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Effect of Different Moisturizing Agents on Cleaning Quality of Rigid Endoscopes: A Meta-Analysis

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ABSTRACT: Objective This study aims to evaluate the effects on the cleaning quality of rigid endoscopes of four moisturizing agents, including multi-enzyme cleaner, self-made heparin, foam multi-enzyme moisturizer, and gel moisturizer. **Methods** A systematic search of Chinese and English databases covering CNKI, WanFang, VIP, CBM, PubMed, Web of Science, and Embase was conducted for randomized controlled trials (RCTs) evaluating moisturizing agents for cleaning rigid endoscopes from database inception to March 2025. Meta-analysis was performed using the software RevMan 5.3. **Results** A total of nine randomized controlled trials were included in the meta-analysis. Compared with multi-enzyme cleaner, self-made heparin significantly improved the cleaning pass rate of rigid endoscopes as assessed by visual inspection ($RR=1.01$, 95% CI : 1.00~1.03; $P=0.03$) and residual protein test ($RR=1.01$, 95% CI : 1.00~1.03; $P=0.04$). Foam multi-enzyme moisturizer demonstrated superior cleaning efficacy to multi-enzyme cleaner in ATP bioluminescence assay ($RR=1.23$, 95% CI : 1.03~1.48; $P=0.02$) and occult blood test ($RR=1.10$, 95% CI : 1.04~1.17; $P=0.002$). However, no statistically significant difference was observed between the two agents in visual inspection ($RR=1.04$, 95% CI : 0.99~1.09; $P=0.14$) or residual protein test ($RR=1.08$, 95% CI : 0.93~1.26; $P=0.31$). Gel moisturizer significantly outperformed multi-enzyme cleaner in both visual inspection ($RR=1.05$, 95% CI : 1.03~1.08; $P=0.001$) and occult blood test ($RR=1.02$, 95% CI : 1.00~1.05; $P=0.02$). **Conclusion** Self-made heparin and gel moisturizer demonstrated superior cleaning efficacy compared with the multi-enzyme cleaner for rigid endoscopes. Foam multi-enzyme moisturizer significantly outperformed multi-enzyme cleaner in ATP bioluminescence and occult blood tests but showed no significant advantage in visual inspection or residual protein testing. These findings support the selective application of alternative moisturizing agents based on cleaning assessment methods and clinical context.

KEY WORDS: Moisturizing agents; Rigid endoscopes; Cleaning quality; Meta-analysis

Rigid endoscopes are characterized by complex structural designs and long, narrow lumens, which render them particularly challenging to clean. During surgical procedures, these instruments come into direct contact with blood, villous tissue, secretions, and other organic matter, leading to substantial residual soiling on both external surfaces and internal channels after use. The difficulty of cleaning is further exacerbated for instruments used in emergency surgeries during nighttime, which require considerably more time and effort to process^[1-3]. Prolonged expo-

sure of residual organic contaminants, such as proteins and carbohydrates, on instrument surfaces promotes bacterial proliferation and the formation of biofilms. Biofilm development not only obstructs the contact between disinfectants and instrument surfaces but also substantially increases the complexity of the cleaning process. Effective moisture retention pretreatment immediately following surgical use has been shown to significantly enhance cleaning quality, which is a critical determinant of successful sterilization^[4]. Pretreatment moisturizing agents serve

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to maintain instrument hydration and facilitate preliminary soil removal, thereby preventing the desiccation of blood and other organic debris on surfaces and within lumens, a key factor in mitigating cleaning difficulty. Consequently, selecting an appropriate moisturizing agent is essential for optimizing cleaning outcomes^[5-6]. Although current industry standards mandate timely moisture retention pretreatment after instrument use, no consensus has been reached regarding the specific type or formulation of moisturizing agent to be applied. To address this gap, the present study conducts a systematic review and meta-analysis to evaluate the effects of different moisturizing agents on the cleaning efficacy of rigid endoscopes, to provide evidence-based guidance for the selection of effective and safe pretreatment strategies in clinical practice.

1 Materials and Methods

1.1 Literature search

A systematic literature search was performed in the following electronic databases from their inception to March 2025: CNKI, WanFang, VIP, CBM, PubMed, Web of Science, and Embase. Randomized controlled trials (RCTs) investigating the application of moisturizing agents in the cleaning of rigid endoscopes were identified. A combination of subject headings and free-text terms was employed, and the reference lists of all included studies were manually screened to identify additional eligible publications. The following Chinese search terms were used: “腔镜器械”, “硬式内镜”, “保湿”, “预处理”, “多酶”, “凝胶”, “泡沫”, “肝素”, “清洗质量”, and “随机.” The English search strategy included the terms: “Endoscopes”, “endoscopic Instruments”, “Angioscopes”, “Colonoscopes”, “Uretoscopes”, “Proctoscopes”, “moisture”, “pre-rinse”, “pre-disinfection”, “precleaning”, “pre-treatment”, “enzymatic cleaner”, and “randomized controlled trial”.

