Features and Medical Applications of Microfiber Cloth for Cleaning Instruments with Wipes

Graduate School of Bioresources, Mie University

Satoshi Fukuzaki

INTRODUCTION

At medical institutions, it has been reported that various contact-based infections occurred through medical engineering (ME) instruments and environmental surfaces[1~3]. In particular, places that healthcare workers frequently come into contact with, such as the control panels, touch panels, and monitoring screens of ME instruments as well as door knobs and railings, require appropriate wipe cleaning and disinfection to remove various contaminants and viable microbes transferred from fingers and gloves.

Healthcare workers generally use so-called "environmental cloths" to wipe ME instruments clean. These wipes are made of cotton cloth, nonwoven fabrics, or wipe cleaning cloth impregnated with a solution containing disinfectant with or without detergent. The cloth may be made of cotton, polyester, rayon, polypropylene, or polyethylene as a single material or a combination of multiple materials. This wiping operation is an important cleaning procedure because it is possible to wipe an instrument or surface clean while simultaneously disinfecting it in a safe and simple manner. However, a certain amount of disinfectant remains on the surface after wipe cleaning. Centers for Disease Control and Prevention guidelines strongly recommend refraining from using disinfectant on ME instrument touch panels and infant incubators during use[4]. Therefore, a chemical-free cleaning cloth that efficiently wipes off surface contaminants by itself or with water, while keeping soil from readhering to the surface, is much desired.

One such form is a woven wipe made of ultrafine fibers. This article focuses on a microfiber cloth known as Toraysee for CE (hereinafter, "Microfiber Cloth CE"), which was recently confirmed to be a useful material for routine cleaning with wipes in medical practice. The manufacturing method, product design and characteristics, wiping performance, and precautions for performing the wiping procedure are also explained herein.

WHAT IS AN ULTRAFINE FIBER?

The unit "tex" is used to express fiber thickness (fineness). One tex is defined as the mass in grams of a 1000-m-long filament. A conventionally-used unit is the decitex (dtex), which is equivalent to 1/10 of a tex. The relationship between fiber diameter and dtex is dependent on the fiber density ; e. g., polyester fibers (density of approximately 1.38 g/cm^3) with a fineness of 1 dtex have a diameter of approximately 10 μm.

Key words : Microfiber cloth, Ultrafine fiber, Medical engineering instrument, One-way wiping

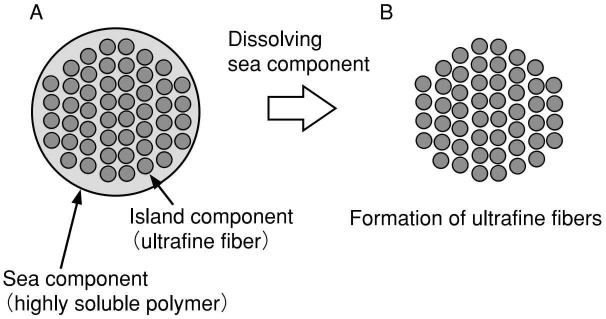

Fig. 1 Principle of manufacturing ultrafine fibers (B) from sea-island type composite fibers (A)

While no formal definition exists for an ultrafine fiber, any fiber finer than silk (fineness of approximately 1.4 dtex), which is considered to be the finest of all naturally-occurring practical fibers, is deemed to be an ultrafine fiber[5]. Furthermore, ultrafine fibers at and below 0.5 dtex are categorized as microfibers because the ultrafine fiber characteristics, such as touch and flexibility, are prominent in this range.

MANUFACTURING METHODS FOR ULTRAFINE FIBERS

Methods of manufacturing ultrafine fibers are broadly classified into filament and random (e.g., the melt blown method) methods[5]. As examples of the filament method, direct spinning and composite fiber manufacturing processes are summarized below.

In the direct spinning process, hot molten polymer is extruded through a spinneret (nozzle) with numerous drilled holes up to a few mm in diameter to form multifilaments, which are cooled, solidified, and reeled. Fibers produced by this technique are widely utilized for apparel and industrial applications. However, in the case of polyester, the diameters of fibers that can be manufactured stably for routine use in facilitates are as low as approximately 10 μm. Stable production of ultrafine fiber requires strict control of polymer viscosity (fluidity), accuracy, and positioning of holes on the spinneret, and specific cooling and solidification conditions, in addition to special techniques and facilities for processing of ultrafine threads into the desired product. Therefore, it is extremely difficult to spin fibers with a diameter of 10 μm or less.

In the composite fiber manufacturing process, on the other hand, a composite fiber, composed of two polymers with different degrees of solubility in solvents, is usually produced, drawn in the same manner as the conventional fiber to improve fiber characteristics, and made into ultrafine fiber. There are two main processes of turning composite fiber into ultrafine fiber, i. e., either the peeling/separation or the sea-island type based on the morphology of the composite fiber cross section. The peeling/separation type uses chemical or physical processing to separate two components ; the sea-island type produces ultrafine fibers from composite fibers by dissolving the "sea component" (highly soluble polymer), thereby leaving the "island component" (barely soluble polymer) as ultrafine fibers (**Fig. 1**).

