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Article

Optimization of rigid endoscope drying method based on negative pressure suction device: Evaluation of its impact on drying efficiency and occupational safety

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Abstract: Methods: A randomized controlled trial design was employed. Four types of rigid endoscopes were selected: fiber optic instruments, lens instruments, forceps instruments, and tubular instruments, with 100 samples from each category. The samples were assigned to a control group (traditional drying method) and an experimental group (negative pressure suction device). The experimental group used a negative pressure suction device combined with a drying cabinet for drying, while the control group employed wiping, a high-pressure air gun, and a drying cabinet. Drying time for each type of instrument was measured, and noise levels during the drying process were assessed using a noise meter. The data were analyzed using independent sample t-tests for intergroup comparisons, with a significance level set at $P < 0.05$. **Results:** The experimental group showed significantly shorter drying times for fiber optic instruments, lens instruments, and forceps instruments compared to the control group. The drying time for fiber optic instruments in the experimental group was 316.9 ± 1.97 s, significantly shorter than the control group's 326.53 ± 4.43 s ($t = 6.28$, $P < 0.001$). The drying time for lens instruments in the experimental group was 315.07 ± 1.80 s, compared to 320.54 ± 4.21 s in the control group ($t = 3.78$, $P < 0.001$). However, for tubular instruments, the experimental group's drying time was 660 s, markedly longer than the control group's 327.04 ± 4.99 s ($t = 211.09$, $P < 0.001$). In terms of noise levels, the experimental group exhibited significantly lower noise exposure for fiber optic and lens instruments compared to the control group. The average noise for fiber optic instruments was 45.79 ± 0.17 dB in the experimental group, while it was 63.73 ± 0.67 dB in the control group ($t = 82.55$, $P < 0.001$). **Conclusion:** The negative pressure suction device significantly improves the drying efficiency of rigid endoscopes, especially for instruments with simpler structures, and effectively reduces noise exposure, enhancing occupational safety. However, for complex tubular instruments, further optimization of the negative pressure suction device is required.

Keywords: negative pressure suction device; rigid endoscope; drying efficiency; occupational safety

1. Introduction

Endoscopic surgery is widely used in the diagnosis and treatment of various diseases, and rigid endoscopes have become a commonly used tool in clinical practice due to their precision and minimally invasive characteristics [1]. However, the cleaning and drying of endoscopic instruments after surgery is a critical step to ensure their reuse and to prevent cross-infection. Current drying methods for endoscopic instruments mostly rely on manual wiping, high-pressure air guns, and other traditional techniques. While these methods are effective, they are relatively

inefficient, and noise exposure poses a potential occupational health risk to medical staff [2]. As the demands for efficiency and safety in the operating room environment continue to rise, optimizing drying methods has become an important area of research.

Although current studies have explored the cleaning and drying of various endoscopic instruments, drying efficiency remains low for instruments with complex structures. Furthermore, there is a lack of systematic evaluation of the impact of noise exposure on the health of medical staff [3]. Negative pressure suction technology, as an emerging drying method, has the potential to quickly remove moisture. However, its specific effects on different endoscopic instruments and its impact on occupational safety have not yet been fully studied. Cleaning and drying of endoscopic instruments before reuse is a crucial step in preventing cross-contamination, particularly in controlling hospital-acquired infections (HAI). Studies have shown that incomplete drying may lead to pathogen retention, thereby increasing the risk of infection [4]. In recent years, related research has further emphasized the critical role of endoscope drying in reducing the spread of pathogens [5]. An effective drying procedure helps to reduce the survival rate of microorganisms on the endoscope surface, thereby decreasing the occurrence of hospital infections [6]. Therefore, optimizing endoscope drying techniques not only contributes to improved efficiency but also has a profound impact on infection control in hospitals.

This study aims to evaluate the application of a negative pressure suction device in the drying of rigid endoscopic instruments, particularly its effects on drying efficiency and occupational safety. By comparing it with traditional drying methods, the study seeks to explore the suitability of the negative pressure suction device for instruments with different structures, providing scientific evidence for optimizing drying methods in operating rooms and offering data support for future equipment improvements.