1.2 Inclusion and exclusion criteria

Studies were eligible to be included if they met the following criteria: (1) study design: RCT; (2) study population: rigid endoscopes; (3) inter-

vention: moisture retention pretreatment using multi-enzyme cleaner, self-made heparin, foam multi-enzyme moisturizer, or gel moisturizer; (4) language: published in Chinese or English; (5) outcome measures: cleaning quality assessed by visual inspection, residual protein test, ATP bioluminescence assay, or occult blood test.

Studies were excluded if they met any of the following criteria: (1) non-original research, including animal experiments, reviews, systematic reviews, meta-analyses, and conference abstracts; (2) duplicate publications or articles for which the full text could not be obtained; (3) studies that did not employ the specified interventions or did not report the required outcome measures; (4) studies from which valid outcome data could not be extracted.

1.3 Literature screening and data extraction

Literature screening and data extraction were conducted independently by two reviewers using EndNote software in accordance with the predefined inclusion and exclusion criteria. Titles and abstracts were initially screened to remove studies irrelevant to the research topic. Full texts of potentially eligible articles were then retrieved and thoroughly reviewed to confirm final inclusion. Following the screening process, the two reviewers independently extracted data from the included studies and cross-checked the extracted information. Discrepancies were resolved through discussion or consultation with a third reviewer. The extracted data were subsequently summarized in a standardized form.

1.4 Quality assessment of included studies

The methodological quality of the included studies was independently assessed by two reviewers using the revised Cochrane risk of bias (RoB 2) tool. Any disagreements were resolved through discussion or, if necessary, by consultation with a third reviewer. The assessment encompassed the following seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, completeness of outcome data, selective outcome reporting, and other sources of bias.

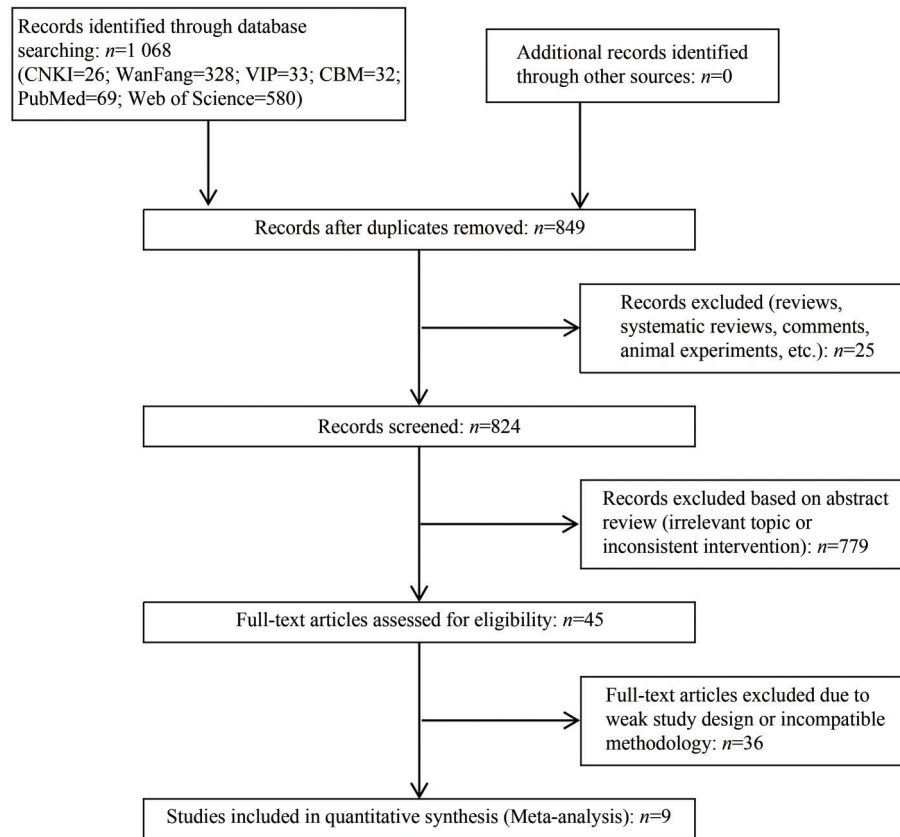


Figure 1 Literature screening flow diagram

1.5 Statistical analysis

Meta-analysis was performed using RevMan 5.3 software (Cochrane Collaboration, Oxford, UK). Statistical heterogeneity among the included studies was assessed using Cochran's Q test and quantified by the I^2 statistic. A fixed-effects model was employed when heterogeneity was not statistically significant ($I^2 < 50\%$ and $P > 0.1$); conversely, a random-effects model was applied when substantial heterogeneity was detected ($I^2 \geq 50\%$ or $P \leq 0.1$). All outcome measures were dichotomous, and the effect size was calculated as a risk ratio (RR) with 95% confidence intervals (CI). In instances where heterogeneity could not be reliably assessed or meta-analysis was inappropriate, a descriptive analysis was conducted. A two-sided P value < 0.05 was considered statistically significant.

