution Biocides Solution 7558700. Silver Spring (MD): Food and Drug Administration; 2018.
91. FDA. MAUDE adverse event report: Advanced Sterilization Products Cidex OPA Solution Biocides Solutions 7833925. Silver Spring (MD): Food and Drug Administration; 2018.
92. FDA. MAUDE adverse event report: Medivators Rapicide PA High-Level Disinfectant Test Strips Chemical Indicator 7639885. Silver Spring (MD): Food and Drug Administration; 2018.
93. FDA, MAUDE adverse event report: Olympus Medical Systems Corporation Olympus OES Cystonephrofiberscope 8364744, 2019, Food and Drug Administration; Silver Spring (MD).
94. Centers for Medicare and Medicaid Services. Palomar Health: statement of deficiencies and plan of correction. Baltimore (MD): Centers for Medicare and Medicaid Services; 2010.
95. Garrick D. Escondido: PPH testing 3,400 patients when only 45 at risk of exposure; officials blame use of expired disinfectant. The San Diego Union-Tribune; June 15, 2010.
96. Food and Drug Administration. The FDA provides interim results of duodenoscope reprocessing studies conducted in real-world settings: FDA safety communication. Available from: https://www.fda.gov/medical-devices/safety-communications/fda-provides-interim-results-duodenoscope-reprocessing-studies-conducted-real-world-settings-fda. Accessed September 16, 2019.
97. Ofstead CL, Quick MR, Eiland JE, Adams SJ. A glimpse at the true cost of reprocessing endoscopes: results of a pilot project. Communiqué 2017;Jan/Feb:63-78.
98. FDA. MAUDE adverse event report: Medivators Inc. DSD-201 Automated Endoscope Reprocessor 8332264. Silver Spring (MD): Food and Drug Administration; 2019.
99. FDA. MAUDE adverse event report: Medivators Inc. DSD-201 Automated Endoscope Reprocessor 8368486. Silver Spring (MD): Food and Drug Administration; 2019.
100. FDA. MAUDE adverse event report: Medivators DSD-201 Automated Endoscope Reprocessor 8466920. Silver Spring (MD): Food and Drug Administration; 2019.
101. Centers for Medicare and Medicaid Services. UCSF Medical Center, San Francisco CA: statement of deficiencies. Baltimore (MD): Centers for Medicare and Medicaid Services; 2015.
102. Metrex Research Corp. Metrex MetriCide™ 28 material safety data sheet. Available from: https://www.metrex.com/sites/default/files/content/education-file/education-file-upload/MetriCide%2028%20Canada%20MSDS%20(7-14-2015).pdf. Accessed September 16, 2019.
103. Olympus Corporation of the Americas. *Acecide®-C* use-solution material safety data sheet. 2014. Available from: https://medical.olympusamerica.com/sites/default/files/pdf/Acecide-C_MSDS_Use_Solution.pdf. Accessed September 18, 2019.
104. FDA. MAUDE adverse event report: Medivators Advantage Plus Automated Endoscope Reprocessor 7293237. Silver Spring (MD): Food and Drug Administration; 2018.
105. FDA. MAUDE adverse event report: Medivators Advantage Plus Automated Endoscope Reprocessor 8214665. Silver Spring (MD): Food and Drug Administration; 2018.
106. FDA. MAUDE adverse event report: Medivators Advantage Plus Automated Endoscope Reprocessor 8180192. Silver Spring (MD): Food and Drug Administration; 2018.
107. Mehta AC, Gildea T. Response to Shulimzon and Chatterji. Chest 2019;155:1301.
108. Pynnonen MA, Whelan J. Reprocessing flexible endoscopes in the otolaryngology clinic. Otolaryngol Clin North Am 2019;52:391-402.
109. Mehta AC, Gildea T. Burying our heads in the sand: cross-contamination during bronchoscopy. Chest 2018;154:1001-3.
110. Gawande A. The checklist manifesto. New York (NY): Picador; 2010.