2. Materials and methods

2.1. Study design

This study adopted a randomized controlled trial design to compare the effects of a negative pressure suction device and traditional drying methods on the drying efficiency and noise levels of rigid endoscopic instruments. The experimental subjects included four commonly used types of rigid endoscopic instruments: fiber optic instruments, lens instruments, forceps instruments, and tubular instruments. Each type of instrument was randomly assigned to a control group and an experimental group, with the control group using traditional methods and the experimental group using the negative pressure suction device for drying [7]. A total of 100 samples were selected for each type of instrument, with 50 samples allocated to the experimental group and 50 samples to the control group. The experiment operators were blinded to the group assignments (double-blind). The experiments were conducted under constant temperature and humidity conditions, with ambient noise controlled below 20 dB (A) to ensure measurement accuracy.

To ensure the consistency of experimental operations and the reliability of data, all experimental personnel in this study received standardized training before the start of the experiment. The training content included the use of negative pressure suction

devices, the standardized cleaning and drying procedures for endoscopic instruments, and the correct use of noise measurement instruments. All operators conducted multiple simulation operations before the formal experiment to ensure strict adherence to the experimental protocols during the experiment, avoiding deviations caused by human factors.

2.2. Experimental equipment and instruments

The instruments used in the experiment included four commonly used types of rigid endoscopic instruments: (1) Fiber optic instruments: Endoscopic instruments designed to transmit light sources through optical fibers; (2) Lens instruments: Endoscopic devices used for imaging; (3) Forceps instruments: Specialized surgical forceps for endoscopic procedures; (4) Tubular instruments: Flexible tubular instruments designed for the transmission of fluids or gases. All instruments were sourced from the same manufacturer and underwent a standardized cleaning process to ensure that the initial moisture levels of all instruments were consistent before entering the drying process.

Application of the Negative Pressure Suction Device: The experimental group used the Yuwell 7A-23B electric negative pressure suction device, with a negative pressure value of −90 kPa and an airflow rate of 20 L/min. This device was primarily applied to the drying of fiber optic instruments, lens instruments, and forceps instruments. The device quickly removes residual moisture from the surface and interior of these instruments through negative pressure technology, significantly improving drying efficiency. However, for instruments with complex structures, such as tubular devices, the effectiveness of the negative pressure suction device is relatively limited, and further optimization or combination with other drying technologies is required to enhance drying efficiency.

2.3. Measurement of drying time

The measurement of drying time was divided into the following three steps and recorded separately for the experimental group and the control group, based on the type of instrument:

(1) Wiping Time: A sterile wiping cloth was used to wipe the surface of the instrument, ensuring that visible moisture was removed. The experimenters used a stopwatch to measure the time from the start of wiping until completion. In the experimental group, due to optimized design, wiping was not required for the forceps instruments and tubular instruments, so the duration of this step was recorded as zero.

(2) Medical High-Pressure Air Gun Usage Time: After wiping, a medical high-pressure air gun was used to dry the internal cavities and surfaces of the instruments, ensuring that the airflow reached all internal and surface areas. The drying duration was measured using a stopwatch from the time the air gun was turned on until no visible moisture remained on the surface or inside the instrument. In the experimental group, optimized design eliminated the need for air gun drying for the fiber optic instruments and lens instruments, so the duration for this step was recorded as zero.

(3) Total Drying Time: The total drying time was the cumulative time of the entire drying process, including wiping, high-pressure air gun drying, and drying cabinet processing. The drying cabinet processing time was fixed at 300 s. After wiping and high-pressure air gun drying, the instruments were placed in the drying cabinet. The total drying time was the sum of the wiping time, air gun drying time, and the fixed 300 s of drying cabinet time. In the control group, only tubular instruments utilized a combination of high-pressure air gun drying and the fixed 300 s drying cabinet time. In the experimental group, the optimized drying method involved a combination of a negative pressure suction device with a fixed 360 s duration and a medical drying cabinet with a fixed 300 s duration.

The average drying time for each type of instrument was expressed as mean ± standard deviation. The drying times for each type of instrument were compared using independent sample t-tests, with a significance level set at $P < 0.05$.

2.4. Measurement of noise levels

The measurement of noise levels was conducted in strict accordance with equipment noise standards, using a noise meter (measuring range of 30−130 dB(A), with an error margin of no more than 0.5 dB(A)). The laboratory was set up in a soundproof environment, with background noise controlled below 20 dB(A) [8]. Each noise measurement was taken 1 meter away from the equipment, with the noise meter's position fixed to ensure the consistency of the results [9].

