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Flexible gastrointestinal endoscope processing challenges, current issues and future perspectives

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SUMMARY

Background: At present, the most frequent method for processing flexible gastrointestinal (GI) endoscopes is cleaning followed by high-level disinfection as terminal sterilization is often not practicable. Post-processing monitoring studies consistently show high levels of positive cultures remaining on endoscopes, which can lead to patient infection and even fatality. The processing deficiency is attributed to the complex design of endoscopes, incomplete cleaning, formation of biofilms and lack of margin of safety with high-level disinfection.

Objective: To demonstrate that flexible GI endoscopes can be practicably terminally sterilized.

Methods: An endoscope sterilization cycle was developed in a vaporized hydrogen peroxide sterilization system. The cycle was used to study the sterilization of flexible GI endoscopes which included colonoscopes and duodenoscope and material compatibility for both original flexible GI endoscopes and those experimentally modified endoscopes using compatible materials.

Results: Testing demonstrated that the vaporized hydrogen peroxide can sterilize flexible GI endoscopes (colonoscopes, duodenoscope) with a sterility assurance level of 10^{-6}. Additionally, no recoverable survivors were detected when devices were artificially soiled with hard water and serum. Material compatibility test results demonstrated that replacing molybdenum disulphide lubricant with a graphite-based inert lubricant can make them compatible with vaporized hydrogen peroxide sterilizers.

Conclusion: Flexible GI endoscopes can be practicably terminally sterilized using vaporized hydrogen peroxide sterilization technologies if their materials are revised to become compatible.

Introduction

Gastrointestinal (GI) endoscopy procedures are widely performed globally for both diagnostics and therapeutic reasons [1,2]. In the USA, there are an estimated 10 million GI procedures a year [3].

The preferred method for processing semi-critical devices is sterilization according to Spaulding classification [4];

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however, practicable sterilization is difficult to achieve as GI endoscopes are delicate. Currently, the most frequent method of reprocessing is high-level disinfection (HLD). Flexible endoscopes are cleaned at point-of-use immediately after each procedure, followed by manual cleaning and high-level disinfection [5] using chemical disinfectants. Although endoscopes go through a cleaning and disinfection process after every patient use, infection-related cases linked to endoscopes are reported, and continue to increase at an alarming rate [6—9].

A valid question is why these problems persist even though two stages of cleaning are performed (point of use and manual cleaning) followed by HLD. Why is HLD incapable of doing its job? To answer this question, three important factors should be considered: complexity of GI endoscope design, formation of biofilms and margin of safety.

Complexity of GI endoscope design. GI endoscopes can be up to 3.5 m in length and have several narrow channels with inner diameters from 1 to 1.5 mm for air and water channels and 2—6 mm for biopsy/instrument channels [10]. Some of these channels merge or bifurcate, further adding to the design complexity.

Formation of biofilms. Clinical studies have shown that infections associated with reusable endoscopes are primarily initiated by the micro-organisms adhering to the biomaterial surfaces on endoscopes and forming biofilms [8,11,12]. Many inadequately processed endoscopes are contaminated and remain wet after processing [13] which provides a suitable environment for biofilm formation. The formation of endoscopic biofilm during clinical practice can be related to reuse of detergent, manual cleaning, and incomplete drying of processed endoscopes. Developed biofilms protect the micro-organisms from exposure to detergents and germicides, which increase the likelihood of survival through a decontamination process.

Margin of safety. At present there is an insufficient margin of safety associated with the decontamination process of GI flexible endoscopes [14].

To improve the margin of safety, a shift from HLD to sterilization can help. Terminal sterilization is described with a sterility assurance level typically set at 10^{-6}. This surpasses the threshold for chemical disinfection, although it needs to be seen against the reduction of at least 12_{log} attained from a full terminal sterilization cycle [15].

