



OPEN An investigation into cleaning quality of suction-type metal lumen instruments: a cross-sectional study

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The highest unqualified cleaning rate of suction-type lumen instruments is a major challenge for a central sterile supply department (CSSD). However, A few comprehensive studies have analyzed the main factors affecting cleaning quality. In response, this study aimed to explore the current state and the factors affecting the cleaning quality of reused suction-type metal lumen instruments in CSSD. The results revealed that the qualified cleaning rates determined by the 5x magnifier visual inspection with light source method, OB reagent method, and ATP bioluminescence detection method were 94.2%, 72.6%, and 60.5%, respectively. The results also showed a significant difference between the three methods ($X^2 = 60.293$, $P < 0.001$). Meanwhile, the binary logistic regression analysis revealed that the time interval between instrument recycling and cleaning, pollution level, pretreatment soaking time, cleaning technique, and the presence of visible bloodstains or dirt after pretreatment are independent risk factors that influence the cleaning quality of suction-type metal lumen instruments. Based on these results, the cleaning quality of suction-type metal lumen instruments needs further improvement.

Keywords Suction instruments, Metal lumen, Cleaning quality

All reusable diagnostic and therapeutic instruments, devices, and items in hospitals must undergo cleaning, disinfection, and sterilization¹. Cleaning involves the complete process of removing contaminants from medical instruments, devices, and items. It consists of flushing, washing, rinsing, and final rinsing procedures². The cleaning quality of medical instruments is a critical factor affecting healthcare associated infections, as effective cleaning is essential for successful disinfection or sterilization and is a key step in controlling healthcare associated infections³. The increasing frequency of invasive procedures in clinical practice has necessitated the use of suction-type metal lumen instruments. Although contaminants on the outer surfaces of these instruments are relatively easy to remove, the inner walls of the lumens pose a greater challenge due to the attachment of blood, body fluids, and pus caused by negative pressure suction⁴.

After substandard cleaning quality, blood, bodily fluids, or other organic substances left on the instruments provide ample nutrients for bacterial growth, which can promote bacterial proliferation⁵. The hidden areas of the instruments provide an environment for biofilm formation, making instruments highly prone to biofilm development⁵. Magda et al.⁶ found that the presence of inorganic or organic matter significantly reduces the effectiveness of sterilization methods such as autoclaving, ethylene oxide, or hydrogen peroxide. This may lead to sterilization failure, increase surgical risks, and elevate the likelihood of hospital-acquired infections. In addition, biofilm formation shortens the lifespan of instruments, increasing the costs for hospitals and departments.

For medical instruments with lumens, sterilization is more challenging for solid instruments. The main problem is the removal of air from the lumens. The presence of air does not allow the sterilizing agent to effectively reach certain parts of the inner lumen surface, making it difficult for some areas to meet the required sterilization conditions⁷. Therefore, ensuring the cleaning quality of lumen instruments is critical to the effectiveness of sterilization. Hu Yingying⁸ reported a rewash rate of 21.73% for lumen instruments based on quality control circle activities. Wenyan et al.⁹ reported that suction devices used in orthopedic surgeries are more prone to blockage and are more complex to operate compared to standard suction devices. Ying et al.¹⁰ found that pediatric suction instruments have narrower diameters and longer, curved lumens compared to other instruments. Blood accumulation can occur due to the suction force, further increasing the difficulty of cleaning. The cleaning quality of hospital instruments is closely associated with the overall medical quality of the

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hospital. Inadequate cleaning of instruments can increase the risk of infections and threaten patients' safety¹¹. Based on the WS310.1-2016 *Central Sterile Supply Department Management Standards* Part 1¹², controlling each step in the instrument cleaning process and enhancing the cleaning quality of reused instruments highly relies on the overall medical and nursing quality of the hospital.

