American Journal of Infection Control xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Unseen threats: Lumens 2.0 study reveals the hidden challenges of cleaning lumened surgical instruments

Cori L. Ofstead MSPH [a,*], Abigail G. Smart MPH [a], Jill E. Holdsworth MS, CIC, FAPIC, NREMT, CRCST, CHL [b], Brandon M. Gantt MHA, CRCST, CHL, CER, LSSGBH [c], Larry A. Lamb AGTS [a], Kevin M. Bush Jr DHSc, EdD, FACHE, CPPS, CPHRM, CPHQ, CIC [d]

[a] *Ofstead & Associates, Inc., Bloomington, MN*
[b] *Infection Prevention Department, Emory University Hospital Midtown, Atlanta, GA*
[c] *Shared Surgical Services Department, Emory Healthcare, Tucker, GA*
[d] *Perioperative Enterprise Department, Emory Healthcare, Tucker, GA*

Key Words:
Surgical site infection
Borescope
Sterilization
Equipment contamination/prevention and control
Arthroscopic

Background: Surgical site infections can cause significant morbidity requiring lengthy antimicrobial treatment. Infections have been linked to surgical instruments with retained tissue and foreign debris, as the presence of blood or soil interferes with sterilization effectiveness. This study aimed to determine the prevalence of visible soil or debris inside instruments and evaluate the impact of recleaning efforts.

Methods: Borescopes were used to inspect lumens of instruments used for orthopedic, neurologic, or ear-nose-throat procedures. Whenever visible soil or debris was observed, the instrument was recleaned up to 3 times and reinspected to assess the impact of additional cleaning.

Results: Researchers performed 117 inspections (40 unique instruments, 77 reinspections). All instruments had complex lumens that impede access by brushes. Debris and discoloration or residues were observed inside 100% of instruments, with rusty patches in 95%. Some soil was removed by recleaning, but visible soil remained in most lumens and fragments of lint or brush bristles were visible upon repeat inspection.

Conclusions: Cleaning in accordance with the manufacturer's instructions was not effective for lumened surgical instruments. Solutions will require collaboration between infection prevention, sterile processing, and manufacturers to evaluate risk and develop strategies for improving processing outcomes.

BACKGROUND

Surgical site infections (SSIs) are common in some settings[1-4] and can cause morbidity, require lengthy antimicrobial treatment,[4-6] or result in catastrophic outcomes requiring surgical debridement or removal of implanted tissue or devices.[4-7] The root cause of these infections is often elusive,[1,8] and may be attributed to patient demographics, comorbidities, and health behaviors.[2,8-10] However, a rigorous investigation by Tosh et al determined 7 orthopedic surgery patient infections were likely linked to sterilization failure of an arthroscopic shaver handpiece due to the presence of organic soil, bone fragments, and a brush bristle in the lumen.[5] Their identification of retained soil and debris is concerning because others have found sterilization systems do not reliably eliminate microbes when blood,[11] bone fragments,[12] fatty tissue,[13] or other foreign debris are

* Address correspondence to Cori L. Ofstead, MSPH, Ofstead & Associates, Inc., 7831 East Bush Lake Road, Suite 203, Bloomington, MN 55439.
E-mail address: cori@ofsteadinsights.com (C.L. Ofstead).

Funding/support: This study was supported in part by an unrestricted research grant from Healthmark Industries—A Getinge Company. The sponsor was not involved in designing or conducting the study, collecting data, interpreting findings, or preparing this paper.

Conflicts of interest: CLO, AGS, and LAL are employees of Ofstead & Associates, Inc, which has received research grants, study materials, educational materials, or consulting contracts from Advanced Health Solutions, Advanced Sterilization Products, Ambu, Boston Scientific Corporation, Cleanis, Healthmark Industries, Laborie, Lumicell, Nanosonics, Neptune, Pentax, Ruhof China (Fanco International), and Steris/Cantel/Medivators. JEH, BMG, and KMB have nothing to disclose.

https://doi.org/10.1016/j.ajic.2025.02.003

present on the instruments. Researchers have found viable, culturable microbes on 20% to 90% of dirty instruments[11] following sterilization cycles in ethylene oxide gas or hydrogen peroxide gas plasma systems and on 3%,[14] 11%,[12] and 40% to 80%[13] of dirty instruments processed in steam autoclaves. Tissue and foreign debris may carry microorganisms that are deposited into surgical wounds.[15] In addition, foreign microbodies such as lint or bone fragments may alter the surgical site tissue environment and impede immune responses, thus creating a better habitat for microbial growth.[15]

