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Medical instrument reprocessing: current issues with cleaning and cleaning monitoring

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The complexity of medical devices has increased over the past 10 years, and outbreaks of infections due to contaminated devices have focused attention on the need to adequately clean medical devices in order to ensure the adequacy of disinfection and sterilization. There has been a paradigm shift in reprocessing of medical devices, with increased emphasis on a quality management systems approach that requires validated cleaning instructions from manufacturers and ongoing monitoring by reprocessing personnel to ensure adequacy of cleaning. This article reviews the current issues related to medical device reprocessing and summarizes the approaches used for monitoring cleaning efficacy for surgical instruments and flexible endoscopes.

Reusable medical devices are designed to be used repeatedly on patients, and the manufacturer's instructions for use (MIFU) must include specific, validated instructions for cleaning as well as for disinfection and/or sterilization. Guidelines for the preparation of instructions for reusable medical devices outline what manufacturers need to provide to ensure that the health care facility can reproducibly provide a device that is safe to use on patients.[1,2] If medical devices (eg, surgical instruments, phacoemulsion handpieces) are not properly reprocessed, there is a risk that they will be contaminated with microorganisms that could be transmitted to multiple patients, causing colonization or infections.[3-7] The review by Southworth[8] indicated that infections transmitted by contaminated instruments have occurred for a variety of instrument types and a range of disinfection and sterilization modalities, including failures in cleaning, disinfection, sterilization, and rinsing, with eye surgery instruments (eg, phacoemulsion handpieces) being most frequently reported. Similarly, endoscope contamination has been attributed to failure of cleaning, disinfection, or sterilization; biofilm formation; and wet storage.[9-15] The survey published by Thaker et al[14] indicated that implementation of the 2015 Food and Drug Administration (FDA) supplemental measures for duodenoscopes[16] has been variable in the United States.

As awareness of infection transmission through contaminated medical devices increases, it is becoming increasingly apparent that a quality management systems (QMS) approach[17,18] is needed, regardless of the type of medical device being processed. A QMS approach has been defined as "a formalized system that documents processes, procedures, and responsibilities for achieving quality policies and objectives. A QMS helps coordinate and direct an organization's activities to meet customer and regulatory requirements and improve its effectiveness and efficiency on a continuous basis."[19] The quality monitoring processes for sterilization technologies are well established;[20-22] however, for high-level disinfectant (HLD) processes, only recently have quality monitoring processes been introduced that go beyond just checking reusable HLDs to ensure a minimal effective concentration.[19,20,23] Despite this progress, there has been little in the way of establishing quality monitoring of manual or automated cleaning efficacy for any type of reusable medical device, despite the recognition that disinfection and sterilization processes will fail if the cleaning has not been performed adequately. The objective of this report is to review issues related to the adequacy of cleaning and cleaning monitoring for surgical instruments and flexible endoscopes using both manual and automated methods.

SURGICAL INSTRUMENTS

Microbial and organic load

The microbial load on patient-used surgical instruments (Table 1) is relatively low; Cloutman-Green et al[24] reported $\leq 10^2$ colony-forming units (CFU)/cm^2, which is similar to the findings of other published

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Table 1
Contamination levels on surgical instruments compared to those on flexible endoscopes after patient use before cleaning

Contaminant	Surgical instrument maximum level detected*	Flexible endoscope maximum level detected†
Bacteria, $\log_{10}$ CFU/cm^2	1.7	7.0
Protein, μg/cm^2	2413.0	115.5
Hemoglobin, μg/cm^2	108.0	85.5

*Data were extracted from Cloutman-Green et al.[24]
†Data were extracted from Alfa et al.[41]

studies.[25-27] The microbial levels varied depending on the type of surgery, with cesarean-section surgery showing the highest CFU/cm^2.[24] Significantly fewer organisms were detected from clean-contaminated vs contaminated surgeries (average of 41 ± 84 CFU/device vs 201 ± 126 CFU/device), and infected surgical procedures were found to have the highest level of contamination.[27] The most common microbes detected from surgical instruments used for clean orthopedic surgery were coagulase-negative staphylococci, *Staphylococcus aureus*, and *Bacillus* spp.[26] Detection of Gram-negative bacteria increased in clean-contaminated and infected orthopedic surgery, but the predominant isolates were still *Staphylococcus* and *Bacillus* spp,[26] a finding similar to data from other published studies.[25,27]

The quantitative assessment of organic residuals on patient-used surgical instruments (Table 1) confirmed there were high levels of organic residuals, with average total organic carbon (TOC) levels ranging from 23 to 64 μg/cm^2; protein, from 4 to 942 μg/cm^2; and hemoglobin, from 9 to 34 μg/cm^2.[24] Biofouling of surgical power tools is also common.[28] In addition to organic residuals, retention of tissue and bone fragments inside cannulated orthopedic instruments may contribute to steam sterilization failures, leading to infection transmission.[29-31] The recent study by Smith et al[32] confirmed that retained bone debris inside cannulated orthopedic instruments may not be sterile despite steam sterilization.