Li et al. explored the factors affecting the cleaning quality of reused medical equipment in CSSDs over the past five years and demonstrated that suction-type lumen instruments have the highest unqualified cleaning rate, reaching 44.44%¹³. Although routine cleaning processes, including scrubbing, high-pressure water gun flushing, and machine washing, can remove visible contaminants, the wide variety of suction-type metal lumen instruments, their varying lengths, and small lumens make it difficult to thoroughly clean residual blood, body fluids, and tissue debris from the lumens^{14,15}. CSSDs in different hospitals currently employ various cleaning methods for suction instruments that exhibit varying levels of efficacy. A few comprehensive studies have analyzed the main factors affecting cleaning quality as a basis for establishing scientific and rational cleaning procedures, appropriate cleaning methods, and optimal soaking times for pretreatment enzyme detergents for suction-type metal lumen instruments.

This study investigates the cleaning quality of 190 suction-type metal lumen instruments in a grade A tertiary hospital in order to observe and analyze the factors affecting cleaning outcomes. The goal is to identify effective solutions to improve the cleaning quality of suction-type lumen instruments, thereby ensuring medical safety, reducing healthcare associated infections, and providing a basis for managerial decisions.

Methods

Study materials

From September 2023 to March 2024, 190 suction-type metal lumen instruments from a grade A tertiary hospital were selected using a random number table. The inclusion criteria were as follows: (1) instrument size: lumen instruments with a diameter ≥ 2 mm, and the distance from any point within the lumen to its opening communicating with the external environment was ≤ 1500 times its inner diameter; (2) instrument material: metal lumen instruments; (3) Instrument structure: lumen instruments with openings at both ends; and (4) instrument function: commonly used surgical instruments for suctioning accumulated blood, body fluids, and pus. The exclusion criteria were also as follows: (1) plastic, glass, or silicone lumen instruments; (2) special infection instruments: instruments contaminated with prions, gas gangrene, and unknown sudden infectious disease pathogens; and (3) instruments that exceeded the effective sterilization period and thus needed re-sterilization.

Research tools

General survey form of instrument cleaning conditions

The authors developed an instrument-cleaning registration form based on the literature review. The form included details such as the department (head and neck surgery, general surgery), method technique (open, minimally invasive), duration of surgery, the time interval between instrument recycling and cleaning, the length of suction-type metal lumen instruments, pollution level (slight, heavy), pretreatment before washing (manual pretreatment, mechanical pretreatment), presence of visible bloodstains or dirt after pretreatment, cleaning method (manual cleaning, machine cleaning), the conductivity of pure water, water temperature of multi-enzyme cleaning solution, duration of cleaning operation, and the operator's workload, working years, and educational attainment.

Cleaning quality detection

Reference Standard The cleaning quality of suction-type metal lumen instruments was assessed based on "Central sterile supply department (CSSD) - Part 2: Standard for the operating procedure of cleaning, disinfection, and sterilization" WS310.2-2016¹⁶.

Detection timing

Detection was conducted after the cleaning process during the drying stage, removing water from the surface and lumen of the instruments. The cleaned suction-type instruments were placed on a dedicated lumen drying rack and hung in the drying cabinet to ensure complete drying of both the external and internal areas. As per WS310.2-2016, *Central Sterile Supply Department Management Standards* Part 2: Standard for Operating Procedure of Cleaning, Disinfection, and Sterilization, the temperature for metal instruments was adjusted to 70–90 °C¹⁶. As generally recommended by the product instructions for metal instruments, the drying duration was set to 20 min for metal instruments. After the drying cycle, items were retrieved by opening the drying cabinet door while wearing heat-resistant gloves¹⁷.

Sampling method

Trained inspectors sampled cleaned and dried suction-type metal lumen instruments in the CSSD every week between September 2023 and March 2024. A total of 425 suction-type metal lumen instruments were numbered (001-425). By utilizing a random number table, a single number was chosen as the initial reference point, specifically the number located in the 8th row and 10th column, which is 0. The numbers were sequentially read from left to right, commencing at 0, until a three-digit number 099, which is lesser than 425, was attained. The corresponding suction instrument was selected (numbers outside the range or repeated numbers were discarded) until 190 suction-type metal lumen instruments were sampled.

Detection tools

(1) 5x Magnifier Visual Inspection with Light Source Method.