After the Tosh et al investigation, the Food and Drug Administration (FDA) released a safety alert stating that retained tissue in arthroscopic shavers can "compromise the entire sterilization process." They urged facilities to ensure personnel follow device manufacturer's instructions for cleaning and consider inspecting shaver handpiece lumens to ensure fluid and tissue have been eliminated.[16] In response, Azizi et al at the University of Michigan used borescopes to inspect lumened instruments and found visible soil in 100% of 144 suction tips from 12 neurosurgery trays. Recleaning removed debris from only 36 instruments. More rigorous cleaning regimens removed some debris, but did not eliminate all visible soil.[17] Several other studies reported visible soil, debris, or discoloration on > 90% of surgical instruments.[17-19] One study detected protein and hemoglobin on orthopedic depth gauges with visible soil.[19] Another study found 100% (23/23) of heavily used stainless-steel instruments harbored > 10 μg of protein and 61% (14/23) had > 1,000 μg of protein. They found 85.7% (6/7) of instruments inspected with scanning electron microscopy had visible biofilm.[20]

A recent study by Ofstead et al found a high prevalence of visible defects in arthroscopic shaver handpieces and suction tips used for cervical or lumbar laminectomy.[18] Researchers found 94% (17/18) of lumens had visible debris or discoloration. Recleaning was somewhat effective for suctions, but not effective for shavers. Retained lint, blue debris, and brush bristles were discovered inside shavers after recleaning. New shavers developed scratches, retained soil, and rust within 5 uses.

This study was conducted to determine the prevalence of visible defects in lumens and hinges of instruments used for orthopedic, neurosurgery, and ear-nose-and-throat (ENT) procedures and evaluate the impact of recleaning for any instruments with retained soil or debris.

METHODS

Setting

This study was conducted in the sterile processing department of a large academic medical center by epidemiologists, infection preventionists, and sterile processing personnel. The study was approved by facility leadership as a quality improvement project that did not involve human subjects and was exempt from Institutional Review Board oversight.

Subjects/instruments

Researchers aimed to inspect a diverse sample of instruments to expand the validity and generalizability of previously reported findings.[17-19] The study involved enrolling a convenience sample of surgical instruments with lumens or dead ends. Instruments were selected based on availability and anticipated need for use. Before inspection, instruments were manually cleaned with detergent and disposable brushes, run through a STERIS AMSCO 700 Series HP automated washer/disinfector system, and steam sterilized in a STERIS AMSCO Evolution HC-1500 Prevac steam sterilizer with a 4-minute exposure and 30-minute dry time according to the facility's usual practices.

Visual inspection methods

Visual inspections were performed by researchers with training and experience using borescopes. All inspections were performed with at least 3 researchers present. Lumens and dead ends were photographed with 1.06-mm and 1.9-mm-diameter borescopes (FIS-007 Flexible Inspection Scope, Healthmark Industries) by inserting the borescope into the distal end and advancing to the proximal end. Instruments with dead-end lumens were inspected from lumen entry to the dead end.

Protocol for repeat cleaning and reinspection

Determinations about the need for recleaning were made by a sterile processing manager in consultation with an infection prevention manager and the study's principal investigator. An instrument with visible soil or debris was recleaned and reinspected as follows. The first round of recleaning was done by technicians who did it in accordance with their usual practices. If soil or debris were still present, it was cleaned again with supervision by a sterile processing manager to ensure adherence with manufacturer's instructions for use (IFU) and returned for reinspection. If the instrument still appeared dirty, the lumen was filled with enzymatic detergent solution and soaked for 30 minutes before brushing and flushing in accordance with IFU and reinspected.

If residual soil or discoloration was still visible, sterile swabs were available for attempting to remove soil under borescope guidance, in hopes that retained debris could be further examined and photographed. Decisions about whether to use swabs were made based on instrument architecture and soil location. After inspections were completed, instruments were removed from service or recleaned and sterilized before being returned to use.

RESULTS

From May through July 2024, a total of 117 inspections were performed, including initial inspections of 40 unique instruments and 77 follow-up inspections. Inspected instruments included 1 Conmed Advantage Turbo Shaver used for resection of bone and soft tissue; 2 Medtronic Joimax arthroscopic shaver handpieces used for neurosurgery; 2 Stryker Sonopet iQ ultrasonic aspirator systems and torque wrenches used during brain, spine, and ENT surgeries; and 33 instruments found in 4 Stryker TPX trays, including handpieces and attachments used for surgery involving small bones.

Architectural features of inspected instruments

All of the instruments had architectural features that impede access by brushes and prevent visualization during the cleaning process. Lumen diameters within an instrument varied significantly between instruments and frequently changed within an instrument, with grooves parallel to the lumen and multiple ridges and ledges perpendicular to the lumen (Fig. 1).