The noise measurements were divided into the following three stages:

(1) Minimum Noise (Noise MIN): During the entire drying process, the noise meter recorded data every s. The minimum noise was defined as the lowest value recorded throughout the drying process.

(2) Average Noise (Noise AVG): The noise meter recorded data every second, and the average noise level for the sample was calculated as the mean of all recorded data points.

(3) Maximum Noise (Noise MAX): The maximum noise was defined as the highest noise level recorded during the entire drying process.

The above noise measurements were performed on fiber optic, lens, forceps, and tubular instruments in both the experimental and control groups. The noise data for each type of instrument was expressed as mean ± standard deviation and compared between groups using independent sample t-tests, with $P < 0.05$ indicating statistical significance [10].

2.5. Occupational safety assessment

The occupational safety assessment was primarily based on the noise exposure levels measured during the experiment. According to national occupational safety and health standards, prolonged noise exposure exceeding 80 dB (A) may impact the auditory health of healthcare workers [11]. In this study, the focus was on the average noise exposure (Noise AVG) at different stages of the drying process. By comparing the noise data from the control group and the experimental group across various types of instruments, the study aimed to evaluate whether the negative pressure suction

device could effectively reduce noise exposure, thereby lowering the occupational health risks for healthcare workers.

In addition to noise exposure, operator comfort and fatigue levels are also important aspects of this study's evaluation of occupational safety. To assess these factors, the experimental operators completed standardized questionnaires on comfort and fatigue levels (such as the Borg Rating of Perceived Exertion scale) before and after the experiment. Additionally, heart rate monitoring and electromyographic (EMG) recording of muscle activity were conducted to further quantify the physical burden and fatigue experienced during the operation process.

2.6. Data statistics and analysis

All experimental data were analyzed using SPSS 22.0 statistical software. Drying time and noise levels were expressed as mean ± standard deviation. Statistical analysis of intergroup differences in drying time and noise levels was conducted using independent sample t-tests, with a significance level set at $P < 0.05$. The statistical differences in total drying time and noise levels between the experimental and control groups for each type of instrument were evaluated using *t*-values and *P*-values. Significant results were used to validate the advantages of the experimental group in terms of drying efficiency and occupational safety [12].

3. Results

3.1. Comparison of drying times for different rigid endoscopic instruments

The study showed that the experimental group generally outperformed the control group in terms of drying times across different instruments, demonstrating the advantage of the negative pressure suction device in improving drying efficiency. During the drying process of rigid endoscope fiber optic instruments, the total drying time in the experimental group was 316.9 ± 1.97 s, significantly shorter than the 326.53 ± 4.43 s in the control group ($t = 6.28$, $P < 0.001$). Notably, the experimental group omitted the use of the medical high-pressure air gun, while the control group had a drying time of 9.12 ± 2.73 s, further highlighting the advantage of the negative pressure suction device (**Table 1**).

For lens instruments, the total drying time in the experimental group was 315.07 ± 1.80 s, which was also significantly shorter than the 320.54 ± 4.21 s in the control group ($t = 3.78$, $P < 0.001$). Although the wiping time in the experimental group was longer (15.07 ± 1.80 s) compared to the control group's 5.43 ± 2.72 s, the negative pressure suction device accelerated the overall drying process (**Table 2**) [13].

In the comparison of forceps instruments, the total drying time in the experimental group was 314.47 ± 3.61 s, significantly better than the 320.82 ± 2.86 s in the control group ($t = 4.36$, $P < 0.001$). The experimental group reduced the use of the medical high-pressure air gun (14.47 ± 3.61 s) through the negative pressure suction device, further improving efficiency (**Table 3**).

For tubular instruments, the drying time in the experimental group was notably longer than in the control group, with the experimental group taking 660 s, compared

to 327.04 ± 4.99 s in the control group (t = 211.09, P < 0.001). This result contrasts with the other instruments, indicating that the performance of the negative pressure suction device may be limited in the drying of tubular instruments (**Table 4**).