The 5x magnifier visual inspection with the light source method uses a 5x magnifier to observe residuals. Detection method: Each dried instrument, tool, and item was inspected using a 5x magnifier equipped with a light source. The surfaces, joints, and teeth of the instrument were checked to ensure they were clean and free of bloodstains, dirt, water scales, or rust spots; additionally, their functionality was assessed to ensure they were undamaged. Then sterile cotton swabs moistened with sterile injection water were used to wipe the lumen openings, side holes, and other holes. If the cotton swabs showed no stains, the cleaning was deemed qualified.

(2) Occult blood (OB) reagent method. The pyramidon semi-quantitative test reagent (occult blood, OB) produced by Baso Diagnostic Inc. in Zhuhai, China, was employed to monitor cleaning quality by detecting serum residues on instruments. An OB reagent is a type of test strip used for OB testing. It is highly sensitive to blood or serum in bodily fluids and detects serum levels greater than 5 mg/L. Detection method: A 15-cm cotton swab soaked in sterile injection water was used to repeatedly wipe the sampling area 10 cm from the lumen opening. Two drops of reagent A and two drops of reagent B were then applied to the cotton ball. If the cotton ball turned purplish-red or purplish-blue, it indicated a positive result and unqualified cleaning. If there was no color change, it indicated a negative result and qualified cleaning.

(3) Adenosine triphosphate (ATP) bioluminescence detection method. The ATP bioluminescence detection method utilizes the 3 M Clean-Trace ATP system to generate a luminescent reaction by utilizing adenosine triphosphate (ATP). A fluorometer then measures the fluorescence intensity of the sampling swab, displaying the results in relative light units (RLU). This method reflects the level of microbial residue, which is used to assess the cleaning quality of instruments. Detection method: Fixed inspectors wore disposable polyethylene gloves and masks. The lumen was sampled using a perfusion method where 40 ml of sterile injection water was poured into one end of the lumen and collected in a sterile bag from the other end. A water quality sampling swab was used to sample the sterile injection water from the sterile bag. The swab was then placed in a tube with luciferase, activated immediately, and shaken horizontally for 5 s. The sample was placed in the ATP bioluminescence detector, which provided an RLU reading within 15 s. An RLU value of ≤ 200 was considered qualified.

Over the past decade, the ATP bioluminescence detection method has been widely used in hospitals across the UK and the USA for the rapid monitoring of cleanliness in both hospital environments and medical instruments. China's WS/T 367–2012 Technical Specifications for Disinfection in Medical Institutions A.1.1.3 also suggests that hospitals can adopt ATP bioluminescence for periodic measurement of protein residues on diagnostic instruments, tools, and other items, or for assessing the effectiveness of their cleaning and decontamination. This method allows for on-site detection and is both convenient and rapid, resolving the need for bacterial culture. The ATP bioluminescence detection technology utilizes the luciferase-ATP reaction system, converting chemical energy into light energy. During detection, the reagent is thoroughly mixed with the sample, leading to cell wall or membrane rupture and ATP release. Luciferase reacts with ATP, releasing phosphate groups and emitting light, which is detected using a luminometer. The results are displayed in relative light units (RLU), indicating the amount of ATP and reflecting the level of microbial contamination and organic residues, such as blood, bodily fluids, secretions, or drainage fluids. The results of ATP detection are accurate, as 3 M China Ltd. conducts multiple product tests before release. Every time the ATP luminometer is turned on, it performs a series of self-diagnostic checks, including initial background measurements and calibration, ensuring that it is functioning correctly. Details of three detection methods (Table 1).