For example, the TPX-footed blue attachment lumen passed all the way through the instrument and had multiple ridges and ledges that changed the lumen diameter, 2 shiny, smooth grooves parallel to the lumen, and holes perpendicular to the lumen that appeared to lead to cavities not accessible by the borescope (Fig. 1A). Many of the lumens terminated in dead ends with grooves or O-rings around the edge of the terminal surface. The TPX MIS hub had several ledges and a groove parallel to the lumen that appeared to have space underneath the edges. The lumen terminated in a dead end with 4

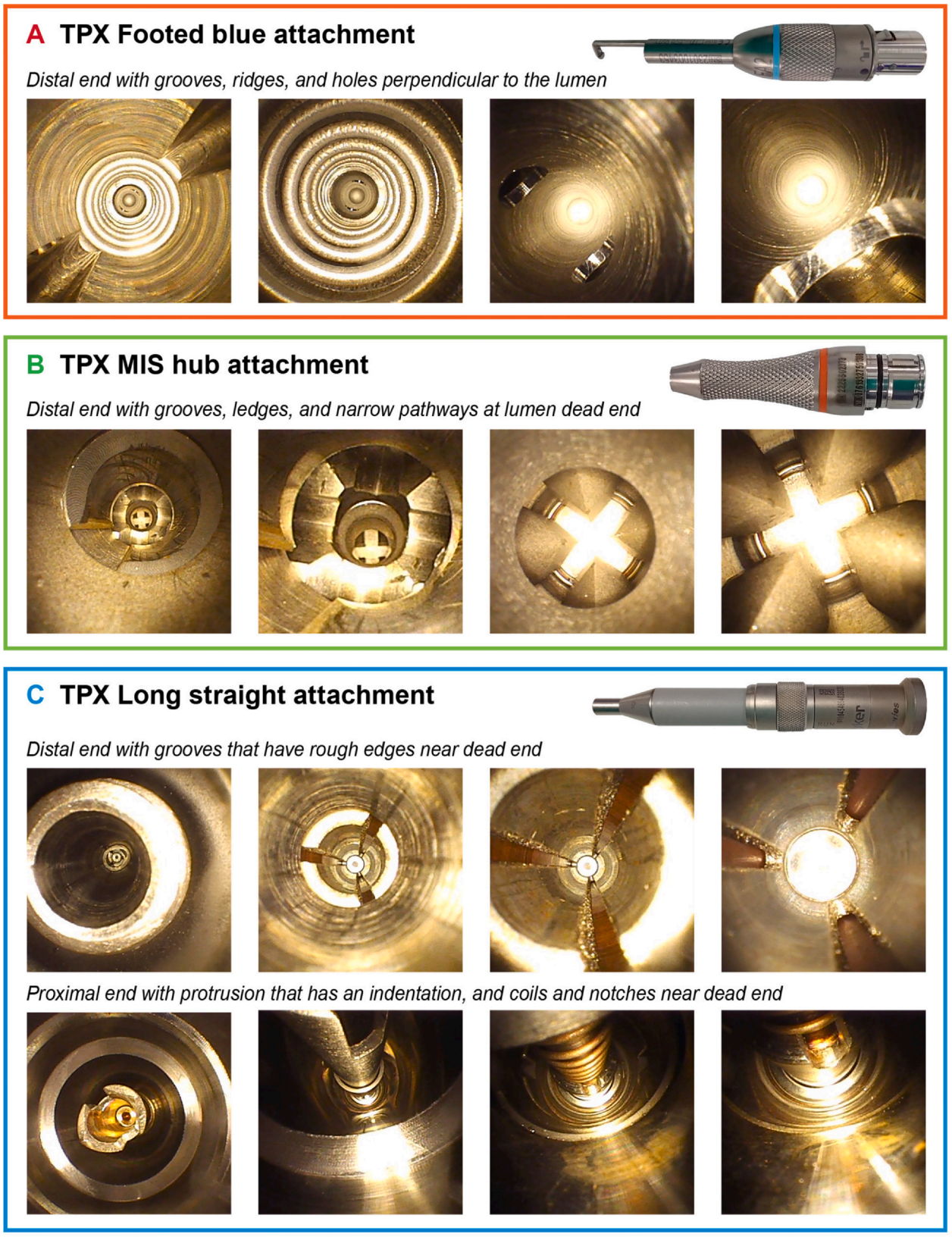

Fig. 1. Architecture of Stryker TPX system attachments.

Fig. 2. Architecture of arthroscopic shavers and an ultrasonic aspirator.

rectangular columns on top of what appeared to be an O-ring (Fig. 1B). The TPX long straight attachment had 2 lumens terminating in dead ends. The distal end lumen had multiple ridges and ledges, with 3 grooves parallel to the lumen that appeared to have rough edges and a copper-colored surface (Fig. 1C).

The proximal end had a complex structure (shaft) protruding into the center of the lumen. This shaft had a depressed area on top, and it was larger in diameter near the lumen entrance than further into the lumen. There was a copper-colored coil near the dead end, with a notch perpendicular to the lumen that appeared to have an interior surface (Fig. 1C).

The 2 Medtronic Joimax arthroscopic shavers appeared different from each other (Fig. 2). Some lumen segments of Shaver 1 were purple, and it had a suction control valve that should be rotated during cleaning (Fig. 2A). The valve body had 2 holes perpendicular to the lumen. The lumen exited the distal end in a deep cavity, and it was challenging to insert the borescope through the distal end because the lumen exit was difficult to see and access (Fig. 2A, distal end). There were 3 smooth grooves parallel to the lumen near the suction connector. The lumen of Shaver 2 also had ledges and ridges, with rough, swirly surfaces and holes perpendicular to the lumen near the suction lever (Fig. 2B).