Table 1. Comparison of drying times for rigid endoscope fiber optic instruments (Unit: s).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Wiping (x ± s)	17.41 ± 2.93	16.9 ± 1.97		
Medical Air Gun (x ± s)	9.12 ± 2.73	-		
Drying Cabinet (x ± s)	300	300		
Total Drying Time (x ± s)	326.53 ± 4.43	316.9 ± 1.97	6.28	< 0.001

Table 2. Comparison of drying times for rigid endoscope lens instruments (Unit: s).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Wiping (x ± s)	5.43 ± 2.72	15.07 ± 1.80		
Medical Air Gun (x ± s)	15.11 ± 3.75	-		
Drying Cabinet (x ± s)	300	300		
Total Drying Time (x ± s)	320.54 ± 4.21	315.07 ± 1.80	3.78	< 0.001

Table 3. Comparison of drying times for rigid endoscope forceps instruments (Unit: s).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Wiping (x ± s)	3.98 ± 1.22	-		
Medical Air Gun (x ± s)	16.84 ± 2.54	14.47 ± 3.61		
Drying Cabinet (x ± s)	300	300		
Total Drying Time (x ± s)	320.82 ± 2.86	314.47 ± 3.61	4.36	< 0.001

Table 4. Comparison of drying times for rigid endoscope tubular instruments (Unit: s).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Wiping (x ± s)	27.04 ± 4.99	-		
Medical Air Gun (x ± s)	300	300		
Drying Cabinet (x ± s)	-	360		
Total Drying Time (x ± s)	327.04 ± 4.99	660	211.09	< 0.001

3.2. Comparison of noise levels for different rigid endoscopic instruments

The comparison of noise levels revealed that, during the drying process of most rigid endoscopic instruments, the experimental group exhibited significantly lower noise levels compared to the control group, indicating that the negative pressure suction device has a clear advantage in reducing healthcare workers' noise exposure.

In the comparison of fiber optic instruments, the minimum noise in the experimental group was 45.45 ± 0.15 dB (A), compared to 46.18 ± 0.61 dB (A) in the control group (t = 3.67, P < 0.001). The experimental group's average noise level was significantly lower than that of the control group (45.79 ± 0.17 dB (A) vs. 63.73 ± 0.67 dB (A), t = 82.55, P < 0.001), and the maximum noise followed the same trend (**Table 5**).

In lens instruments, the noise level in the experimental group was further reduced. The experimental group's average noise level was 45.77 ± 0.22 dB (A), while the control group's was 63.95 ± 0.40 dB (A) (t = 126.01, P < 0.001). The minimum and maximum noise levels were also significantly lower in the experimental group, at 45.40 ± 0.16 dB (A) and 46.14 ± 0.44 dB (A), compared to the control group (t = 7.03, P < 0.001; t = 143.51, P < 0.001) (**Table 6**).

However, for forceps instruments, the noise comparison showed no significant difference between the experimental and control groups [14]. There was no statistical significance in the differences between the minimum, average, and maximum noise levels of the experimental and control groups (P > 0.05), suggesting that the negative pressure suction device did not produce notable effects in noise reduction for this type of instrument (**Table 7**).

For tubular instruments, the experimental group exhibited significantly better noise levels compared to the control group, particularly in terms of average noise. The experimental group's average noise level was 46.14 ± 0.37 dB (A), while the control group's was 63.81 ± 0.54 dB (A) (t = 85.29, P < 0.001). There were also significant differences in minimum and maximum noise levels (t = 7.60, P < 0.001; t = 84.62, P < 0.001), indicating that the negative pressure suction device was highly effective in controlling noise for this type of instrument (**Table 8**).

Table 5. Comparison of noise levels for rigid endoscope fiber optic instruments (Unit: dB (A)).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Noise MIN (dB (A)) (x ± s)	46.18 ± 0.61	45.45 ± 0.15	3.67	< 0.001
Noise AVG (dB (A)) (x ± s)	63.73 ± 0.67	45.79 ± 0.17	82.55	< 0.001
Noise MAX (dB (A)) (x ± s)	81.27 ± 1.27	46.13 ± 0.30	85.12	< 0.001

Table 6. Comparison of noise levels for rigid endoscope lens instruments (Unit: dB (A)).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Noise MIN (dB (A)) (x ±s)	46.49 ± 0.47	45.40 ± 0.16	7.03	< 0.001
Noise AVG (dB (A)) (x ± s)	63.95 ± 0.40	45.77 ± 0.22	126.01	< 0.001
Noise MAX (dB (A)) (x ± s)	81.41 ± 0.64	46.14 ± 0.44	143.51	< 0.001

Table 7. Comparison of noise levels for rigid endoscope forceps instruments (Unit: dB (A)).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Noise MIN (dB (A)) (x ± s)	46.46 ± 0.40	46.45 ± 0.41	0.02	0.98
Noise AVG (dB (A)) (x ± s)	63.91 ± 0.66	64.09 ± 0.53	0.72	0.49
Noise MAX (dB (A)) (x ± s)	81.36 ± 1.34	81.74 ± 1.19	0.66	0.52

Table 8. Comparison of noise levels for rigid endoscope tubular instruments (Unit: dB (A)).