Data processing and analysis

- (1) The obtained data were inserted into Excel and double-checked by two individuals. All statistical analyses were performed in SPSS-26.0 analysis, and the significance level was determined to be 0.05.
- (2) All measurement data were examined by the Shapiro-Wilk test. The data with a normal distribution pattern were described using mean $\pm$ standard deviation ($\bar{x} \pm s$) and the enumeration data were described using frequency and constituent ratio.
- (3) The measurement data following a normal distribution and those with the homogeneity of variance were analyzed using the independent sample t-tests or the univariate analysis of variance. Non-normally distributed data or those with heterogeneity of variance were analyzed using non-parametric tests to determine differences between the groups in cleaning quality. Enumeration data were compared using the chi-square test. Variables

Detection tools	Measured properties	Measured value	Working principles	Make	Model
5x Magnifier visual Inspection with light source method	Qualitative detection	No visible stains indicate a qualified result.	Using magnification through a lens, the object's image appears larger on the retina.	Taizhou Kangli Medical Equipment Co., Ltd.	YX-GYFDJ02
OB reagent method	Semi-quantitative detection	No color change to purple-red or purple-blue indicates a qualified result.	This method is based on the peroxidase-like activity of ferrous hemoglobin, which catalyzes H ₂ O ₂ as an electron acceptor, causing a color change. The intensity of the color correlates with the level of hemoglobin.	Zhuhai Beisuo Biotechnology Co., Ltd.	20,172,401,477 test paper method
The ATP bioluminescence detection method	Quantitative detection	≤ 200 RLU is considered a qualified result.	The reagent is thoroughly mixed with the sample, and the cell wall or membrane ruptures, releasing ATP. Luciferase reacts with ATP, releasing phosphate groups and emitting light, which is detected by a luminometer. The results are displayed in RLU, reflecting the ATP content.	3 M China Ltd.	70,200,789,215 LX25

Table 1. Details of detection tools.

with statistical differences in univariate analysis were included in binary logistic regression analysis to determine the independent risk factors affecting cleaning quality.

Results

Qualified cleaning rates of three detection methods

The qualified cleaning rates determined by the 5x magnifier visual inspection with the light source method, the OB reagent method, and the ATP bioluminescence detection method were 94.2%, 72.6%, and 60.5%, respectively. There was a statistically significant difference between the three detection methods in qualified cleaning rates ($X^2 = 60.293, P < 0.001$). Further pairwise comparisons revealed statistically significant differences between the 5x magnifier visual inspection with light source method and the OB reagent method ($X^2 = 31.985, P < 0.001$), between the 5x magnifier visual inspection with light source method and the ATP bioluminescence detection method ($X^2 = 61.560, P < 0.001$), and between the OB reagent method and the ATP bioluminescence detection method ($X^2 = 6.256, P < 0.012$) (Table 2).

Univariate analysis using ATP bioluminescence detection method to determine cleaning quality of suction-type metal lumen instruments

Among the 190 suction-type metal lumen instruments, the annual sterilization frequency of lumen instruments, the duration of surgery and the operator’s educational attainment were not statistically significant ($P > 0.05$). Factors such as the number of lumen instruments in the instrument pack, the department, method technique, the time interval between instrument recycling and cleaning, pollution level, pretreatment soaking time, presence of visible bloodstains or dirt after pretreatment, cleaning technique, workload, and working years were statistically significant ($P < 0.05$) (Table 3).

Binary logistic regression analysis using ATP bioluminescence detection method

A multivariate logistic regression model was developed using cleaning quality as the dependent variable (unqualified=0, qualified=1) and the statistically significant factors from the univariate analysis as the independent variables. Stepwise regression (inclusion criteria=0.05, exclusion criteria=0.10) was employed to select the variables (the assignment of the independent variables is shown in Table 4). The results indicated that the time interval between instrument recycling and cleaning, pollution level, pretreatment soaking time, cleaning technique, and presence of visible bloodstains or dirt after pretreatment were independent risk factors affecting the cleaning quality of suction-type metal lumen instruments (Table 5).

Discussion

Cleaning is the prerequisite and key to the successful disinfection and sterilization of medical instruments. This study collected 190 reused suction-type metal lumen instruments from a CSSD and found that 75 instruments (39.5%) had unqualified cleaning results, as detected by the ATP bioluminescence detection method. This result is similar to the findings of Li Aiqin et al., who reported that suction-type lumen instruments had the highest unqualified cleaning rate (44.4%) among reused medical instruments in CSSDs¹³. The binary logistic regression analysis revealed that the time interval between instrument recycling and cleaning, pollution level, pretreatment soaking time, cleaning method, and presence of visible bloodstains or dirt after pretreatment were independent risk factors affecting the cleaning quality of reused suction-type metal lumen instruments in CSSDs.