2 Results

2.1 Literature search results

A total of 1,068 records were identified through the initial database search. Following the removal

of duplicate publications and studies that did not satisfy the predefined inclusion criteria with respect to study population, design, interventions, or outcome measures, nine eligible studies were ultimately included in the meta-analysis. The detailed literature screening and selection process is presented in Figure 1.

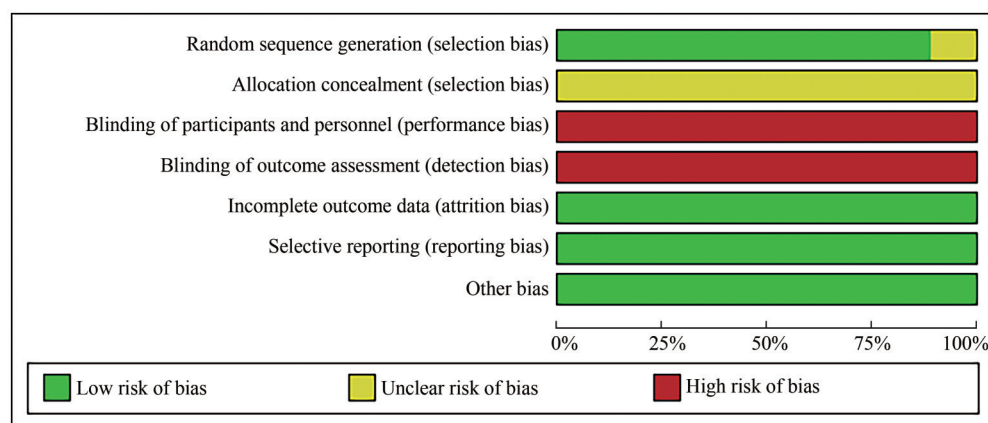
2.2 Quality assessment and general characteristics of included studies

Nine randomized controlled trials, encompassing a total of 4,566 rigid endoscopes, were included in this meta-analysis. The studies evaluated four types of moisturizing pretreatment agents: multi-enzyme cleaner, self-made heparin, foam multi-enzyme moisturizer, and gel moisturizer. The methodological quality and risk of bias of the included studies are summarized in Table 1 and Figure 2, respectively. The general characteristics of the included studies are presented in Table 2.

2.3 Comparison between multi-enzyme cleaner and self-made heparin moisturizing agent on the mois-

Table 1 Quality assessment of included randomized controlled trials

Included Study	Year	Randomization	Allocation Concealment	Blinding	Completeness of Outcome Data	Selective Reporting	Other Bias
WEI Y Y ^[7]	2024	Yes	Unclear	No	Yes	No	No
CHEN X Y ^[8]	2020	Yes	Unclear	No	Yes	No	No
ZHU G H ^[9]	2018	Yes	Unclear	No	Yes	No	No
LIANG Y Y ^[12]	2016	Yes	Unclear	No	Yes	No	No
SHI M ^[10]	2021	Unclear	Unclear	No	Yes	No	No
WANG X ^[11]	2022	Yes	Unclear	No	Yes	No	No
WU Q ^[13]	2017	Yes	Unclear	No	Yes	No	No
YANG X M ^[14]	2021	Yes	Unclear	No	Yes	No	No
QIN J ^[15]	2014	Yes	Unclear	No	Yes	No	No

**Figure 2 Risk of bias summary****Table 2 General characteristics of nine included studies**

No.	Author	Study Subjects	Sample Size		Intervention		Cleaning Method	Outcome Indicators
			Control	Expt.	Control	Expt.		
1	WEI Y Y ^[7]	Laparoscope	583	583	a (1:200)	b	Manual + Ultrasonic	①②
2	CHEN X Y ^[8]	Laparoscope	100	100	a (1:200)	b	—	①②
3	ZHU G H ^[9]	Laparoscope	100	100	a (1:270)	b	—	①②
4	SHI M ^[10]	Rigid endoscope	60	60	a (1:200)	cd	Mechanical	①③
5	WANG X ^[11]	Laparoscope	50	50	a (1:300)	c	Mechanical	①②③④
6	LIANG Y Y ^[12]	Laparoscope	820	822	a	c	—	①③
7	WU Q ^[13]	Rigid endoscope	60	60	a (1:200)	d	Manual + Ultrasonic	①④
8	YANG X M ^[14]	Laparoscope	20	20	a (1:300)	c	Mechanical	①②③④
9	QIN J ^[15]	Rigid endoscope	482	496	a (1:200)	d	Manual + Ultrasonic	①④

Note: a, multi-enzyme cleaner; b, self-made heparin; c, foam multi-enzyme moisturizer; d, gel moisturizer; ①, visual inspection method; ②, residual protein test; ③, ATP bioluminescence assay; ④, occult blood test.

ture retention effect of rigid endoscopes

2.3.1 Cleaning pass rate by visual inspection method

Three studies compared the effects of multi-enzyme cleaner and self-made heparin on the cleaning quality of rigid endoscopes using the visual inspection method. Heterogeneity testing revealed no significant heterogeneity among the included studies ($I^2=0\%$, Q test $P=0.95$), warranting the use of a fixed-effects model for pooling effect sizes. The pooled analysis demonstrated that the self-made heparin was associated with a significantly higher cleaning pass rate compared with the multi-enzyme cleaner ($RR=1.01$, 95% CI: 1.00~1.03; $Z=2.14$, $P=0.03$), indicating superior moisture retention efficacy as assessed by visual inspection (Figure 3).

