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Critical Node Control Combined with a Fully Automatic Dental Cleaning Machine for Cleaning and Disinfection of Dental Handpieces

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ABSTRACT: Objective This study aims to evaluate the effectiveness of critical node control management based on the "structure-process-outcome" quality evaluation indicators combined with a fully automatic cleaning and disinfecting machine for the cleaning and disinfection of dental handpieces. **Methods** A phased implementation grouping method was adopted. From March to July 2025, 500 dental handpieces were selected as the control group and received routine quality management. From August to December 2025, another 500 dental handpieces were selected as the observation group and received critical node control quality management combined with treatment using a fully automatic cleaning and disinfecting machine. The two groups were compared in terms of pre-processing pass rate, cleaning pass rate, incidence of oil stain wet pack, and clinical satisfaction. **Results** The observation group showed a significant higher pre-processing pass rate (99.2% vs. 95.6%, $P<0.05$) and a higher cleaning pass rate (99.4% vs. 97.6%, $P<0.05$) than the control group, as well as a lower incidence of oil stain wet pack (0.6% vs. 3.8%, $P<0.05$). In addition, satisfaction among both doctors and nurses improved significantly after the intervention ($P<0.05$). **Conclusion** Critical node control management combined with a fully automatic cleaning and disinfecting machine can effectively improve the cleaning and disinfection quality of dental handpieces, reduce the incidence of oil stain wet pack, and enhance clinical service satisfaction, thereby offering great value in preventing iatrogenic cross-infection.

KEY WORDS: Critical node control; Dental handpiece; Fully automatic cleaning and disinfecting machine; Cleaning and disinfection; Cross-infection

Dental handpieces are the most frequently used and most heavily contaminated instruments in dental diagnosis and treatment, thus classified as high-risk devices. They contain multiple internal lumens and gaps[1-2]. During operation, they may aspirate pathogenic microorganisms and tissue debris. Furthermore, contaminants remaining inside the lumens and crevices of a handpiece can become solid scale adhering to the inner walls of the lumens after exposure to high temperature and high pressure. If not thoroughly cleaned, disinfected, and sterilized promptly, they can easily lead to cross-infection. Traditional processing of dental handpieces, typically involving manual cleaning, alcohol wiping, mechanical oiling, and drying cabinets, is prone to issues including incomplete cleaning, uneven oiling, high operator variability, and poor quality control and traceability. Despite the increased use of fully automatic cleaning and disinfecting machines in recent years, which have enhanced cleaning efficiency to a certain degree, systematic quality management remains essential for achieving full process control and traceable quality. The critical node control management model establishes quality control points for each work step, uses "structure-process-outcome" quality evaluation indicators[3], and integrates quality testing, work specification guidelines, and work procedures into quality standards[4] to address problems occurring in routine quality management. Combined with the advantages of a fully automatic cleaning and

disinfecting machine, such as labor savings, fast cleaning speed, and thorough disinfection, this approach can effectively remove dirt and some microorganisms from handpieces, prevent mucus and clots from clogging the bearing lumen[5], prolong the service life of handpieces, improve their performance, and effectively prevent iatrogenic cross-infection. This study aimed to investigate the application effect of critical node control management combined with a fully automatic cleaning and disinfecting machine in the cleaning and disinfection of dental handpieces, so as to provide a reference for quality improvement in dental instrument processing.

1 Materials and Methods

1.1 General data

Using a prospective before-after design in which groups were assigned according to the implementation phase, we selected 1,000 dental handpieces from our hospital. All handpieces were of the same brand and model, had a service life of ⩽3 years, and showed no obvious wear or deformation. From March to July 2025, 500 pieces were randomly selected as the control group and received routine quality management. From August to December 2025, the other 500 pieces were randomly selected as the observation group and received critical node control quality management combined with treatment using a fully automatic cleaning and disinfecting machine. Handpieces in both groups were processed by the same dedicated staff. Baseline data showed no differences between the two groups (P>0.05), indicating they were comparable.