The Stryker Sonopet ultrasonic aspirators had 2 lumens. The suction lumen was much larger than the lumen used for infusing irrigation fluid into the surgical site (Fig. 2C). Both lumens had multiple ledges and ridges that changed the diameter.

Researchers observed multiple defects inside lumens of 100% of instruments (Table 1). During initial inspections, scratches were seen inside 95% (38/40) of instruments and the reciprocating saws had eroded O-rings in the electrical connectors (Fig. 3A). All instruments had discolored surfaces. Brown, rust-colored, or orange patches were visible in 95% (38/40), black discoloration was observed in 60% (24/40), and 33% (13/40) had white residues that appeared to be “water spots” or detergent residue (Fig. 3B). Visible debris was apparent in 100% of instruments, with brown, yellow, orange, or white chunks in 88% (35/40) and black chunks in 38% (15/40). Fibrous debris that appeared to be lint or brush bristle fragments was observed in 73% (29/40) (Fig. 3C).

All 3 shavers were removed from service following the initial inspection. The remaining instruments were sent back to the decontamination area for additional cleaning based on the presence of discoloration or debris (Table 1). Researchers reinspected 75% (30/40) instruments after 1 round of recleaning, 72.5% (29/40) instruments after 2 rounds of recleaning, and 45% (18/40) instruments after 3 rounds of recleaning.

Table 1
Defects observed inside surgical instruments during initial inspection

Tray	Instrument ID	Damage	Discoloration			Debris		
			Brown, rust-colored, or orange	Black	White	Brown, orange, yellow, or white	Lint or brush bristles	Black
TPX 001	14 cm angled	X	X		X	X	X	
	12 cm angled	X	X	X			X	X
	Footed blue		X			X	X	X
	Long straight	X	X	X		X	X	
	Maestro	X	X	X		X	X	X
	Nonfooted red	X	X			X	X	X
TPX 003	14 cm angled	X	X	X		X	X	X
	12 cm angled	X	X	X	X	X	X	X
	Footed blue	X	X			X		
	Long straight	X	X		X	X		X
	Maestro	X	X			X		
	Nonfooted red	X	X	X			X	
	MIS hub	X	X			X	X	
	7 cm straight	X	X	X	X	X	X	
	Driver			X	X			
	Reciprocating saw	X	X	X	X	X	X	
TPX 004	14 cm angled	X	X	X		X	X	X
	12 cm angled	X	X	X		X	X	
	7 cm straight	X	X	X	X	X	X	X
	Long straight	X	X			X	X	
	Maestro	X	X			X	X	
	Footed blue	X					X	X
	Nonfooted red	X	X	X			X	X
TPX 006	14 cm angled	X	X	X		X		
	12 cm angled	X	X	X		X		X
	Footed blue	X	X			X		
	Long straight	X	X	X		X		
	Maestro	X	X			X	X	
	MIS hub	X	X	X		X	X	
	Nonfooted red	X	X	X	X	X		
	7 cm straight	X	X	X		X		X
	Driver	X	X	X	X	X	X	
	Reciprocating saw	X	X	X		X		
CONMED 1 shaver		X	X			X	X	
JOIMAX 1 shaver		X	X	X		X	X	X
JOIMAX 2 shaver		X	X	X	X	X	X	X
SONOPET 002 aspirator		X	X	X	X	X	X	
Torque Wrench 002		X	X		X	X	X	
SONOPET 007 aspirator		X	X			X	X	
Torque Wrench 007		X	X		X	X	X	
Totals (%) (N = 40)		38 (95%)	38 (95%)	24 (60%)	13 (33%)	35 (88%)	29 (73%)	15 (38%)