2.3.2 Cleaning pass rate by residual protein test

Three studies compared the effects of multi-enzyme cleaner and self-made heparin on the cleaning quality of rigid endoscopes using the residual protein test. Heterogeneity testing revealed no significant heterogeneity among the included studies ($I^2=0\%$, Q test $P=0.60$), justifying the application of a fixed-effects model for pooling effect sizes. The pooled analysis demonstrated that the self-made heparin was associated with a significantly higher cleaning pass rate compared with the multi-enzyme cleaner ($RR=1.01$, 95% CI: 1.00~1.03; $Z=2.01$, $P=0.04$), indicating superior moisture retention efficacy as assessed by residual protein testing (Figure 4).

2.4 Comparison between multi-enzyme cleaner and foam multi-enzyme moisturizer on cleaning quality of rigid endoscopes

2.4.1 Cleaning pass rate by visual inspection method

Four studies compared the effects of multi-enzyme cleaner and foam multi-enzyme moisturizer on the cleaning quality of rigid endoscopes using the visual inspection method. Heterogeneity testing revealed substantial heterogeneity among the included studies ($I^2=76\%$, Q test $P<0.1$), warranting the application of a random-effects model for pooling effect sizes. The pooled analysis demonstrated that the foam multi-enzyme moisturizer was not associated with a statistically significant difference in cleaning pass rate compared with the multi-enzyme cleaner ($RR=1.04$, 95% CI: 0.99~1.09; $Z=1.46$, $P=0.14$), indicating that no significant difference in moisture retention efficacy could be detected between the two agents as assessed by visual inspection (Figure 5).

2.4.2 Cleaning pass rate by ATP bioluminescence assay

Four studies compared the effects of multi-enzyme cleaner and foam multi-enzyme moisturizer on the cleaning quality of rigid endoscopes using the ATP bioluminescence assay. Heterogeneity testing revealed substantial heterogeneity among the included studies ($I^2=94\%$, Q test $P<0.1$), warranting the application of a random-effects model for pooling effect sizes. The pooled analysis demonstrated that

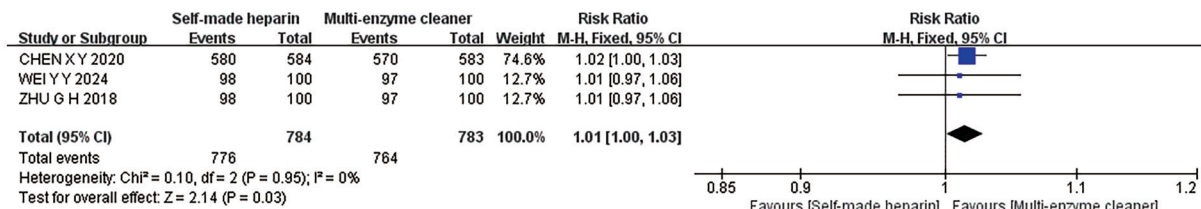


Figure 3 Forest plot of meta-analysis comparing self-made heparin versus multi-enzyme cleaner on cleaning pass rate assessed by visual inspection methods

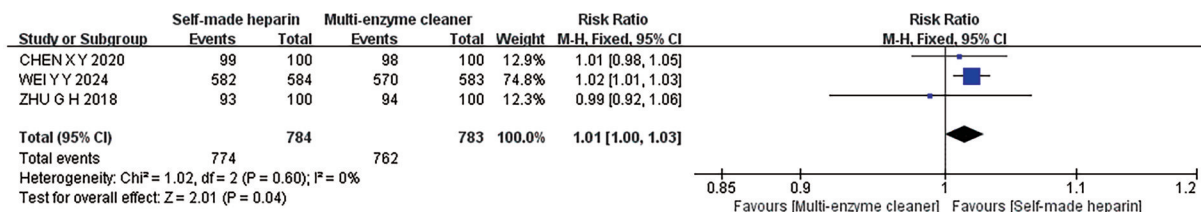


Figure 4 Forest plot of meta-analysis comparing self-made heparin versus multi-enzyme cleaner on cleaning pass rate assessed by residual protein test