These studies indicate that, although surgical instruments typically have low microbial levels, the level of organic residuals is high, and inadequate removal of patient secretions, tissue, and bone, for example, may result in failure of the sterilization process.[29-33] These findings emphasize the importance of the cleaning process to ensuring adequate sterilization.

Manual vs automated cleaning

Medical devices are cleaned manually as well as by automated washers. The current ANSI/AAMI ST79[22] guideline supports the efficacy of automated washer-disinfectors (WDs) for reprocessing the majority of surgical instruments (often with sonication before cleaning in the WD). The automation of cleaning ensures that the process will be reproducibly performed and done more efficiently than manual cleaning,[22,34] and the WD provides thermal decontamination of instruments which reduces the infection risk to reprocessing personnel who then handle the instruments for packaging and sterilization.[22]

For delicate surgical instruments, such as those used for eye surgery, cleaning in a WD cannot be done.[35] For phacoemulsion handpieces, the use of automated flushing units with sterile distilled or reverse osmosis water is recommended by the MIFU; however, reprocessing staff may question the cleaning efficacy when detergent is not used. The guiding principle in such situations is to ensure that the validated manufacturer's instructions are followed using the water quality and preferably the automated flushing devices recommended and that staff are properly trained regarding the reprocessing of such instruments.[35]

Monitoring cleaning

The adequacy of cleaning of medical devices can be evaluated by monitoring the WD when automated methods are used or by monitoring the cleaned device itself. Current guidelines recommend that monitoring the cleaning efficacy in WDs should be performed at least weekly, preferably daily.[20,22] A wide range of commercial cleaning monitoring tests are available for WDs (Table 2), but it is difficult to compare the efficacy of one WD cleaning monitor to another as there are no current standardized criteria for such tests; for example, what level of defect in detergent concentration, temperature, water quality, or spray-arm water impingement pressure will cause the cleaning monitor to fail? More research is needed to establish standardized criteria for WD cleaning monitors so guidelines can be developed. Despite this limitation, the use of such cleaning monitors does ensure that there is regular monitoring of WD cleaning efficacy within the constraints of the cleaning monitor used.

Rapid cleaning monitoring tests can detect organic residuals such as TOC, protein, hemoglobin, and carbohydrate on the surface of surgical instruments. The ninhydrin test for protein has been evaluated for monitoring surgical instruments;[36] however, this test does not detect all proteins and there are many false negative results, so it has not been widely implemented. Other quantitative assays for TOC and protein can be used.[24] Table 3 shows a comparison of rapid cleaning indicators and summarizes the strengths and weaknesses of these methods. Azizi et al[34] compared 2 rapid adenosine triphosphate (ATP) testing methods to assess the cleaning adequacy of surgical instruments processed through a WD, as well as data from a comparison of cleaning surgical instruments after manual vs WD cleaning using a rapid protein-hemoglobin-carbohydrate test. The authors indicated that the similarity of results from the 2 rapid ATP test kits indicated that the test results were reliable.[34] Recently, ATP testing has been used to demonstrate that the cleaning of ultrasound probes requires improvement.[37] Although rapid ATP tests have been used to assess cleaning adequacy for surgical instruments[34] and ultrasound probes,[37] more clinical studies are needed to establish the cut-off level of ATP (often measured as relative light units [RLUs]) for each test kit that reliably indicates that adequate cleaning has been achieved. Azizi et al[34] reported that the rapid protein-hemoglobin-carbohydrate test (Table 3) demonstrated the superiority of WD cleaning compared to manual cleaning of surgical instruments.