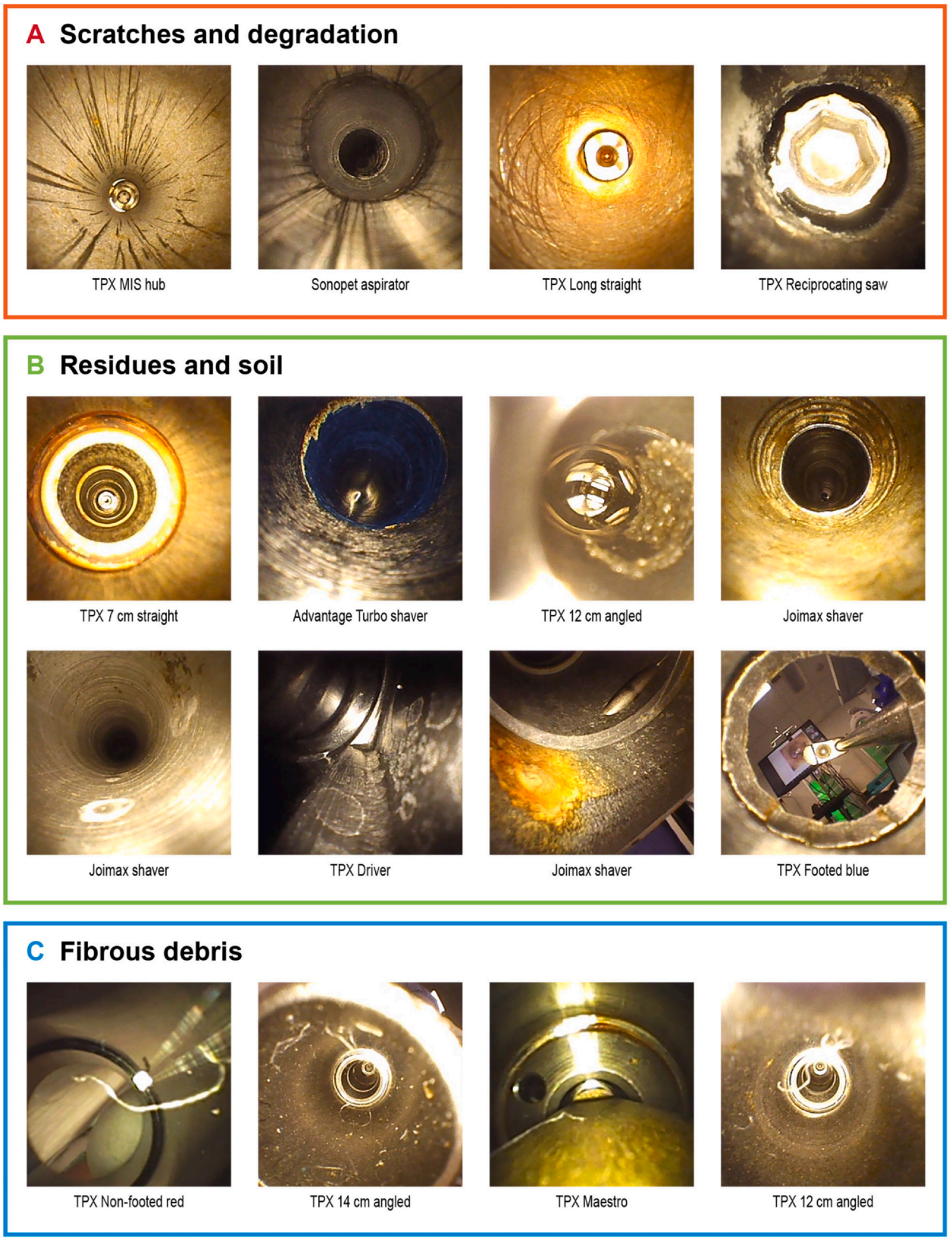

Fig. 3. Defects observed inside surgical instruments.

Visible defects

Recleaning was never completely effective, and 100% of instruments still had discoloration or debris after recleaning. In some cases, recleaning removed soil or debris, but new fragments of fibrous debris were visible upon repeat inspection. This new debris appeared to be lint or brush bristles. Droplets of fluid were observed inside several instruments that had been recleaned and dried using forced air prior to reinspection.

The irrigation lumens of both Sonopet aspirators had patches of yellow and orange debris that remained through 3 rounds of recleaning (Fig. 4A). One patch of yellow debris in the irrigation lumen of Sonopet 002 changed, with a chunk missing after the third recleaning (Fig. 4A). Recleaning of TPX attachments had variable impact. For a long straight attachment, most of the rust-colored residue and yellow debris disappeared after the third round of cleaning (Fig. 4B). In contrast, yellow debris was still present on a ledge of a 12-cm angled attachment after repeated recleaning. During recleaning of the TPX attachments, researchers also discovered that certain dead-end lumens were not completely occluded as initially thought. In some cases, water and air were still able to pass through specific sections of the complex designs, indicating partial patency.

In most instruments, there was orange or brown discoloration around a groove at the lumen's dead end. It was not fully removed by recleaning and commonly remained unchanged (Fig. 4B, nonfooted red attachment). Researchers investigated further to discern whether these grooves contained removeable residues. Sterile 1-mm swabs were used to rub surfaces under borescope guidance. The swabs turned orange or had black or brown particles embedded on the swab (Fig. 4C). Swabs were also used to remove other residues, and in almost every case, there was visible soil on the swab. Researchers observed that technicians would not have been able to reach these areas with brushes because instrument architecture prevented access without using a borescope to guide movements when cleaning.

DISCUSSION

Cleaning lumened surgical instruments presents challenges, primarily due to their intricate design and exposure to biological debris during use, which can hinder sterilization effectiveness. During this study, researchers inspected surgical instruments used for orthopedic, neurosurgical, and ENT procedures and found visible chunks of debris inside 39 of 40 (97%) instruments, with 73% harboring fibrous debris that appeared to be lint or brush bristles. Brown, orange, or rust-colored discoloration was observed inside 38 (95%) instruments. All instruments had complex architecture that prevented access by brushes and did not allow technicians to see during cleaning. Recleaning in accordance with IFUs was not effective, and visible soil and discoloration remained even after multiple rounds of recleaning. These findings were consistent among all instrument types, brands, and models inspected.