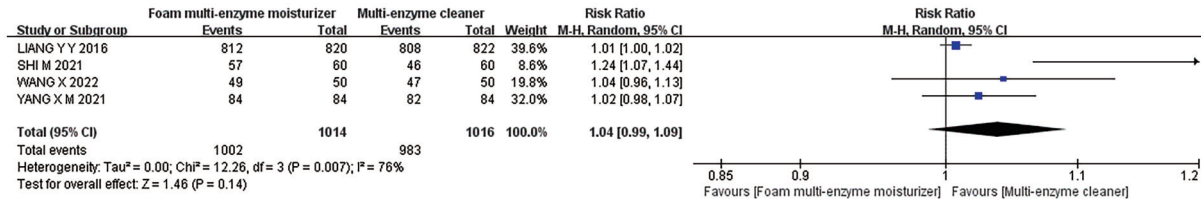


Figure 5 Forest plot of meta-analysis comparing foam multi-enzyme moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by visual inspection method

the foam multi-enzyme moisturizer was associated with a significantly higher cleaning pass rate compared with the multi-enzyme cleaner ($RR=1.23$, 95% CI : 1.03~1.48; $Z=2.30$, $P=0.02$), indicating superior moisture retention efficacy as assessed by ATP bioluminescence assay (Figure 6).

2.4.3 Cleaning pass rate by occult blood test

Two studies compared the effects of multi-enzyme cleaner and foam multi-enzyme moisturizer on the cleaning quality of rigid endoscopes using the occult blood test. Heterogeneity testing revealed no significant heterogeneity among the included studies ($I^2=0\%$, Q test $P=0.38$), justifying the application of a fixed-effects model for pooling effect sizes. The pooled analysis demonstrated that the foam multi-enzyme moisturizer was associated with a significantly higher cleaning pass rate compared with multi-enzyme cleaner ($RR=1.10$, 95% CI : 1.04~1.17; $Z=3.13$, $P=0.002$), indicating superior moisture retention efficacy as assessed by occult blood testing (Figure 7).

2.4.4 Cleaning pass rate by residual protein test

Two studies compared the effects of multi-

enzyme cleaner and foam multi-enzyme moisturizer on the cleaning quality of rigid endoscopes using the residual protein test. Heterogeneity testing revealed substantial heterogeneity among the included studies ($I^2=81\%$, Q test $P<0.1$), warranting the application of a random-effects model for pooling effect sizes. The pooled analysis demonstrated that the foam multi-enzyme moisturizer was not associated with a statistically significant difference in cleaning pass rate compared with multi-enzyme cleaner ($RR=1.08$, 95% CI : 0.93~1.26; $Z=1.01$, $P=0.31$), indicating that no significant difference in moisture retention efficacy could be detected between the two agents as assessed by residual protein testing (Figure 8).

2.5 Comparison between multi-enzyme cleaner and gel moisturizer on moisture retention effect of rigid endoscopes

2.5.1 Visual inspection method

Three studies assessed the comparative efficacy of the multi-enzyme cleaner and gel moisturizer on the cleaning quality of rigid endoscopes using visual inspection. Heterogeneity testing demonstrated no significant heterogeneity among the included studies

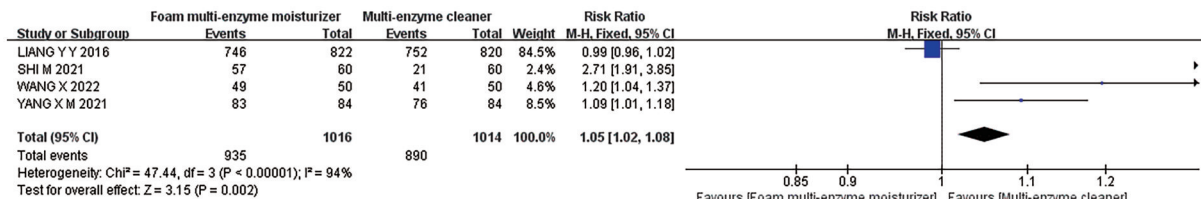


Figure 6 Forest plot of meta-analysis comparing foam multi-enzyme moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by ATP bioluminescence assay

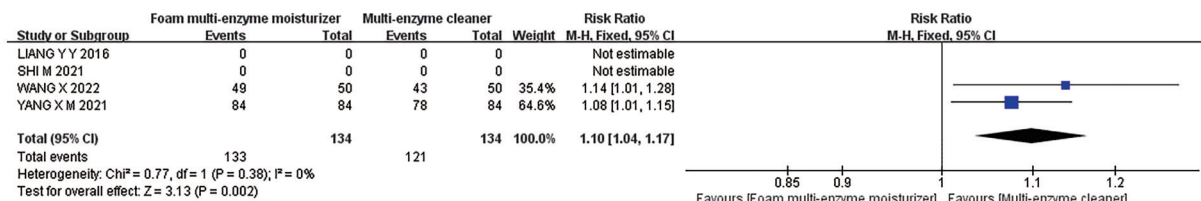


Figure 7 Forest plot of meta-analysis comparing foam multi-enzyme moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by occult blood test



Figure 8 Forest plot of meta-analysis comparing foam multi-enzyme moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by residual protein test

($I^2=47\%$, Q test $P=0.15$), justifying the application of a fixed-effects model for pooling effect sizes. The pooled analysis revealed that the gel moisturizer was associated with a significantly higher cleaning pass rate compared with the multi-enzyme cleaner ($RR=1.05$, 95% CI: 1.03~1.08; $Z=3.94$, $P<0.001$), indicating superior moisture retention efficacy as assessed by visual inspection (Figure 9).