Effects of different detection methods on instrument cleaning quality

In this study, the qualified cleaning rate was obtained 94.2% for the 5x magnifier visual inspection with the light source method, 72.6% for the OB reagent method, and 60.5% for the ATP bioluminescence detection method. Pairwise comparisons showed statistically significant differences between the three methods in the qualified cleaning rates ($P < 0.05$). The 5x magnifier visual inspection with the light source method is a straightforward and versatile visual inspection technique that can be easily operated in any location and under any conditions. It is a routinely employed and essential monitoring technique for evaluating the cleaning quality of medical instruments in CSSDs. However, the subjectivity of human judgment can lead to variability in results. The cleaning staff finds it challenging to recognize the possible problems in the absence of an objective way to assess

Detection methods	Unqualified cleaning n(%)	Qualified cleaning n(%)	Total	Qualified cleaning rates (%)	X ²	P
The 5x magnifier visual inspection with light source method	11 (5.8)	179 (94.2)	190	94.2%	31.985 ^a	<0.001
OB reagent method	52 (27.4)	138 (72.6)	190	72.6%	61.560 ^b	<0.001
ATP bioluminescence detection method	75 (39.5)	115 (60.5)	190	60.5%	6.256 ^c	0.012
X ²	60.293 ^d					
P	<0.001					

Table 2. Qualified cleaning rates of three detection methods. $P < 0.05$ indicates statistical significance.

^aComparison between 5x magnifier visual inspection with light source method and fecal OB reagent (pyramidon semi-quantitative method). ^bComparison between 5x magnifier visual inspection with light source method and ATP bioluminescence detection method. ^cComparison between fecal OB reagent (pyramidon semi-quantitative method) and ATP bioluminescence detection method. ^dComparison of the qualified cleaning rates among the three detection methods.

Item	Unqualified cleaning ^A n = 75	Qualified cleaning ^A n = 115	χ^2/z	p
The number of lumen instruments in the instrument pack [m(p25, p75)]	1 (1, 4)	1 (1, 1)	-4.209 ^B	< 0.001
The annual sterilization frequency of lumen instruments [m(p25,p75)]	559 (190, 1044)	393 (271, 538)	-0.831 ^B	0.406
Department (%)			19.799 ^C	< 0.001
Head and neck surgery	31 (67.4)	15 (32.6)		
General surgery	44 (30.6)	100 (69.4)		
Method technique (%)			6.459 ^C	< 0.011
Open	10 (71.4)	4 (28.4)		
Minimally invasive	65 (36.9)	111 (63.1)		
The duration of surgery(h) [m(p25, p75)]	2.36 (2, 3.41)	2.53 (2.16, 4.01)	-1.846 ^B	0.065
The time from the instrument			26.115 ^C	< 0.001
Recycling to cleaning				
< 20 min	29 (25.0)	87 (75.0)		
≥ 20 min	46 (62.2)	28 (37.8)		
Pollution degree			8.131 ^C	< 0.004
Slight	24(28.2)	61(71.8)		
Heavy	51(48.6)	54(51.4)		
Pretreatment soaking time			31.939 ^C	< 0.001
≤ 2 min	36(73.5)	13 (26.5)		
> 2 min	39(27.7)	102(72.3)		
Presence of visible			7.811 ^C	< 0.005
Bloodstains or dirt				
After pretreatment				
No	52 (34.4)	99 (65.6)		
Yes	23 (59.0)	16 (41.0)		
Cleaning technique			59.434 ^C	< 0.001
Manual cleaning	68(63.6)	39(36.4)		
Machine cleaning	7 (8.4)	76(91.6)		
Workload [m(p25, p75)]	2(1, 2)	1(1, 1)	-4.313 ^B	< 0.001
Working years			6.247 ^C	< 0.044
≤ 1 year	14(63.6)	8 (36.4)		
2–3 years	51(35.7)	92(64.3)		
> 3 years	10(40.0)	15(60.0)		
The operator's education level			0.638 ^C	0.888
Junior high school	24(43.6)	31(56.4)		
High school	29(38.2)	47(61.8)		
College	15(38.5)	24(61.5)		
Undergraduate	7 (35.0)	13(65.0)		