Infection prevention and sterile processing managers in this facility observed that strict adherence to all IFU would be difficult or impossible under normal SPD conditions. Multiple sizes and types of brushes are recommended in the IFU for each instrument and attachment. Instrument trays for systems such as TPX contain 20 or more unique attachments that appear similar on the outside but have vastly different interior architecture (Fig. 1). Each of these attachments requires several different brushes and a knowledge of nooks and crannies that need to be accessed during cleaning. Ensuring total compliance would require substantial training and oversight and necessitate availability of more than a dozen different brushes for processing a single tray of instruments. In addition, researchers observed the instruments had complex internal architecture that prevented access by the correct size of brushes, raising concerns that even perfect adherence to steps recommended in IFU would not achieve contact with all interior surfaces.

Previous studies found similar results, with visible soil, debris, or discoloration in > 90% of inspected surgical instruments such as suction tips,[17,18] orthopedic depth gauges,[19] and arthroscopic shavers.[18] One study found 61% of heavily used stainless-steel instruments harbored > 1,000 ug of protein and 86% harbored biofilm.[20] In another study, surgical instruments with complex architecture could not be disassembled for cleaning. Manual cleaning did not remove patient soil from orthopedic instruments, and biofilm formed within 20 usage cycles. Although cultures were negative after steam sterilization, scanning electron microscopy detected microorganisms embedded in biofilm, which they reported may be viable even if not readily culturable.[21]

Historically, experts stated there was little risk of infection associated with the use of contaminated instruments that were subjected to sterilization.[22] This is because surgical instruments tend to harbor low levels of microbial contamination due to aseptic techniques during procedures and redundancies built into sterile processing protocols. They explained that the only way patients would be at risk of infection would be for several weaknesses in the process to align (like holes in slices of Swiss cheese) and said that is unlikely because of the rigorous protocols. These include pretreatment in the surgical suite before manual cleaning and automated cleaning in the sterile processing department, with visual inspection to ensure cleanliness before sterilization. For simple stainless-steel instruments, following these protocols is thought to reduce the risk of viable microbe transmission to essentially zero.[22]

However, the margin of safety for lumened instruments contains fewer slices of Swiss cheese. Operating room personnel may not pretreat (ie, flush) surgical instrument lumens, so blood and soil may harden on interior surfaces. Although instruments may not be highly contaminated with microbes during surgery, they are placed in decontamination sinks that are used for cleaning hundreds of other instruments and endoscopes that may be highly contaminated. Sinks can harbor pathogens, including multidrug-resistant organisms implicated in outbreaks.[23-27] Instruments immersed in sinks may be exposed to myriad microorganisms, including waterborne pathogens that foster biofilm formation. Sterile processing personnel cannot see inside lumens to verify soil removal like they can with many stainless-steel instruments. Some instruments have lumens that are too small to be accessed with a brush, and IFU recommend flushing as the only method for cleaning. Additionally, certain instruments cannot be submerged in water for ultrasonic cleaning. Reliance on soaking alone is concerning because it is unlikely that enzymatic detergent will adequately enter lumens and dead ends without brushing and flushing. Rutala et al found liquid high-level disinfectant solutions did not passively perfuse lumens when the instruments were submerged. They attributed this to stronger air pressure in the channel compared with the pressure of fluid at their interface.[28] Automated washer-disinfectors circulate detergent solution and hot water over external surfaces of instruments, but not through lumens and therefore cannot remove retained soil. Technicians cannot ensure lumens are clean without using a borescope to inspect every instrument every time, and borescope use is not described in the current IFU for any of the devices inspected during this study. IFU for other instruments do recommend borescope examination[29,30] and numerous studies have demonstrated the value of using borescopes to inspect flexible endoscope ports and channels. They have been essential in outbreak investigations[31-33] and identifying damaged, dirty endoscopes that require recleaning or repair.[34-39]

Even if the sterilization system was able to overcome the residual soil, rust, and debris observed inside lumens during this and other