2.5.2 Occult blood test

Two studies compared the effects of multi-enzyme cleaner and gel moisturizer on the cleaning quality of rigid endoscopes using the occult blood test. The heterogeneity test revealed no statistically significant heterogeneity among the included studies ($I^2=0\%$, Q test $P=0.73$), warranting the use of a fixed-effects model for pooling effect sizes. The pooled analysis demonstrated that the gel moisturizer was associated with a significantly higher cleaning pass rate compared with multi-enzyme cleaner ($RR=1.02$, 95% CI: 1.00~1.05; $Z=2.41$, $P=0.02$), indicating superior moisture retention efficacy as assessed by occult blood testing (Figure 10).

2.6 Subgroup analysis

To investigate potential sources of heterogeneity among the included studies, subgroup analyses were performed based on the key clinical and methodological variables (Table 3). Seven studies were included in the analysis stratified by cleaning method. Moderate heterogeneity was observed between studies employing manual cleaning combined with ultrasonic cleaning and those using mechanical cleaning ($I^2=52\%$, $P=0.05$); accordingly, a random-effects model was applied. This finding suggests that the choice of cleaning method following moisture retention pretreatment significantly influences the pooled effect estimates, with mechanical cleaning demonstrating slightly superior outcomes compared to manual cleaning combined with ultrasonic cleaning, representing a major contributor to the observed heterogeneity.

In the analysis of multi-enzyme cleaner concentration, eight studies were included. Low heterogeneity was detected ($I^2=0\%$, $P=1.00$), and a fixed-effects model was employed. No statistically significant difference was observed between cleaner con-

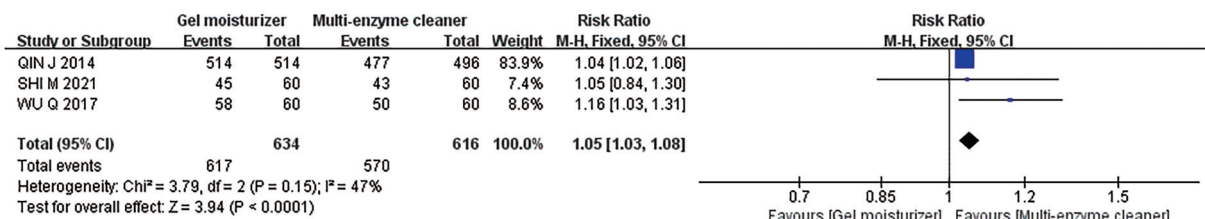


Figure 9 Forest plot of meta-analysis comparing gel moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by visual inspection method

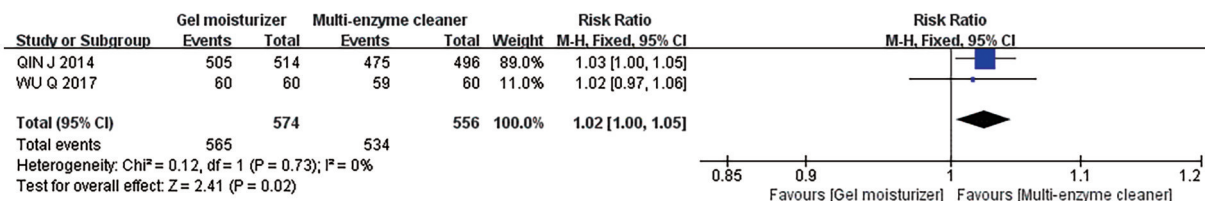


Figure 10 Forest plot of meta-analysis comparing gel moisturizer versus multi-enzyme cleaner on cleaning pass rate assessed by occult blood test

centrations of 1:200 and 1:270~300 ($RR=0.98$, 95% CI : 0.97~1.00, $P=1.00$). In the analysis stratified by instrument type, nine studies were included. Moderate heterogeneity was observed ($I^2=25\%$, $P=0.21$), and a fixed-effects model was used. No significant difference was detected between laparoscopes and rigid endoscopes ($RR=1.02$, 95% CI : 1.01~1.03, $P=0.21$).

Nine studies were also included in the analysis, stratified by sample size. Moderate heterogeneity was present ($I^2=37\%$, $P=0.12$), and a fixed-effects model was applied. No statistically significant difference was observed between studies with sample sizes ≤ 100 and those with sample sizes >100 ($RR=1.02$, 95% CI : 1.01~1.02, $P=0.12$).