Item	Control Group	Experimental Group	*t*-value	*P*-value
Sample Size	100	100		
Noise MIN (dB (A)) (x ± s)	46.37 ± 0.35	45.41 ± 0.19	7.6	< 0.001
Noise AVG (dB (A)) (x ± s)	63.81 ± 0.54	46.14 ± 0.37	85.29	< 0.001
Noise MAX (dB (A)) (x ± s)	81.25 ± 1.08	46.87 ± 0.70	84.62	< 0.001

4. Discussion

The results of this study indicate that the negative pressure suction device demonstrated significant improvements in efficiency during the drying of rigid endoscopes, particularly for fiber optic instruments, lens instruments, and forceps instruments. The experimental data showed that the negative pressure suction device significantly shortened drying times. Compared to the control group, drying time for fiber optic instruments was reduced by approximately 10 s, lens instruments by 5 s, and forceps instruments by 6 s. This reduction in time is attributed to the negative pressure suction device's efficient airflow management technology, which rapidly removes residual moisture from the surface and interior of the endoscopes, thereby eliminating the need for manual wiping and the extra time required for using medical air guns [15]. Based on the time differences observed in the experiment, the results clearly indicate that the negative pressure suction device exhibits higher drying efficiency for these instruments [16]. However, the experimental results for tubular instruments revealed that the negative pressure suction device performed below expectations for these types of instruments. The drying time in the experimental group was significantly longer than in the control group (660 s vs. 327 s). The primary issue lies in the specific structure of tubular instruments, which have deep and narrow internal cavities, making it difficult for the negative pressure suction device to effectively remove moisture in a short period. To address the suboptimal drying performance for tubular instruments, future improvement strategies could involve combining the negative pressure suction device with other drying technologies. For instance, high-pressure airflow combined with negative pressure suction could accelerate moisture removal from the interior of the tubes. Another potential improvement would be to adjust the design of the negative pressure suction device by adding an internal airflow guidance system to more effectively cover the internal cavities of the instruments. Additionally, using heated drying technology in combination with the negative pressure suction device might further enhance drying

efficiency, especially when dealing with complex-structured tubular instruments. Traditional methods, such as the combination of a high-pressure air gun and drying cabinets, provide a more direct and concentrated airflow, effectively covering and drying the interior of tubular instruments in a shorter time [17]. Therefore, it is evident that the drying efficiency of the negative pressure suction device may be limited when used on instruments with complex structures. This observation suggests that while the negative pressure suction device shows clear advantages with simpler structured endoscopic instruments, for more complex instruments, such as tubular devices, optimization of the airflow design and suction power or the integration of additional drying technologies may be necessary to comprehensively improve drying efficiency.

The study results show significant differences in drying efficiency among different types of endoscopic instruments, which are directly related to the structural complexity of the instruments [18]. Fiber optic instruments and lens instruments exhibited higher drying efficiency in the experimental group, mainly because these instruments have relatively simple structures and larger surface areas. The negative pressure suction device was able to more easily reach every surface of these instruments, thereby quickly removing moisture [19]. Since these instruments lack complex internal cavities, the airflow from the negative pressure system could effectively and uniformly cover the entire drying surface, significantly reducing drying time. Fiber optic and lens instruments, due to their simple external structure and large surface area, allowed the negative pressure suction device to evenly and quickly remove moisture. Although forceps instruments are slightly more complex in structure, their primary drying areas are the external jaws and the relatively simple handle region. The negative pressure device was still able to quickly dry these areas. These structural characteristics enabled the negative pressure suction device to demonstrate significant drying advantages for these types of instruments. Despite the slightly more complex structure of forceps instruments, the experimental results still showed that drying times in the experimental group were superior to those in the control group. This could be attributed to the fact that the experimental group eliminated the need for traditional wiping and air gun drying steps, achieving rapid drying directly through negative pressure suction [20]. Although forceps instruments have diverse internal structures, the overall effect of the negative pressure system managed to cover the main surfaces, effectively avoiding the time extension caused by manual wiping. However, the poor drying performance of tubular instruments highlights the limitations of the negative pressure suction device when faced with complex structures [21]. The long, narrow internal cavities of tubular instruments made it difficult for the negative pressure suction to quickly and effectively remove moisture from the inner walls, leading to a significantly extended drying time. This suggests that the design of the negative pressure suction device needs to be adjusted according to the structure of different instruments, particularly for complex instruments like tubular devices. To improve drying efficiency, solutions such as enhancing internal airflow channels may be necessary to better reach the internal walls of tubular instruments. Additionally, combining other technologies, such as high-pressure airflow or heated drying, could further improve the drying efficiency of instruments with complex structures. The extended drying time for tubular instruments compared to other types was mainly due to the complex internal structure of tubular instruments, with narrow and curved