Table 3. Univariate analysis of cleaning quality of suction-type metal lumen instruments. $P < 0.05$ indicates statistical significance. A: [M(P25, P75)]/[Median (IQR)] indicates quantitative data not meeting normal distribution and homogeneity of variance assumptions, described using median (interquartile range); n(%); B: Non-parametric test; C: Chi-square test.

cleanliness. The OB reagent method is characterized by its simplicity, convenience, and reliability of results. However, contamination with copper ions, iron ions, or disinfectants can produce false-positive results¹⁸. The ATP bioluminescence detection method addresses the limitations of visual inspection and the false-positive results of the OB reagent method regarding lumen instruments¹⁹. Nevertheless, this approach incurs greater expenses compared to other methods. Hospitals with limited resources are recommended to utilize the 5x magnifier visual inspection with the light source method and the OB reagent method for regular inspections, supplemented periodically by the ATP bioluminescence detection method for comprehensive evaluation and management.

While all three detection methods were effective to some extent, there were differences in their effectiveness, accuracy, and validity. In the cleaning assessment of suction-type metal lumen instruments, the ATP bioluminescence detection method provides objective and accurate evaluations and is recommended as the primary method for periodic inspections to prevent and control nosocomial infections. Therefore, the periodic application of the ATP biofluorescence detection method is recommended as the first choice in the detection of the inner walls of lumen instruments.

The independent variable	Variable case	Assignment case
Number of lumen instruments in the instrument pack	Continuous variables	Substituting the original values
Department	Dichotomous variables	Head and neck surgery = 1, general surgery = 2
method technique	Dichotomous variables	Open = 1, minimally invasive = 2
Time interval between instrument recycling and cleaning	Dichotomous variables	≥ 20 min = 1, < 20 min = 2
Pollution level	Dichotomous variables	heavy = 1, slight = 2
Pretreatment soaking time	Dichotomous variables	≤ 2 min = 1, > 2 min = 2
Presence of visible bloodstains or dirt after pretreatment	Dichotomous variables	Yes = 1, No = 2
cleaning technique	Dichotomous variables	Manual cleaning = 1, machine cleaning = 2
Workload	Continuous variables	Substituting the original values
Working years	Multi-categorical variables	≤ 1 year = 1, 2 ~ 3 years = 2, ≥ 3 years = 3

Table 4. Assignment of independent variables of binary logistic regression analysis of cleaning quality of suction-type metal lumen instruments.

Item	β	SE	Wald	P	OR	95%CI
Number of lumen instruments in the instrument pack	0.053	0.274	0.037	0.847	1.054	0.616–1.804
The department (1)	1.366	0.963	2.014	0.156	3.921	0.594–25.87
Method technique(1)	0.258	0.985	0.068	0.794	1.294	0.188–8.921
The time from instrument recycling to cleaning(1)	1.565	0.507	9.548	0.002	4.785	1.773–12.915
Pollution degree(1)	0.971	0.478	4.127	0.042	2.641	1.035–6.742
Pretreatment soaking time (1)	1.646	0.583	7.969	0.005	5.185	1.654–16.256
Cleaning technique (1)	3.225	0.605	28.455	0.001	25.149	7.69–82.242
Presence of visible bloodstains or dirt after pretreatment(1)	1.713	0.601	8.138	0.004	5.547	1.709–17.997
Workload	-0.214	0.34	0.394	0.53	0.808	0.415–1.573
Working years			0.618	0.734		
Working years(1)	-0.595	0.813	0.536	0.464	0.552	0.112–2.713
Working years(2)	-0.66	0.924	0.51	0.475	0.517	0.084–3.164
Constant	-5.037	1.917	6.908	0.009	0.006	

Table 5. Binary logistic regression analysis of cleaning quality of suction-type metal lumen instruments.