1.2 Methods

1.2.1 Establishment of a dental instrument research team

The research team consisted of six members: one manager, one equipment engineer, and four dental dedicated staff members. All members held intermediate professional technical titles or higher. The dental dedicated staff had more than three years of experience in sterile supply and were familiar with dental instruments. The team was primarily responsible for literature review; recording, summarizing, and analyzing problems at each step; formulating a detailed instrument management plan; and training dental dedicated staff on the names, structures, usage methods, cleaning steps, and cleaning techniques for dental handpieces; those measures effectively enhance the operational competence of cleaning personnel[6-7].

1.2.2 Establishment of a multi-step quality control chain

(1) A cross-departmental collaborative team was established, consisting of the Department of Healthcare-associated Infection Control, the Department of Stomatology, and the CSSD. (2) The responsibilities of dedicated dental instrument nurses were clearly defined. The head nurse conducted weekly spot checks on instrument cleaning quality, with a focus on handpiece oil stain wet pack and dryness, to ensure that dedicated staff strictly followed standard procedures in all operations. (3) Collaboration with the Department of Healthcare-associated Infection Control was undertaken to regularly supervise the implementation of pre-processing by stomatology nurses. The CSSD was responsible for providing one-on-one specialized training to staff whose pre-processing performance was inadequate. (4) Monthly quality analysis meetings were held to identify factors affecting cleaning quality, analyze problems prone to negligence or error in steps such as pre-processing, collection, and cleaning, and to ensure prompt rectification, feedback, and issue tracking.

1.2.3 Personnel professional skills training

CSSD staff received training on relevant disinfection knowledge for dental instruments, focusing primarily on the names, structures, functions, usage methods, characteristics, and cleaning precautions of dental handpieces. Before cleaning, training was delivered using on-site teaching combined with instrument atlas QR codes[8]. (1) QR code was used to create an “electronic ID” for each instrument set, and a standardized graphic list of instrument sets (including names, quantities, placement specifications, and handling methods) was customized and attached to the detail sheet. (2) Staff could scan the code at any time for learning, using fragmented time

to quickly become familiar with instrument structures and operating procedures[9-10]. (3) A "feedback" entry was embedded in the QR code, allowing user departments to upload photos on-site when problems were identified, thereby enabling real-time problem tracking. Multi-departmental consistency and accuracy were ensured, forming an authoritative knowledge base. Training effectiveness was linked to CSSD quality evaluation, and scores were used to drive targeted training for identified deficiencies. This approach enabled staff to more intuitively learn the operation methods, procedure selection, physical parameter observation, and other aspects of the fully automatic handpiece cleaning and disinfecting machine.

1.2.4 Optimization of cleaning and disinfection process

A new fully automatic cleaning, disinfecting, and oiling integrated machine was purchased for the department. Dedicated nurses were trained on the cleaning operation procedures. After collection, handpieces underwent initial treatment to remove visible surface contaminants. A matching fully automatic cleaning and oiling program was selected. High-pressure clean air drove cleaning water in a high-speed stream, forming a water jet that flushed the internal lumen of the handpiece. An enzyme solution accompanied the water column at the bottom of the handpiece. A total of seven cycles, including pre-wash, main wash, and rinse, were performed. As the temperature increased, lumen cleaning continued until drying. Meanwhile, a centrally radiating oiling tray ensured uniform oil distribution. The operation time was reduced by half compared with traditional processing methods.

1.2.5 Medical staff satisfaction survey

Satisfaction questionnaires were distributed to stomatology doctors and nurses. A total of 200 questionnaires were issued (10 copies to doctors and 10 to nurses per month; 100 before implementation (in control group) and 100 after implementation (in observation group). The questionnaire consists of five dimensions: packaging integrity, quantity accuracy, functional status, dryness, and cleaning quality. Each dimension is rated using a Likert 5-point scale [15]: 1=very dissatisfied, 2=dissatisfied, 3=neutral, 4=satisfied, 5=very satisfied.