A new development in assessing the cleaning adequacy of surgical instruments has been the use of direct staining of protein surface residuals (Table 3). ProReveal (Synoptics Health; Cambridge, UK) is one example that is commercially available to assess cleaned instruments for residual protein.[38] The cleaned instrument is sprayed with a fluorescent stain solution that binds to protein and fluoresces. The stained instrument is place inside the ProReveal unit, which then images the position and level of fluorescence on the instrument and indicates "pass" or "fail" for the cleaning. This method has been reported to detect nanogram levels of protein,[38] but there have been no published studies on utilization of this device in busy health care reprocessing settings. Limitations of this method include an inability to assess the adequacy of cleaning inside lumens and the requirement that the instrument, once tested, must be recleaned to eliminate the fluorescent stain. More clinical studies are needed before this method can be recommended for routine monitoring of cleaning of surgical instruments processed through a WD.

FLEXIBLE ENDOSCOPES

Microbial and organic load

Compared to surgical instruments, patient-used gastrointestinal flexible endoscopes are contaminated with high microbial loads and

Table 2
Monitoring tests for washer-disinfector cleaning

Rapid washer-disinfector cleaning test (manufacturer)	Description	Endpoint assessment	Washer-disinfector defects detected	Published data*
VERIFY All Clean Test (STERIS Corporation; Mentor, OH)	Bright red test soil contains protein, lipids, and endotoxin. Mesh design of holder mimics difficult-to-clean surfaces.	Visual decision is based on residual red color, as per MIFU.	Detergent concentration Wash cycle time Temperature Water pressure Overloading	None available
Wash-Checks (Getinge Group; Rochester, NY)	Red test soil mimics the removal of blood and tissue from surgical instruments. Design of holder mimics surgical instrument joint.	Visual decision is based on residual red color, as per MIFU.	Detergent concentration Wash cycle time Temperature Water pressure	None available
Chemdye 'SPLAT' test (Gallay Medical & Scientific; Mulgrave, Victoria, Australia)	Organic components are red colored. Design of holder creates cleaning challenge.	Visual decision is based on residual red color, as per MIFU.	Detergent concentration Wash cycle time Temperature Water pressure Overloading	None available
gke Clean-Record (gke GmbH; Waldems-Esch, Germany)	Colored synthetic test soil is on plastic carriers. Different colored indicators assess various cleaning challenges. Design of holder does not create a cleaning challenge.	Visual decision is based on residual color for each type of indicator, as per MIFU.	Detergent concentration and type Wash cycle time Temperature Water pressure Overloading	None available
TOSI (Getinge; Gothenburg, Sweden)	Blood-based red test soil contains hemoglobin, albumin, and fibrin. Design of holder creates a challenge by mimicking uneven surfaces of surgical instruments.	Visual decision is based on residual red color, as per MIFU.	Protolytic detergent concentration Wash cycle time Temperature Water pressure Overloading	Alfa et al;[39] Fruh and Pfeifer[40]
PINNACLE (Serim Research Corporation; Elkart, IN)	Test substrate is dyed protein (orange-pink color). Design of holder does not create a cleaning challenge.	Visual decision is based on lighter color of indicator color pad compared to color of internal control standard pad, as per MIFU.	Enzymatic detergent concentration and activity Wash cycle time Temperature Water pressure	Alfa et al[39]

NOTE. The above are examples of washer-disinfector cleaning indicators from various manufacturers; this table does not provide an all-inclusive list.
MIFU, manufacturer's instructions for use.
*Based on search for peer-reviewed publications using PubMed.

Table 3
Pros and cons of rapid test methods for monitoring cleaning of medical instruments and endoscopes

Item monitored	Methods	Pros	Cons	Guidelines
Medical instruments	Adenosite triphosphate test Organic residuals	Ensures that instrument cleaning is done properly Some published clinical data Good audit and training tool	Cost Staff time Frequency of testing	Variable
	ProReveal	Detection of protein not visible to the naked eye Automated, simple readout (pass or fail)	Cost of unit Staff time Necessary to reprocess instrument tested Two reads required, one for each side No published clinical data	Not included
Flexible endoscopes	Adenosite triphosphate test Organic residuals	Ensures that endoscope cleaning is done properly Much published clinical data Good audit and training tool	Cost Staff time	Recommended in some guidelines Per ST91, test weekly but preferably daily
Automated washers	Multiple commercial methods	Ensures that washer-disinfector is cleaning properly	Cost Staff time	Per all guidelines, test weekly but preferably daily

lower organic loads. Alfa et al[41] found that endoscopes may have up to 10^7 CFU/cm^2 of bacteria and up to 115.5 μg/cm^2 of protein after patient use prior to bedside precleaning (ie, these represent the worst-case levels immediately after patient use). A more recent study by Ofstead et al[42] reported that, for positive controls even after bedside cleaning, the levels of organic and microbial residuals were high (protein, 29 μg/mL and >600 CFU). As such, these types of medical devices are very different from surgical instruments that have low microbial load and high organic residuals immediately after patient procedures, as summarized in Table 1.