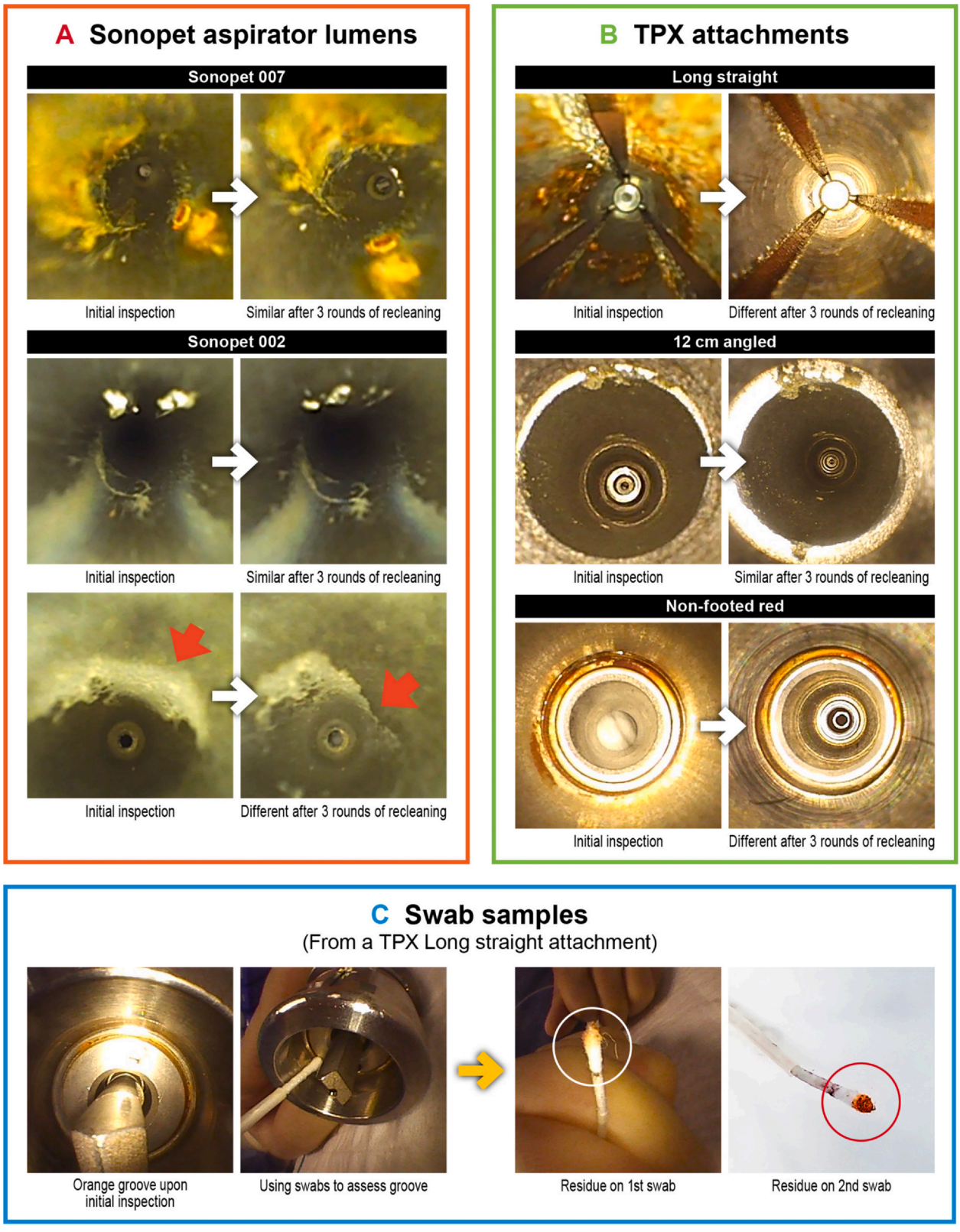

Fig. 4. Impact of recleaning on visible soil.

studies,[17-19] the presence of human tissue and other debris such as lint or brush bristles may increase the risk of poor surgical outcomes. Complications associated with lint contamination of surgical sites include inflammation, adhesions, granulomas, poor wound healing, and infections.[40] In surgical sites, microbodies such as lint may carry microbes and distract local immune defenses that are attempting to eliminate the foreign debris, which contributes to circumstances that support opportunistic infections.[15]

In an outbreak involving orthopedic surgery patients, the pathogen found in patients' joints was genetically indistinguishable from microbes harvested from the decontamination sink and suction bottles. Investigators concluded the infections were likely due to a sterilization failure for arthroscopic shavers due to retained human tissue and brush bristles in the lumen, with exposure due to backflow through the suction channel into surgical sites. Microbial cultures of samples from surgical instruments had no detectable bioburden,[5] but other researchers have reported that microbes embedded in biofilm may not be readily culturable.[21,41] And yet, researchers have detected viable, culturable microbes on large proportions of dirty instruments subjected to low temperature[11] or steam sterilization.[12-14]

Researchers have investigated myriad potential risk factors for SSI, including operating room traffic[42] and air quality,[43] intraoperative hypothermia,[44] and patient factors such as marijuana use[45] and BMI.[46,47] These studies did not consider the possibility of contaminated surgical instruments as a factor contributing to the risk of SSI, and a thorough literature search identified no other human clinical studies focused on this possibility. A recent survey of 890 surgical nurses found that only 6% named OR preparation (including verifying that instruments were sterilized) as an important intervention to reduce SSI.[48] It is essential to heighten awareness of potential use of dirty instruments, so outbreak investigators and clinicians consider this risk factor.