Amongst current commercially available sterilization modalities, only ethylene oxide is both efficacious and compatible with flexible GI endoscopes. However, major drawbacks of ethylene oxide include lack of availability, long turnaround times, high toxicity, flammability, and carcinogenicity [16—18]. Vaporized hydrogen peroxide (with/without plasma or ozone) systems have been available for more than a decade with proven efficacy. They have fast cycle times (usually less than 60 min) and do not release toxic chemicals. However, in the past, vaporized hydrogen peroxide systems have had limited penetration in long and narrow lumens and were not able to sterilize longer flexible endoscopes such as GI endoscopes [10,19, 20].

Recent developments in vaporized hydrogen peroxide sterilization cycles, by creating more turbulence and agitation inside the sterilization chamber through adjusting pressure inside the sterilization chamber, have enabled them to sterilize longer flexible endoscopes. The aim of this study was to evaluate an experimental GI endoscope sterilization cycle for reprocessing of GI flexible endoscopes.

Materials and methods

STERRAD® 100NX Sterilization System (Advanced Sterilization Products Inc., Irvine, CA, USA) was used in this study. An experimental GI endoscope sterilization cycle was developed by creating turbulence inside the chamber such that vaporized hydrogen peroxide molecules could penetrate long and narrow lumens. The full cycle is about 60—70 min, and the hydrogen peroxide concentration inside the chamber was about 5—10 mg/L. Because commercially available trays for STERRAD 100NX System were too small to fit a large colonoscope, a prototype sterilization tray was designed. KIMTECH sterilization wraps from Kimberly Clark, USA were used in this study.

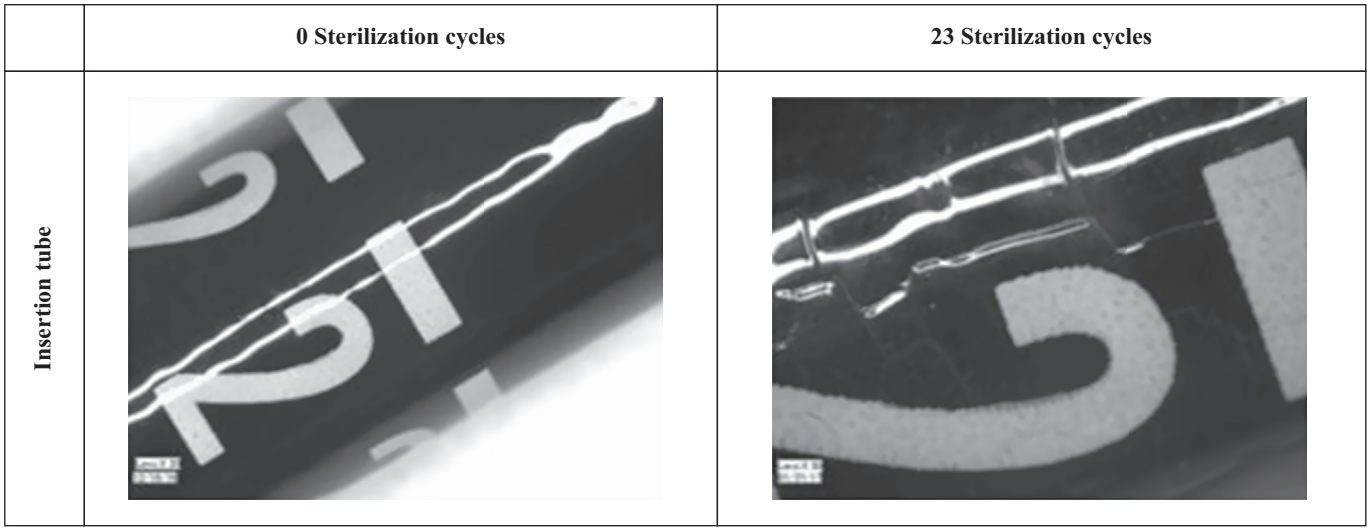

Figure 1. Pentax Medical EG29-i10 gastroscope insertion tube at the beginning and the end of the test. The insertion tube cracked after 23 cycles.

Two colonoscopes, PENTAX Medical EC38-i10L and Olympus CF-HQ190L, a duodenoscope model Olympus TJF-Q180V (with closed elevator wire channel), and a gastroscope, Fujifilm EG-600WR were used. These are amongst the longest, narrowest and heaviest available GI endoscopes. The longest and the narrowest lumens provide the worst-case lumens to sterilize, while heavy devices result in depletion of available sterilant by absorption, condensation and decomposition effects.