Drying of endoscope channels and biofilm formation

As early as 2004, the formation of biofilm was demonstrated by scanning electron microscopy in air-water and suction channels of patient-used flexible endoscopes,[43] and this was still the case for patient-used endoscope channels in 2014.[44] Miner et al[45] demonstrated that there was on average about 200 CFU of bacteria detected per patient-used endoscopes after full reprocessing. They concluded that biofilm may have formed within the endoscope channels and suggested that the US Environmental Protection Agency test[46] for

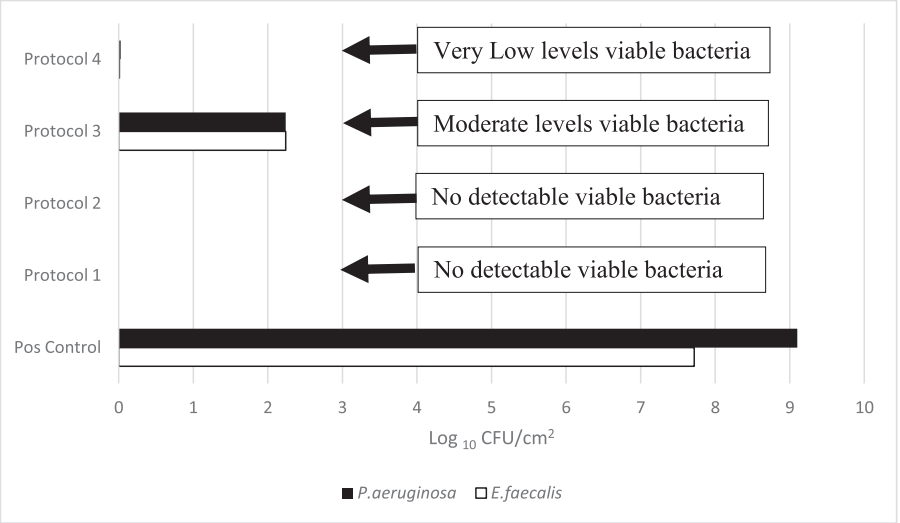
assessment of microbial kill by HLDs did not take into consideration the impact of organic material that is often found in patient-used endoscopes.

The recent data of Rauwers et al[47] indicated that persistent contamination occurred in 22% of fully reprocessed duodenoscopes. Furthermore, the authors stated that, "These results suggest that the present reprocessing and process control procedures are not adequate and safe."[47] Alfa and Sitter[48] were the first to demonstrate that increased microbial levels were detected in patient-ready duodenoscopes due to inadequate drying prior to storage. Studies by Ofstead et al[13,49] have demonstrated persistent moisture in patient-ready endoscope channels stored overnight despite an alcohol rinse and an air purge of all channels (1 minute) in an automated endoscope reprocessor (AER). Their findings indicate that moisture during endoscope storage is a widespread but under-appreciated problem. There is a widespread misconception that the alcohol flush and air purge (1 minute) that are part of the reprocessing cycle in many AERs are sufficient to ensure dry storage. Subsequent clinical studies[14,50] comparing manual air flushing to automated flushing of channels confirmed that elimination of moisture from the channels of duodenoscopes was difficult to achieve by manual flushing of air but that automated air purging after the AER cycle was more effective. Barakat et al[50] demonstrated that 10 minutes of automated air flushing through endoscope channels resulted in no moisture visible by borescope examination of the channels. The issue of moisture in endoscope channels during storage raises concerns that biofilm may form during storage and that such biofilm may prevent adequate cleaning and disinfection.