3 Discussion

With the increasing prevalence of minimally invasive surgery, the volume of such procedures continues to rise steadily. Rigid endoscopes are essential for ensuring the smooth execution of surgical operations; consequently, the management of these instruments is of paramount importance for both surgical outcomes and patient safety^[16-18]. In the context of hospital infection prevention and control, thorough cleaning of medical devices constitutes an indispensable prerequisite for successful sterilization. Inadequate cleaning has been identified as a

significant risk factor for iatrogenic infections^[19]. There is accumulating evidence that suggests that moisture retention pretreatment directly influences the quality of instrument cleaning^[20-24]. Effective pretreatment prevents the formation of biofilms derived from organic contaminants on instrument surfaces, thereby avoiding compromised sterilization resulting from incomplete cleaning. According to the best evidence summary by Liang Yuanyuan et al.^[25], endoscopes should undergo pretreatment immediately after use and be transported to the central sterile supply department for reprocessing within one hour after pretreatment. Accordingly, to ensure optimal clinical safety, more rigorous criteria should govern the selection of pretreatment moisturizing agents^[26-27]. To investigate the comparative effects of different moisturizing agents on the cleaning quality of rigid endoscopes, the present systematic review and meta-analysis included nine randomized controlled trials. Among these, eight studies explicitly implemented random assignment, whereas one study did not provide sufficient detail regarding the randomization method employed. Most of the included studies described their inclusion and exclusion criteria in relative detail. Primary outcome indicators encompassed cleaning pass rates assessed by visual inspection, occult blood testing, residual protein testing, and

Table 3 Subgroup analysis of effects of different moisturizing agents on the cleaning quality of rigid endoscopes

Subgroup / Stratification	Number of Studies	<i>P</i> value	<i>I</i> ²	<i>RR</i>	95% <i>CI</i>
1. Multi-enzyme cleaner concentration					
1:200	5	0.99	0%	0.98	0.97~1.00
1:270~300	3	0.77	0%	0.98	0.95~1.01
Between-group comparison		1.00	0%	0.98	0.97~1.00
2. Instrument type					
Laparoscope	6	0.64	0%	1.01	1.00~1.02
Rigid endoscope	3	0.68	0%	1.03	1.01~1.06
Between-group comparison		0.21	27%	1.02	1.01~1.03
3. Cleaning method					
Manual + ultrasonic cleaning	4	0.03	66%	1.02	1.01~1.03
Mechanical cleaning	3	0.80	0%	0.98	0.96~1.04
Between-group comparison		0.05	52%	1.02	1.01~1.03
4. Sample size					
≤ 100	6	0.83	0%	1.00	0.97~1.03
≥ 100	3	0.01	78%	1.02	1.01~1.03
Between-group comparison		0.12	37%	1.02	1.01~1.02

ATP bioluminescence assay. It should be noted that although some pooled effect sizes in this analysis were located at the critical value of the confidence interval ($RR=1.00$), the differences achieved statistical significance. The clinical significance of these findings should be interpreted in conjunction with the specific clinical context and methodological considerations of the included studies.

3.1 Moisture retention effect of multi-enzyme cleaner

Multi-enzyme cleaner is widely used for the pretreatment of surgical instruments due to its ability to effectively loosen and remove organic residues such as blood stains, mucus, and proteins adhered to instrument surfaces. Previous studies have demonstrated that the application of multi-enzyme cleaner as a pretreatment agent facilitates the dissolution of dried organic matter, thereby enhancing the efficacy of subsequent routine cleaning and contributing to improved disinfection and sterilization outcomes^[6,16-17,28]. However, the effectiveness in removing organic contaminants, such as blood, proteins, and lipids, from internal lumens and narrow crevices remains limited, which may compromise overall moisture retention performance. Furthermore, the enzymatic activity of multi-enzyme cleaner is significantly diminished after approximately four hours of application, and the prolonged retention of residual organic material may lead to microbial proliferation and secondary contamination^[29]. Consequently, multi-enzyme cleaners may be more suitable for instruments used in daytime surgeries, where cleaning can be completed within this four-hour window.

3.2 Comparison of the moisture retention effect between the self-made heparin and multi-enzyme cleaners

Three of the included studies utilized self-made heparin for moisture retention pretreatment of rigid endoscopes^[7-9]. The pooled results of this meta-analysis demonstrated that self-made heparin achieved slightly superior moisture retention efficacy compared with conventional multi-enzyme cleaner, as assessed by both visual inspection and residual protein testing. Consistently, a study by Wang et al.^[30] reported that pretreatment with heparin-based moisturizing solution yielded cleaning outcomes compa-

parable to those achieved with specialized moisturizing gel. The mechanism underlying the efficacy of heparin may be attributed to its strong negative charge, which interferes with the blood coagulation cascade at multiple steps. When applied as a spray, heparin inhibits blood agglutination on instrument surfaces, thereby maintaining moisture and preventing the adhesion of organic residues^[9]. In addition to its satisfactory cleaning performance, self-made heparin offers advantages in terms of low cost and ease of preparation, rendering it a highly feasible option for primary hospitals or resource-limited settings.