Influencing factors

Time interval between instrument recycling and cleaning

This study identified that a time interval of ≥ 20 min between instrument recycling and cleaning is a risk factor for unqualified cleaning quality ($P < 0.002$). Bob Kehoe et al. also found similar results, suggesting that when contaminants remain in lumens for longer periods, it takes more time and advanced equipment to effectively clean them²⁰. Zhou Wenzhe et al. observed that 21.3% of hospitals had a recycling time of ≥ 120 min, and 78.7% of them lacked moisture preservation during transport²¹. In this study, the recycling time in 38.9% of the cases was ≥ 20 min, with a maximum of 96 min. This can be attributed to the proximity of the hospital's CSSD to the operating rooms, delivery rooms, and clinical departments, as well as the establishment of direct or dedicated pathways to expedite the recycling of surgical instruments and reduce handling steps. Similar to the above studies, the unqualified cleaning quality in this study was associated with the absence of on-site moisture pretreatment. Prolonged recycling times allow viscous agents used during surgery to adhere to the surfaces and lumens of instruments, causing blockages and increasing the difficulty and cost of cleaning. This ultimately reduces the lifespan of the instruments. Therefore, instruments that cannot be promptly sent to the CSSD should undergo moisture preservation with agents that prevent protein coagulation and do not corrode the instruments.

Pollution level

Slightly contaminated instruments are those without visible stains or blood traces upon visual inspection. Heavily contaminated instruments carry visible blood, body fluids, secretions, and other contaminants. This study found that heavy pollution was a risk factor for unqualified cleaning quality ($P < 0.042$), and the unqualified cleaning rate of heavily contaminated instruments was significantly higher than that of slightly contaminated ones. This is consistent with the findings of Lopes et al.²². Heavily contaminated instruments exhibit a higher rate of microbial growth and are more likely to have organic residue on their surfaces compared to instruments with only slight contamination²³. Residual organic matter forms a protective layer on microbial surfaces, hindering effective contact between the microorganisms and sterilizing gases. Thus, even physical or chemical cleaning methods may fail, increasing the risk of unqualified cleaning. Furthermore, the absence of staff training in differentiating pollution levels and implementing proper cleaning protocols for heavily contaminated instruments, such as

employing ultrasonic cleaning followed by gentle brush scrubbing of internal lumens and thorough rinsing with high-pressure water guns, also contributes to unqualified cleaning quality of lumen instruments.

Pretreatment soaking time

Soaking refers to the process of immersing instruments, devices, and items in washing water containing medical detergents during manual pretreatment. This study found that a pretreatment soaking time of ≤ 2 min was a risk factor for unqualified cleaning quality ($P < 0.005$). Studies on instrument cleaning guidelines indicate that prolonged instrument placement without timely retrieval and cleaning leads to the accumulation of dried contaminants and bloodstains inside the lumen, increasing cleaning difficulty and resulting in unqualified cleaning quality²⁴. The study results suggested that suction-type metal lumen instruments with dried contaminants and bloodstains should not be cleaned directly. Instead, they should be soaked in a neutral multi-enzyme cleaning solution at 25–40 °C for > 2 min to loosen or digest the attached contaminants, thereby reducing the risk of unqualified cleaning. Furthermore, the recommended manual pretreatment soaking time for the neutral multi-enzyme cleaning solution is 2–10 min. However, the concentration can be appropriately increased and the duration of soaking and cleaning can be extended for heavily polluted lumen instruments. It is also advisable to communicate with the clinical departments to enhance the on-site pretreatment of lumen instruments.