Manual vs automated cleaning

Recent advances in AERs have included FDA-cleared cleaning cycles that replace the manual cleaning with detergent and channel brushes.[51-53] The automation of this aspect of endoscope cleaning was shown by Ofstead et al[54] to improve compliance with endoscope reprocessing, as it eliminated the human factors involved with manual cleaning (eg, not adequately brushing the endoscope channel and accessories). Several commercially available AERs have FDA-cleared cleaning cycles;[51] however, the recent outbreaks of multidrug-resistant organisms in duodenoscopes and other types of flexible endoscopes have raised questions regarding the efficacy of AER cleaning for the lever and lever recess in duodenoscopes and other levered ultrasound endoscopes. This has resulted in the FDA requiring revalidation of AER cleaning cycles[51] and recommending that manual cleaning still be provided for some types of duodenoscopes and some types of AERs.[51] One aspect that had not been addressed was whether the manual MIFU cleaning instructions could reliably eliminate biofilm within endoscope channels.

Alfa et al[55] undertook a study to assess whether the current MIFU for cleaning the instrument channel could reliably eliminate traditional biofilm. They formed traditional biofilm in a polytetrafluoroethylene (PTFE) channel (the same channel found in Olympus colonoscopes) and then processed the biofilm-containing channel following the MIFU (ie, using pump-assisted flushing of detergent and bristle brush or pull-through channel cleaners followed by rinsing and then liquid chemical sterilization with peracetic acid in an AER). An extract of these results is shown in Figure 1. After 5 rounds of traditional biofilm formation followed by full MIFU reprocessing, detectable growth could be detected under 2 of the 4 sets of test conditions. These findings confirmed that the elimination of bacteria within traditional biofilm from the inner surface of flexible endoscope channels was dependent on the combination of detergent and method of friction used for cleaning (bristle brush or pull-through channel cleaner). The authors suggested that the adequacy of biofilm removal by the cleaning process does impact the efficacy of liquid chemical sterilization with peracetic acid even after as few as 5 repeat rounds of traditional biofilm formation and full MIFU reprocessing. It should be noted that this simulated-use testing was done under "worst-case" conditions where traditional biofilm was formed overnight on each of the 5 consecutive days.



Pos Control: No cleaning, no paracetic acid disinfection
Protocol 1: Renuzyme + bristle brush + paracetic acid in AER
Protocol 2: Renuzyme + pull-through cleaner + paracetic acid in AER
Protocol 3: Intercept + bristle brush + paracetic acid in AER
Protocol 4; Intercept + pull-through cleaner + paracetic acid in AER
Data extracted from Alfa et al[54]

Fig 1. Removal of traditional biofilm from within polytetrafluoroethylene (PTFE) channel following manufacturer's instructions for use. Pos Control, no cleaning, no paracetic acid disinfection; Protocol 1, Renuzyme + bristle brush + paracetic acid in an automated endoscope reprocessor (AER); Protocol 2, Renuzyme + pull-through cleaner + paracetic acid in an AER; Protocol 3, Intercept + bristle brush + paracetic acid in an AER; Protocol 4, Intercept + pull-through cleaner + paracetic acid in an AER. Data extracted from Alfa et al.[54]

Role of simethicone residuals in endoscope channel reprocessing

Recent studies have raised concern about the frequent use of simethicone in flexible endoscopy procedures (to clear bubbles from the mucosal surface) because these residuals persist despite using MIFU for cleaning,[56] and the formation of simethicone crystals can occlude the water channel.[57] The inability to adequately remove even low concentrations of simethicone has been confirmed by recent studies.[50,58] Because simethicone fluid (ie, simethicone oil) is difficult to remove by cleaning and the residual oily fluid is difficult to dry, an environment conducive to biofilm formation could result. The role of simethicone fluid residuals on biofilm formation and the ultimate impact on clinical outcomes is unknown.[58-60] However, as noted in the ECRI health devices alert,[61] Olympus alert,[62] and Benmassaoud and Parent article,[60] the main endoscope manufacturers (Olympus, Pentax, and Fujinon) have all warned about simethicone use because of the inability of MIFU cleaning being able to remove it and the possible impact on the efficacy of HLDs. If simethicone is used in the water bottle, Barakat et al[58] recommended using the lowest possible concentration (0.5%).

Monitoring cleaning of endoscopes

Manual cleaning of endoscopes has been shown to be problematic because human factors play a major role resulting in poor compliance.[54] Therefore, it is logical that this would be a critical step in the overall endoscope reprocessing that should be monitored as part of a QMS approach. The two key components for monitoring manual cleaning are 1) establishment of realistic benchmarks for cleaning adequacy, and 2) rapid test methods that demonstrate that the benchmark for adequate cleaning has been achieved. The original published benchmarks for adequate manual cleaning of flexible endoscope channels were <6.4 $\mu g/cm^2$ protein, <2.2 $\mu g/cm^2$ hemoglobin, and <1.8 $\mu g/cm^2$ carbohydrate.[2,41,63,64] A more recent benchmark for cleaning where pump-assisted cleaning was performed[65] indicated that protein should be <2 $\mu g/cm^2$.