Geobacillus stearothermophilus ATCC® 7953™ spores, an aerobic thermophilic bacterium that grows optimally at 55°C, was used and prepared from stock solutions. This micro-organism has high resistance to hydrogen peroxide and is recommended for sterility testing of hydrogen peroxide sterilizers [21].

Sterilization tests

Half-cycle efficacy test

Half-cycle refers to the first half of the experimental cycle, and therefore only half of the vaporized peroxide exposure time. All channels of the endoscopes were inoculated with *G. stearothermophilus* spores, using a direct inoculation method. The inoculum volumes for the suction/biopsy, air/water, and water jet channels were 40, 20, and 10 μL, respectively. The inoculum was pushed into the middle of each channel by means of air. Channel separators were used to isolate the air/water channels while pushing the inoculum to the centre of the channels. After inoculation, the endoscopes were placed in prototype trays. Each half-cycle consisted of two trays. At the end of the cycle, the trays were opened under aseptic conditions. Each channel was flushed individually with sterile recovery fluid. The recovery fluid was vacuum filtered through a sterile 0.45-μm filter unit, and the filter was aseptically transferred to TSA plates. The plates were incubated at least for 48 h at 55—60°C and checked for any growth. Control endoscopes were inoculated alongside the test endoscopes to confirm adequate microbial loading. The recovery efficiency was tested by inoculating each channel with 10—100 cfu of test organism, conditioning for 2 h and then recovering it. The test results showed greater than 50% recovery per channel.

Simulated-use test

Simulated-use tests were performed to assess the efficacy of the full cycle in the presence of a controlled organic and inorganic load. Simulated-use tests are performed as per US Food and Drug Administration (FDA) guidelines [22] using a soil load containing *G. stearothermophilus* spores ($>10^6$ cfu) in 300 ppm AOAC (Association of Official Analytical Chemists) hard water and 5% fetal bovine serum. The endoscopes were inoculated, conditioned, processed as described above. For the simulated-use test, the loads were processed using full sterilization cycle. All samples were incubated and checked for growth after 48 h.

Material compatibility test

Two different tests were performed for materials compatibility.

First, unmodified endoscopes were placed in the sterilizer, and were processed using endoscope sterilization cycle under worst-case conditions (highest sterilizer chamber temperature and hydrogen peroxide dose). After each cycle, the endoscopes were removed from the sterilizer, cooled, visually examined and placed back inside the sterilizer to repeat another cycle.

Second, endoscopes were modified by replacing molybdenum disulphide lubricant with a graphite-based lubricant by a third-party endoscope repair company. After reassembly, endoscopes were examined for functionality and then tested for their materials compatibility in the sterilizer using the same experimental scope sterilization cycle.

Results and discussion

Half-cycle efficacy test

For each endoscope model, half-cycle efficacy testing was performed to provide three data points per channel, i.e. every single channel on each endoscope model was tested three times. The results showed that for all tested endoscopes (Pentax EC38-i10L, Olympus HQ190L and Olympus TJF Q180V) in both top and bottom shelves of the sterilizer became sterile. For control endoscopes, initial inoculum (cfu/channel) for all