1.3 Evaluation indicators

1.3.1 Pre-processing quality of dental handpieces

The pre-processing pass rate is calculated as:

$$\text{Pre-processing pass rate} = \frac{N_1}{D_1} \times 100\%$$

Where,

Numerator (N_1): Number of handpieces with no visible dirt or blood stains on the surface and with lumens promptly flushed without blockage or debris, as inspected by dedicated nurses after collection.

Denominator (D_1): Total number of used high-speed/low-speed dental handpieces returned to the CSSD during the same period (1,000 pieces total: 500 before implementation, 500 after implementation).

1.3.2 Cleaning quality of dental handpieces: magnifying glass inspection

The cleaning pass rate is calculated as:

$$\text{Cleaning pass rate} = \frac{N_2}{D_2} \times 100\%$$

Where,

Numerator (N_2): Number of dental handpieces deemed qualified by visual inspection followed by magnifying glass inspection after cleaning and disinfection.

Denominator (D_2): Total number of high-speed/low-speed dental handpieces subjected to cleaning quality inspection (visual inspection combined with magnifying glass) during the same period, including both qualified and unqualified instrument sets (1,000 pieces total: 500 before implementation, 500 after implementation).

1.3.3 Incidence of dental handpiece oil stain wet pack

The incidence of oil stain wet pack is calculated as:

$$\text{Incidence of oil stain wet pack} = \frac{N_3}{D_3} \times 100\%$$

Where,

Numerator (N_3): Number of dental handpieces that develop oil stain wet pack after cleaning, disinfection, drying, and sterilization.

Denominator (D_3): Total number of dental handpieces processed during the same period (1, 000 pieces total: 500 before implementation, 500 after implementation).

1.3.4 Medical staff satisfaction

The medical staff satisfaction rate is calculated as:

$$\text{Medical staff satisfaction rate} = \frac{N_4}{D_4} \times 100\%$$

Where,

Numerator (N_4): Number of valid questionnaires in which the average score across the five dimensions is ⩾4 points.

Denominator (D_4): Total number of valid questionnaires completed by stomatology doctors and nurses during the same period (invalid questionnaires, e. g., incomplete or those with all options invalid, were excluded).

1.4 Statistical analysis

Data were entered using Microsoft Excel and statistically analyzed using SPSS (version 27.0). Categorical data were reported as frequencies and percentages. Comparisons between observation group and control group were performed using the χ^2 test. A P value of <0.05 was considered statistically significant.

2 Results

2.1 After implementation of the critical node control method, the observation group showed significantly higher pre-processing pass rates (99.2% vs. 95.6%) and cleaning pass rates (99.4% vs. 97.6%), as well as a significantly lower incidence of oil stain wet pack (0.6% vs. 3.8%), compared with the control group (all P<0.05, Table 1).

2.2 Following implementation of the critical node control method, satisfaction levels among stomatology doctors and nurses with CSSD's performance were higher than those in the control group (before intervention), and both differences were statistically significant (P<0.05, Table 2).

3 Discussion

This study compared and analyzed pre-processing quality, cleaning quality, the incidence of oil stain wet pack, and user department satisfaction before and after implementation of node control. The results showed that following node control implementation, the observation group achieved higher pre-processing pass rates and cleaning pass rates, a lower incidence of oil stain wet pack, and greater satisfaction among stomatology doctors and nurses with CSSD compared to the control group. The study concluded that critical node quality control emphasizes the principles of process control, process management, and continuous improvement. Only by continuously refining various measures throughout management and shifting management from post-hoc inspection to pre-event prevention can management become more effective and training more practical.