The benchmark for adequate cleaning using rapid ATP tests (many test kits use RLUs as a measure of ATP) varies depending on the manufacturer as different test kits have different sensitivities. As such the RLU cut-off for cleaning adequacy should to be based on the MIFU for that specific test kit. It should be noted that ATP is generated not only by microbes but also by human secretions (eg, serum, mucous secretions, blood) and as such these rapid ATP tests are optimal for assessing adequacy of cleaning (ie, removal of human secretions with or without microorganisms). However, rapid ATP tests are not a substitute for culture to determine if an endoscope is contaminated after HLD use or sterilization.[66,67] Indeed, a low level of ATP (ie, low RLUs) after full reprocessing does not mean that the endoscope is free of microorganisms, as demonstrated by the data of Ofstead et al,[67] who compared ATP and RLUs for patient-ready endoscopes. It is important to recognize that it takes ~100 to 1000 CFU to generate a signal of 1 RLU.[68-70] As such, the use of rapid ATP testing on patient-ready endoscopes gives a false sense of security when low RLU values are obtained. Furthermore, rapid ATP testing cannot replace culture using the FDA/Centers for Disease Control and Prevention (CDC)/American Society of Microbiology[71] culture protocol, as the latter is currently the definitive way to detect microbial contamination of fully reprocessed flexible endoscopes.

Several commercially available rapid test methods for monitoring the manual cleaning adequacy of flexible endoscopes have been shown to flag when the relevant benchmark is not met.[37,39,70,72-74] These rapid test methods are based on detection of residual organic residues (eg, protein, hemoglobin, carbohydrates) or ATP measured as RLUs. Both simulated-use and clinical studies have shown that these rapid cleaning monitors are useful for assessing the adequacy of manual cleaning prior to submitting the flexible endoscope to disinfection or sterilization.[66,67,70,72,73,75] Indeed, monitoring cleaning adequacy is critical, because if clumps of residual biofilm remain after MIFU cleaning, liquid chemical sterilization will fail regardless of the detergent or bristle brush or pull-through channel cleaner used.[55] The inability to kill microbes in mature biofilm has been well documented,[76,77] and detergents that leave clumps of organisms embedded in biofilm can lead to failure of HLDs.[55,77]

The need to monitor manual cleaning of endoscopes is indicated in ST91,[23] and the suggested frequency is weekly, preferably daily (similar to what is recommended for monitoring the cleaning adequacy of washer-disinfectors). Furthermore, the CDC[78] recommends that health care sites offering endoscopy procedures should audit their current processes to identify gaps and to implement appropriate training (with ongoing competency assessment) and monitoring of the adequacy of the endoscope cleaning process, as well as assessments of endoscope contamination. The CDC audit tools for endoscope reprocessing provide modifiable audit documents that facilitate sites adapting them for their specific site needs.[79]

Infection prevention and control specialists need to be proactive in using gap analysis tools to ensure that all aspects of medical device reprocessing follow a QMS approach. Furthermore, the cleaning stage for surgical instruments and flexible endoscopes should be specifically monitored, and if inadequacies are identified these should be reviewed with reprocessing personnel, reprocessing management, and senior administration to ensure that corrective actions are taken. The risk of not being proactive with monitoring and correcting gaps in reprocessing has been made apparent by the collateral damage (eg, lawsuits, bad publicity, lack of public trust) from recent outbreaks of infections attributed to contaminated surgical instruments and flexible endoscopes. The new paradigm for the cleaning stage of medical device reprocessing requires data from rapid monitoring tools to ensure patient safety as part of a QMS approach.

SUMMARY

There has been a paradigm shift over the past 10 years in terms of cleaning medical devices, including surgical instruments and flexible endoscopes, with an emphasis on using a quality management systems approach. This approach ensures that regulations are in place that manufacturers of medical devices must comply with to provide validated cleaning protocols that are feasible and effective within the health care setting. Furthermore, health care facilities that reprocess medical devices, including flexible endoscopes, must monitor the cleaning of such devices to ensure that manual and automated processes are functioning properly.

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