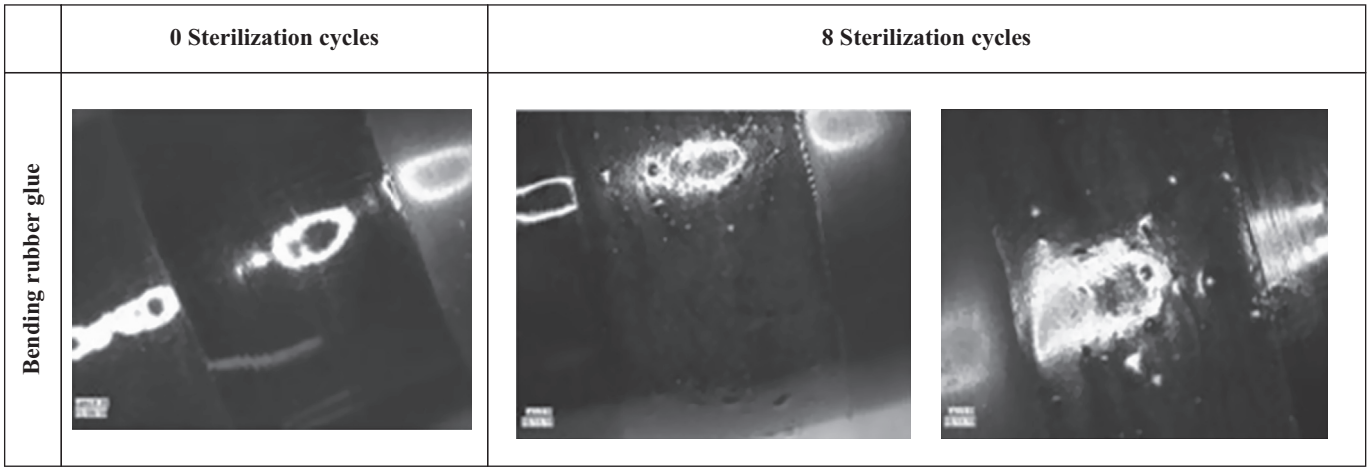

Figure 2. Olympus CF-HQ190L colonoscope glue bead at the beginning and end of test. Blistering of the glue was observed after 8 cycles.

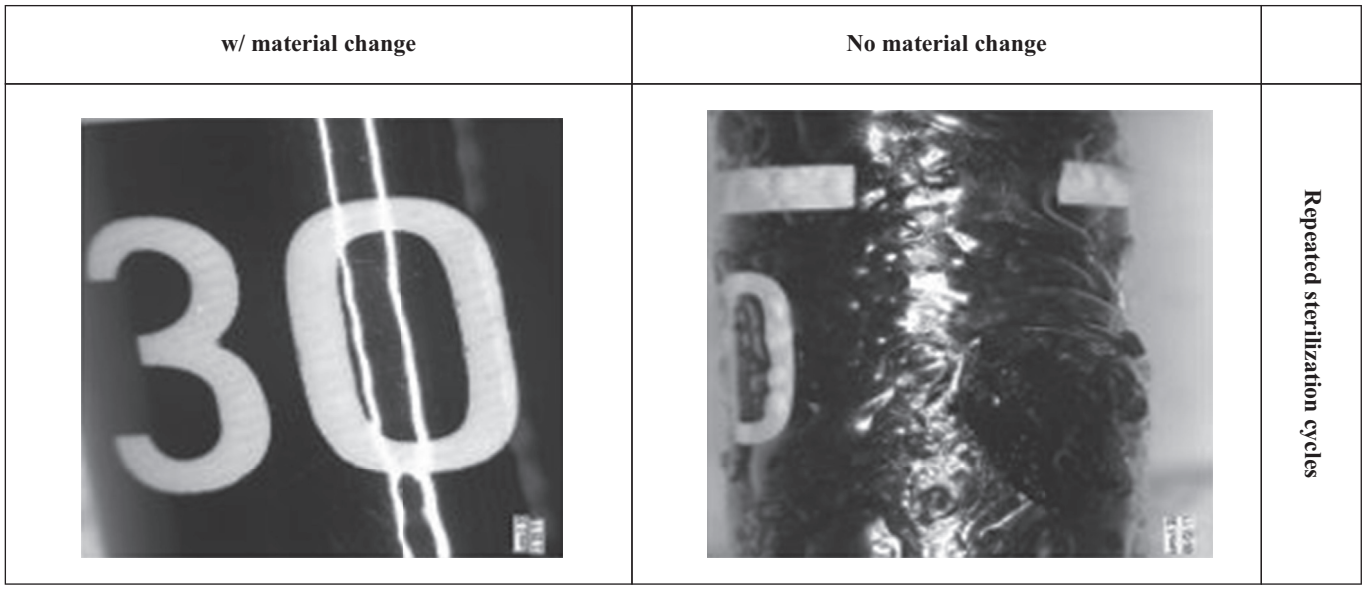

Figure 3. Comparison of the insertion tube of the same endoscope model using the same sterilization cycle when two different lubricants are used.

channels was confirmed with contamination of $>10^6$ cfu of *G. stearothermophilus* before sterilization.