Many steps in the cleaning, disinfection, and supply process of dental handpieces may affect package quality. Using QR code atlases, the entire dental handpiece operation process and corresponding mind maps are attached to the list, facilitating staff operation. Quality problems identified from handpiece collection to packaging are promptly communicated with the user department and uploaded to

Table 1 Comparison of quality indicators for dental handpiece pre-processing, cleaning, and sterilization between two groups

Evaluation Indicator	Control group (n=500)	Observation group (n=500)	χ^2	P
Pre-processing pass rate, n (%)	478(95. 6)	496(99. 2)	12. 794	<0. 001
Cleaning pass rate, n (%)	488(97. 6)	497(99. 4)	5. 482	0. 019
Incidence of oil stain wet pack, n (%)	19(3. 8)	3(0. 6)	11. 898	<0. 001

Table 2 Comparison of medical staff satisfaction between two groups

Evaluation Indicator	Before intervention (n=100)	After intervention (n=100)	χ^2	P
Doctor satisfaction, n (%)	82(82. 0)	95(95. 0)	8. 303	0. 004
Nurse satisfaction, n (%)	96(96. 0)	100(100. 0)	4. 082	0. 043

the "feedback" entry in the QR code, which can be viewed and updated at any time, thereby keeping each step and the factors affecting quality under effective control[11]. By implementing "structure-process-outcome" quality control for dental handpieces, we provide early warning and continuously adjust and improve emerging problems. A problem node that was previously a focus of improvement may no longer be a priority after a period of attention and quality improvement. Regarding handpiece oil stain wet pack, the fully automatic oiling time was repeatedly adjusted and validated, ultimately set at 2 seconds, which effectively eliminated oil stain wet pack and reduced its incidence from 3.8% to 0.6%, achieving the desired effect.

For each step of the existing dental handpiece cleaning process in our department, quality issues were prospectively identified. Root cause analysis (RCA) was used to examine potential and emerging problems, identifying difficulties such as failure to follow cleaning procedures, incomplete cleaning, and uneven handpiece oiling. The research team identified risk points from these problems, reviewed and optimized the original cleaning process, revised work procedures and operating standards, trained relevant personnel, and strengthened the specialized knowledge and sense of responsibility among dental dedicated staff. These efforts effectively improved handpiece cleaning quality and reduced the impact of biofilm formation on sterilization efficacy[12-13]. The cleaning quality pass rate in the observation group was as high as 99.4%.

Satisfaction is an important indicator for measuring the quality of CSSD services[14]. In this study, the satisfaction of stomatology doctors and nurses improved significantly: doctor satisfaction increased from 82.0% to 95.0%, and nurse satisfaction rose from 96.0% to 100.0%. The cross-departmental collaborative "Department of Healthcare-associated Infection Control – Department of Stomatology – CSSD", as a trinity multi-step quality control chain, broke down previous information silos between departments. By establishing a dedicated communication group, clinical departments were able to directly and promptly report performance issues, such as abnormal noise and insufficient speed during handpiece use, to CSSD dedicated staff. The CSSD then used this feedback as an important quality information node, tracing back to previous steps (e.g., cleaning, oiling, maintenance) for analysis and improvement. This formed a closed-loop management model of "clinical problem feedback → step traceability and rectification → quality improvement → clinical validation"[15], transforming clinical departments from passive recipients into active co-builders of quality. Therefore, node control is not merely a technical and procedural control but also a two-way communication mechanism.

In summary, the multi-step quality control chain based on critical node control management enables prospective identification and improvement of quality-related issues. These measures not only enhance staff awareness of quality and responsibility but also improve the accuracy and safety of sterile item supply. Furthermore, the fully automatic handpiece cleaning machine has automated cleaning programs that perform internal and external cleaning, oiling, drying, and surface disinfection of dental handpieces. This largely eliminates the arbitrariness and procedural errors associated with manual operation, prolongs the service life of handpieces, improves their performance, and effectively prevents iatrogenic cross-infection.

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