3.3 Comparison of moisture retention effect between foam multi-enzyme moisturizer and multi-enzyme cleaners

Four of the included studies compared the effects of multi-enzyme cleaner and foam multi-enzyme moisturizer on the cleaning quality of rigid endoscopes^[10-13]. The pooled results of this meta-analysis demonstrated that the foam multi-enzyme moisturizer exhibited superior moisture retention efficacy compared with conventional multi-enzyme cleaners when assessed by ATP bioluminescence assay and occult blood testing. The enhanced performance of foam-type formulations may be attributed to their mechanism of action. When applied as a spray, the foam multi-enzyme moisturizer combines the multi-enzyme solution with an air stream to generate foam with strong adsorptive properties and high surface tension. This foam rapidly penetrates and uniformly covers the instrument surface, including joint gaps and internal lumens, thereby facilitating the prompt decomposition of residual organic contaminants while maintaining instrument moisture. This approach reduces cleaning difficulty, minimizes manual handling, and effectively improves overall cleaning efficacy^[26,31]. However, no statistically significant differences were observed between the foam multi-enzyme moisturizer and conventional multi-enzyme cleaner in assessments conducted via visual inspection or residual protein testing ($p>0.05$). Several factors may account for these findings. Firstly, visual inspection is inherently subjective and limited in its capacity to reliably detect bacteria, viruses, or minute contaminants on

instrument surfaces^[30]. Secondly, both agents share a common mechanism of action, enzymatic decomposition of residual proteins, which may explain the comparable outcomes observed in protein-based assessments. Notably, Shi et al.^[10] reported that when foam multi-enzyme moisturizer and conventional multi-enzyme cleaner were applied to rigid endoscopes, cleaning quality assessed by ATP bioluminescence assay after 12 hours revealed that the mean relative light unit (RLU) value for the foam pretreatment group was significantly lower than that for the multi-enzyme cleaner group. This finding underscores the enhanced decontamination capacity of foam-type formulations. By combining enzymatic activity with superior permeability, foam multi-enzyme moisturizers are particularly well-suited for rigid endoscopes characterized by long, narrow lumens and complex structural features, especially those subjected to nighttime or delayed reprocessing^[32].

3.4 Comparison of the moisture retention effect between gel moisturizer and multi-enzyme cleaner

Three of the included studies compared the effects of multi-enzyme cleaner and gel moisturizer on the cleaning quality of rigid endoscopes^[14-16]. This meta-analysis indicates that the moisture retention effect of the gel moisturizer was superior to that of the multi-enzyme cleaner as assessed by both visual inspection and occult blood testing. Moisturizing gel is primarily composed of humectants, hydrophilic agents, occlusives, and lubricants. Humectants absorb moisture from the environment to maintain instrument hydration; hydrophilic components facilitate moisture retention by binding water; occlusives form a protective film on the instrument surface to prevent moisture evaporation; and lubricants help soften contaminants while protecting endoscopes from corrosion^[33-34]. Owing to their high adhesiveness and sustained moisturizing capacity, gel moisturizers are particularly suitable for scenarios involving heavy contamination or a high risk of delayed cleaning^[7,10], such as rigid endoscopes that require prolonged storage prior to reprocessing following emergency surgical procedures.

3.5 Study limitations

It should be acknowledged that several limitations exist in this meta-analysis. Firstly, the overall methodological quality of the included studies was suboptimal, characterized by inadequate reporting of allocation concealment and blinding procedures. A substantial proportion of studies were assessed as having a high risk of bias, which may compromise the validity and reliability of the pooled effect estimates. Secondly, the included studies primarily focused on the type of moisturizing agent employed, with no systematic evaluation of the potential impact of different cleaning techniques on the cleaning quality of endoscopes. Thirdly, the number of eligible studies was relatively small, sample sizes were limited, and considerable statistical heterogeneity was observed across several comparisons. Additionally, all the included trials were published in Chinese, and no relevant English-language studies met the inclusion criteria, which may introduce language bias and limit the generalizability of the findings.

In conclusion, this meta-analysis demonstrates that gel-type and self-made heparins confer superior cleaning efficacy compared with conventional multi-enzyme cleaners for the moisture retention pretreatment of rigid endoscopes, with statistically significant differences observed particularly in visual inspection and occult blood testing. Foam multi-enzyme moisturizers exhibited enhanced decontamination performance in ATP bioluminescence assays and occult blood tests, rendering them suitable for the pretreatment of heavily soiled or structurally complex instruments. Beyond technical improvement, enhancing cleaning pass rates represents a critical strategy for the prevention and control of hospital-acquired infections. The widespread adoption of highly effective moisturizing agents is expected to substantially reduce the risk of iatrogenic infections attributable to inadequate instrument reprocessing and contribute to the overarching goal of “safe reprocessing, zero infections.” Future efforts should prioritize the expeditious development of evidence-based guidelines for the selection and use of moisturizing agents for rigid endoscopes in China, to ad-

vance the standardized construction of sterile supply departments.

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