Simulated-use test

The results for each endoscope model (Pentax EC38-i10L, Olympus HQ190L and Olympus TJF Q180V) showed that all channels in top and bottom trays became sterile in the presence of a soil load containing *G. stearothermophilus* spores ($>10^6$ cfu) in 300 ppm AOAC hard water and 5% fetal bovine serum.

Material compatibility tests

Test results for unmodified endoscopes: Figure 1 shows the Pentax EG29-i10 gastroscope insertion tube at the beginning and the end of the test. The insertion tube cracked after 23 cycles. Figure 2 shows blistering of the epoxy glue after only eight cycles on an Olympus CF-HQ190L.

Based on these results, the endoscope would need to be sent for repair after a few uses. This may not be acceptable as it would increase the overall repair costs and require an additional inventory to accommodate device downtime. Moreover,

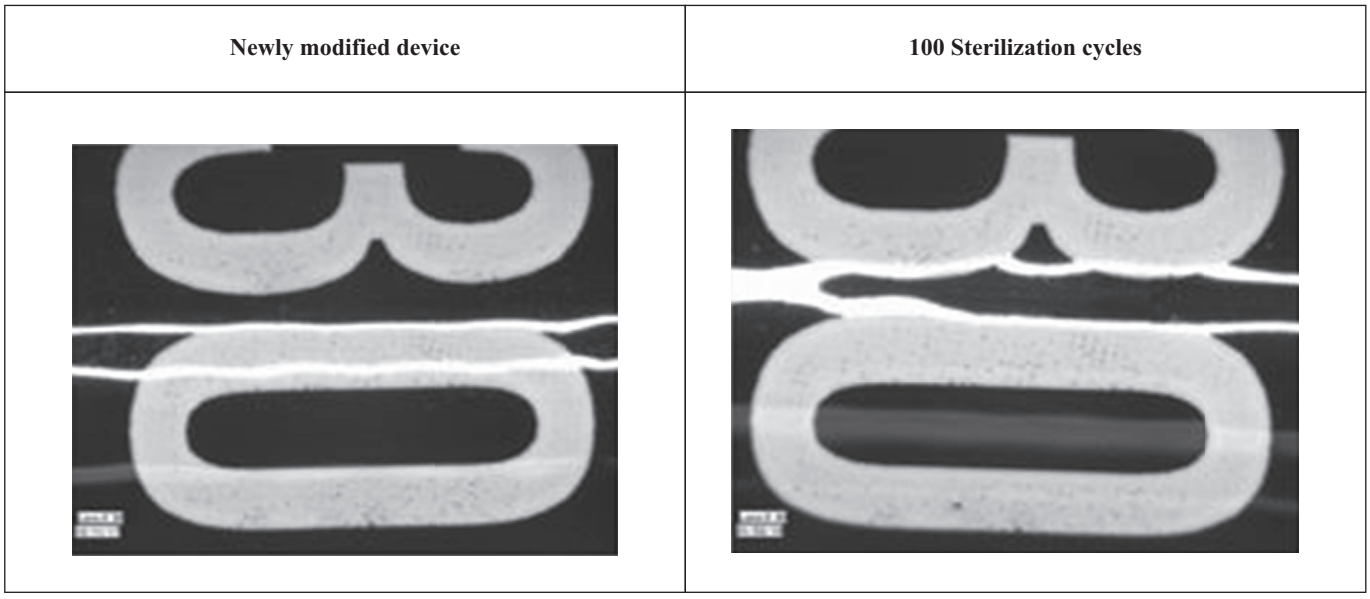

Figure 4. Comparison of a single endoscope before and after 100 cycles of sterilization using a vaporized hydrogen peroxide process.