Presence of visible bloodstains or dirt after pretreatment

This study showed that the presence of visible bloodstains or dirt after pretreatment was a risk factor for cleaning quality ($P < 0.004$); accordingly, the more visible bloodstains or dirt after pretreatment, the lower the cleaning quality. According to Cori L., the pre-removal of these contaminants can effectively reduce pollution and bacterial residue during the cleaning process, serving as a necessary prerequisite for ensuring qualified cleaning quality²⁵. However, certain instruments are not promptly subjected to pretreatment, and even cleaning brushes are not adequately cleaned after each use²⁶. Moreover, the excessive workload of the staff (e.g., cleaning two or more lumen instruments simultaneously) increases cleaning difficulty²⁷. Michael G. Zywił found that timely pretreatment can impose less burden on the cleaning process and increase the cleaning quality²⁸. It is also essential to use appropriate cleaning tools, such as brushes and flushers, and to ensure that they are cleaned and disinfected after each use and replaced timely to maintain functionality. To further improve cleaning quality, the staff are recommended to perform a pretreatment quality check for any remaining visible bloodstains or dirt on the internal surfaces of the lumen instruments.

Cleaning method

The results of this study demonstrated that manual cleaning produced significantly higher rates of unqualified cleaning when compared to machine cleaning; therefore, it was a significant risk factor for unqualified cleaning quality ($P < 0.001$). This is consistent with the findings of Harry P Wetzler et al.²⁹. Because of the distinctive design of lumen instruments, it is challenging to achieve comprehensive cleaning through manual methods, as the human eye cannot readily detect small amounts of hemoglobin spread throughout the lumens and hidden details. Fully automated injection machines designed for specific lumen instruments can connect to compatible models. These machines control standard levels of flushing pressure, water temperature, and drying duration to guarantee cleaning quality and consistency. Moreover, these machines offer remarkable advantages in minimizing the risk of needlestick injuries among the medical staff, enhancing cleaning efficiency, and reducing labor costs. However, adequate pretreatment is necessary before the mechanical cleaning of heavily contaminated instruments.

Conclusion

The study results highlight the need for improvement in the cleaning quality of suction-type metal lumen instruments. Factors such as the time interval between instrument recycling and cleaning, pollution level, pretreatment duration of soaking, cleaning method, and presence of visible bloodstains or dirt after pretreatment were found as independent risk factors affecting the cleaning quality of suction-type metal lumen instruments.

Based on the analysis of independent risk factors, a cleaning procedure was developed for suction-type lumen instruments in the head and neck surgery department. Based on different surgical methods and recycling times, particular attention was given to the soaking period during pretreatment, the ultrasonic cleaning time, and the combination of manual and machine cleaning. A series of training sessions were also held. Automatic spray cleaning machines and vacuum boiling cleaning devices are recommended to reduce the frequency of manual cleaning and improve cleaning quality. For manual cleaning, lumen-specific cleaning brushes should be used to thoroughly scrub the lumens, ensuring complete and thorough cleaning. The cleaning tools must be replaced in a timely manner to maintain their function.

Below is a comprehensive comparison between ATP bioluminescence detection method with 5x magnifier visual inspection and fecal OB reagent detection methods. Although all three detection methods have certain advantages, for suction-type metal lumen instruments, both the 5x magnifier visual inspection with light source method and the fecal OB reagent cannot effectively detect the internal conditions of instruments with long lumens, small diameters, and curved sections. Therefore, for inspecting the inner walls of suction-type lumens, it is recommended to regularly use the ATP bioluminescence detection method as the preferred option.

The results of the three detection methods suggest that the current cleaning quality of suction-type metal lumen instruments still requires improvement. This study thoroughly identified the independent risk factors significantly affecting the cleaning process. This information is useful for optimizing the cleaning procedures for suction-type lumen instruments, focusing on key indicators, thereby improving the cleaning quality of surgical instruments and ensuring patient safety.

This study had certain limitations, such as a small sample size and potential selection bias. When preparing enzyme detergents for manual soaking in the experimental phase, the difficulty in controlling the water temperature may have affected the results. Due to limitations in manpower and time, the manual cleaning and mechanical operation procedures for suction-type lumen instruments have not yet been fully implemented, posing certain restrictions.

Future studies should expand the sample size and utilize evidence-based nursing practices to analyze the barriers and facilitators affecting the cleaning quality of suction-type lumen instruments. Interventional studies should be conducted at both the system and practitioner levels to evaluate the effectiveness of the cleaning quality.

Data availability

Data is provided within the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

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