cavities that hindered the ability of the negative pressure suction device to effectively cover and quickly remove moisture from deep inside. The uneven airflow distribution within tubular instruments limited the overall drying efficiency. To address this issue, future improvements could focus on upgrading the airflow guidance system to ensure more uniform coverage of the internal walls of the tubes. Combining technologies like high-pressure airflow or heated drying may further enhance the drying efficiency of instruments with complex structures.

This study evaluated the performance of the negative pressure suction device in reducing noise exposure, and the results indicate that it offers significant advantages in improving occupational safety [22]. The experimental data show that the noise levels of fiber optic instruments and lens instruments were significantly lower when using the negative pressure suction device compared to the control group, with average noise levels reduced from approximately 63 dB to around 45 dB. This difference suggests that the negative pressure suction device not only improves drying efficiency but also effectively reduces noise exposure, thereby minimizing the risks of noise-induced harm to healthcare personnel during extended work periods [23]. Prolonged exposure to high noise levels is known to negatively impact hearing health and workplace comfort. The noise control benefits of the negative pressure suction device, particularly for these instruments, significantly reduce occupational safety risks. Prolonged high noise exposure can lead to long-term adverse effects on the hearing health and comfort of medical staff, especially for those working in high-noise environments such as operating rooms. This can result in hearing damage, fatigue, and decreased concentration. By significantly reducing noise levels, the negative pressure suction device not only mitigates these health risks but also provides a quieter working environment, which may help improve work efficiency and reduce the occurrence of noise-induced occupational illnesses. Therefore, the noise reduction advantages of the negative pressure suction device have important potential implications for improving the long-term occupational health of medical personnel. For forceps instruments, the noise comparison between the experimental group and the control group showed minimal differences, possibly due to the complex internal structure of the forceps instruments [24]. Since the negative pressure suction device did not demonstrate a significant advantage in noise control for this type of complex structure, it indicates some limitations in its noise control capabilities. Conversely, the noise levels for tubular instruments were significantly reduced in the experimental group, suggesting that the negative pressure suction device can maintain stable and low-noise operation during prolonged continuous use. Overall, the negative pressure suction device demonstrated great potential in reducing noise exposure, especially for endoscopic instruments that require long drying times. Its low-noise operation contributes to providing a safer working environment for healthcare personnel.

5. Limitations of the study and future research directions

Although this study demonstrated the effectiveness of the negative pressure suction device in improving drying efficiency and controlling noise, there are still limitations when dealing with instruments of complex structure. The significantly prolonged drying time for tubular instruments suggests that the design of the negative

pressure suction device is limited when facing intricate internal cavity structures [4]. Future research should consider optimizing the device by incorporating airflow guidance or other technologies to enhance its drying capability for complex instruments. Another limitation of this study is that its evaluation of occupational safety was restricted to noise exposure, without addressing other potential safety risks, such as particle release or microbial contamination during the drying process. Future research could include monitoring particulate matter and air quality to further explore the overall safety of this device in an operating room environment.

Additionally, the experiments were conducted under controlled laboratory conditions of constant temperature and humidity, which may differ from actual clinical operations. Therefore, future studies could test the device in real clinical environments to assess its performance under various conditions, providing better guidance for clinical applications. The innovative aspect of this study lies in its first systematic evaluation of the negative pressure suction device's effectiveness in drying various rigid endoscopic instruments, particularly the significant advantages observed with fiber optic, lens, and forceps instruments. The device not only improved drying efficiency but also effectively reduced noise exposure, enhancing occupational safety for healthcare personnel. The results of this study offer new evidence for optimizing rigid endoscope drying methods in clinical practice, and future applications could further extend its use in real clinical settings.

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