Table I
Functionality results for modified Fujifilm EG-600WR and unmodified Olympus TJF-Q180V after repetitive exposure to vaporized hydrogen peroxide sterilization cycles

		Modified endoscope (alternative lubricant) Fujifilm EG-600WR		Unmodified endoscope Olympus TJF-Q180V	
		OEM specification	100 cycles	OEM specification	~24 cycles
Maximum angulation	Up	210°	210°	120°	65°
	Down	90°	95°	90°	50°
	Left	100°	105°	110°	75°
	Right	100°	112°	90°	70°

OEM, original equipment manufacturer.

as the testing evaluated the visual impact of device, damage occurring to the endoscopes may have initiated prior to the first observation and visual observation may not capture all functional aspects of the device.

Bronchoscopes, cystoscopes and ureteroscopes had similar material compatibility issues about 25 years ago, until endoscope manufacturers and vaporized hydrogen peroxide sterilizer manufacturers collaborated to change the design of those endoscopes to become compatible with vaporized hydrogen peroxide. At that time, it was found that a lubricant used inside the endoscope was responsible for the incompatibility with vaporized hydrogen peroxide. The lubricant which contained molybdenum disulphide was used to reduce the friction between the components within the insertion tube. Once vaporized hydrogen peroxide is diffused, it can react with molybdenum disulphide to form corrosive acids (e.g., sulphuric acid) leading to corrosion and material effects as observed. In the case of bronchoscopes, ureteroscopes and cystoscopes, this lubricant was replaced with a more inert lubricant.

Materials compatibility test results with modified endoscopes: Figure 3 shows a comparison of the insertion tube of the same endoscope model using the same sterilization cycle when two different lubricants are used. If an original Fujifilm model EG-600WR is exposed to 50 cycles, it is destroyed while the same scope model, with a different lubricant can easily go through 100 cycles of sterilization. Figure 4 shows a comparison of a single endoscope before and after 100 cycles of sterilization using a vaporized hydrogen peroxide process. No visual anomalies were observed on the insertion tube as denoted post repeated processing for an unmodified endoscope as depicted in Figures 1 and 3.

Functionalities of the maximum angle for modified endoscope Fujifilm EG-600WR and unmodified Olympus TJF-Q180V after exposure up to 100 cycles were inspected. Table I demonstrates the devices' angulation capabilities. Unmodified endoscopes suffered substantial loss of flexibility upon total deflection of the distal tip whereas modified devices were relatively unchanged. These results show loss of lubricity due to oxidation of the lubricant which affects the overall function of the device. However, use of a lubricant of a different chemistry results in total angulation being maintained.

In conclusion, current flexible endoscopes have very complicated geometric designs, making them difficult to clean and disinfect. Poor cleaning and residual moisture promote formation of biofilms inside lumens [8,11,13] which further complicates cleaning and disinfection as an inadequately cleaned endoscope may not be effectively disinfected or sterilized because micro-organisms can hide underneath the soil, and therefore proper cleaning is required to provide contact between remaining micro-organisms and the sterilant vapour. In simple terms, cleaning is like the foundation of the processing 'building'. Without a sound foundation (cleaning), the building (processing) will collapse.

Current high-level disinfection processes do not have enough margin of safety to account for incomplete cleaning, resulting in potentially insufficient decontamination after processing. Increasing the margin of safety by using sterilization rather than disinfection is currently impractical. Ethylene oxide has multiple drawbacks and is not widely available; we showed that there are endoscope compatibility issues with vaporized hydrogen peroxide systems. There remains an urgent need to improve the decontamination or sterilization of flexible endoscopes. We suggest that this can be achieved by designing them to be easier to clean (e.g., constructed from modular parts), and/or manufacturing them with robust materials that can withstand sterilization.

Only once these changes are made, coupled with effective staff training, process control/monitoring, use of detergents with proven effectivity against biofilms and inspection of endoscopes, can the current risk of outbreaks of infection related to flexible endoscopes be successfully overcome.

Conflict of interest statement
The authors are employees of Advanced Sterilization Products. This study has been funded by Advanced Sterilization Products and the authors have no other conflict of interest to disclose.

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