Despite the lack of scientific inquiry about the use of dirty instruments, there is substantial evidence that inadequate processing impacts patient safety and the provision of essential services. Surgical services in several facilities have been interrupted when operating room personnel and surgeons discovered trays of dirty instruments. Orthopedic surgeons at a facility in Texas stopped performing elective surgeries after 49 instrument sets with visible tissue, blood, and bone fragments were delivered to operating rooms during a 41-day period.[49] A state health department inspection of a facility in Pennsylvania found that orthopedic instruments were not clean and had retained bone fragments. Six procedures were delayed or canceled due to problems with instrument sterilization. Surveyors determined the facility was not in compliance with state rules and regulations.[50] Negative consequences for failing to ensure that surgical instruments are clean and sterile have included lawsuits by exposed patients. A class action lawsuit in Colorado alleged that a hospital failed to adequately process spine and orthopedic surgery instruments, did not notify patients or health care providers of the inadequate sterilization, and "unjustly profited from the surgeries…." Patients were notified and encouraged to undergo testing for bloodborne pathogens. The facility paid $6.5 million to settle claims brought by approximately 3,000 exposed patients who tested negative for bloodborne pathogens.[51] These preventable breaches resulted in patient exposure, negative media attention, and financial consequences. Preventing these situations requires substantial investment of training and resources.

In response to the findings of this study, sterile processing and infection prevention personnel collaborated to develop an action plan for reducing risk and developed a multidisciplinary IFU Conflict Resolution Committee. Instruments that were not able to be cleaned were returned to the manufacturer for restoration or replacement. Managers reached out to vendors to discuss maintenance and expectations that loaner instruments meet standards for cleanliness or face rejection. The facility is transitioning to lint-free towels and tray liners. To optimize processing outcomes, the facility developed visual aids and provided enhanced training for staff. The educational in-services address sources of contamination, proper brush size selection, brushing techniques to prevent the shedding of brush bristles, and using borescopes for inspecting lumens. Competency assessments and audits of practices will be used to ensure adherence to standardized protocols.

Limitations

This was a single-site study that involved assessments of only 3 types of instruments, which limits the generalizability. Researchers did not have access to brand-new instruments for comparison. The study protocol did not involve assessing procedural usage or instrument repair history. More research on these factors would be beneficial. Before the initial inspection and during the first round of recleaning, instruments were processed in accordance with the facility's usual practices, and researchers did not perform audits, assess adherence with standards and IFU, or monitor technician identity or delays in processing via the facility's instrument tracking system. Initial inspections were performed on instruments from 1 TPX tray (004) delivered to researchers after manual cleaning and a washer/disinfector cycle, as no fully processed instruments were available that day due to unexpected procedural requirements. The lack of a sterilization cycle for these instruments should have had no impact on visible defects or soil. No biochemical tests for residual soil were performed, and researchers did not attempt to harvest samples or determine whether the observed defects were organic or inorganic debris (eg, blood or tissue vs lint or brush bristles) or degradation of instrument surfaces (eg, etching or rust). This may have required destructive sampling as described by Azizi et al, involving substantial resource allocation and cost.[52] The scope of the study did not involve determining risk to patients. The impact of the findings on patient safety is unknown, as no patients or medical record data were accessed during this study. Future studies should attempt to identify prevalence of visible defects and retained debris inside lumens, develop methods of harvesting samples that do not require destruction of the instruments, and evaluate the linkage between instrument cleanliness and patient outcomes.

CONCLUSIONS

Given these findings, infection preventionists and sterile processing leaders should advocate for collaborative efforts with manufacturers to address these challenges (Supplementary Table S1). In this facility, a multidisciplinary team developed a comprehensive dashboard of Post-Case Audits to monitor and evaluate the condition of instruments upon return from the surgical suite. It allows the tracking of factors such as gross contamination, instrument damage, and the application of pre-enzymatic sprays to minimize retained tissue or foreign bodies within lumened devices.

Many organizations lack standardized protocols that mandate the use of borescopes for inspecting all lumened or channeled instruments. However, this study underscores the value of incorporating best practices to ensure high-quality processing. This includes routine use of borescopes to assess cleaning effectiveness for surgical instruments with lumens, along with training programs and visual references to ensure staff can interpret inspection results. When IFUs are found to be inadequate, health care organizations should collaborate with local representatives and manufacturers to establish extended cleaning practices that align with clinical needs and patient safety standards.

In the future, lumened surgical instruments should be designed to support cleaning effectiveness while meeting the needs of surgeons. Manufacturers should perform rigorous real-world product testing to ensure cleanability and support frontline personnel by providing more practical IFU. Service contracts could be enhanced to

include comprehensive reviews of reprocessing practices, ensuring instruments are adequately maintained throughout their lifecycle. Eventually, advanced technologies like artificial intelligence–supported borescopes could assist sterile processing staff by reducing reliance on subjective assessments to determine whether instruments are safe for patient use. In some cases, a shift toward disposable lumened instruments may be necessary to mitigate contamination risks. More research and transparency about these issues is needed to inform national guideline–issuing bodies and overcome the hidden challenges of cleaning lumened surgical instruments and ensuring safer patient care.

Acknowledgments

The authors would like to thank Amanda Hall, MPH and Aaron L. Preston, RN, BSN, CIC for their assistance with borescope inspections and acknowledge personnel in the sterile processing department for their involvement in recleaning instruments during the study.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at doi:10.1016/j.ajic.2025.02.003.

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