MANUFACTURING AND PRODUCT DESIGN OF MICROFIBER CLOTH

This article focuses on Microfiber Cloth CE, which is manufactured by the sea-island type process using two types of polyester (100%) polymers with different degrees of solubility. The manufacturing process starts with composite spinning (spinning-drawing) to produce sea-island type fiber, followed by advanced processing (e.g., thread processing, plain knitting), refining (removal of sizing agent), and reduction processing (dissolution of sea component) to ultimately produce fabric cloth composed only of microfibers approximately 2 to 5 μm in diameter. Subsequent processing procedures include staining, high-pressure fluid spraying to form a structure of randomly entangled fibers, water jet punching to generate air spaces between microfibers, and finishing to achieve a pre-specified width by heating the cloth while holding both ends to maintain its tension. The above-described process provides Microfiber Cloth CE with the fiber diameter, density, air space volume between fibers, and surface area, in the intended balance.

With this manufacturing method, the island component (polyester) is protected by surrounding the sea component in the earlier part up to advanced processing with a fiber diameter similar to that of conventional fibers (in the 10 to 30 μm range). This allows generation of uniform microfibers having favorable characteristics without unnecessary damage even during advanced processing, where the fiber is exposed to relatively strong force. The usability of routine advanced processing facilities is also an industrial advantage.

In addition, Microfiber Cloth CE is processed to provide bacteriostatic properties to suppress bacterial growth on the fibers[6]. This technique is not a posterior process designed to coat the fiber surface with a bacteriostatic agent but rather a process involving the incorporation of a pyrithione antibacterial agent into the fiber, ensuring a long-lasting bacteriostatic action.

Microfiber Cloth CE is pre-washed with pure water and provided as single sheet packages, each sealed in a clear polypropylene bag, in consideration of various usages at medical institutions. The product itself is unsterilized, but the sheet may be sterilized at the medical institution where it is to be used, as necessary, by removing it from the product packaging and placing it in a sterilization bag.

PRINCIPLE OF WIPING A SURFACE OR INSTRUMENT CLEAN WITH A MICROFIBER CLOTH

Cleaning cloth performance is dependent on friction between the object to be cleaned and the cloth, contact area, as well as soil absorption and retention within the cloth. While wipe cleaning appears to be a simple procedure, a cleaning cloth that has been impregnated with water efficiently facilitates dissolution and absorption of the soil into the cloth. That is, a cloth suitable for wipe cleaning will have appropriate water absorptivity, adsorption affinity for the soil, and a configuration that achieves a large specific surface area and porosity.

Fig. 2 shows scanning electron microscope (SEM) images of the surface (A) and the cross section (B) of Microfiber Cloth CE. As seen in the cross sectional image, the island type microfiber has numerous gaps called "micro-pockets" (encircled in the image). Liquid and solid soils picked up and trapped in these gaps are likely to be quickly absorbed inside the cloth via the capillary phenomenon.

Fig. 3 is a schematic diagram illustrating the concept of cleaning by wiping with a cloth with a common fiber diameter vs. Microfiber Cloth CE[6]. A common fiber cloth has a larger fiber diameter, which provides a smaller working area for wiping the object to be cleaned and an

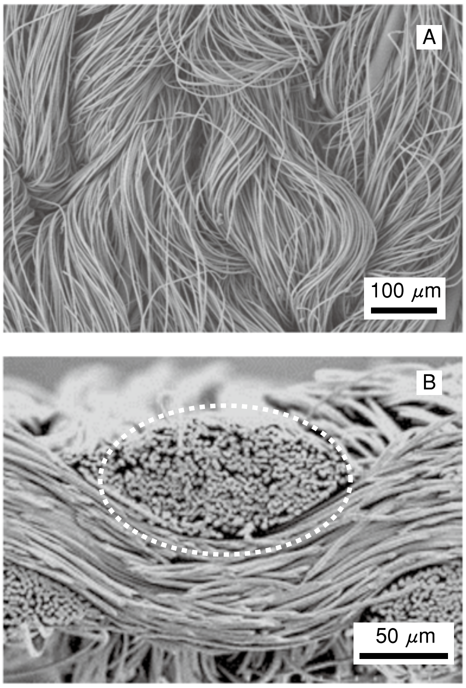

Fig. 2 SEM images of the surface (A) and the cross section (B) of Microfiber Cloth CE

The circle in panel B indicates "micro-pockets".

insufficient total absorption area relative to a soil particle. Also, nonwoven fabric has a very high water retention capacity, which tends to cause readsorption of the soil back onto the surface to be cleaned if excess water is present. In contrast, Microfiber Cloth CE has a smaller fiber diameter and a greater weight per unit area of 200 to 210 g/m^2, corresponding to a fiber density several times greater than that of common nonwoven fabric used for wiping objects/surfaces clean, thus providing a significantly greater contact surface area. Therefore, the microfibers can efficiently attract the soil on the object to be cleaned, effectively picking up the soil into micro-pockets between fibers. The soil within the cloth is thought to be further adsorbed onto microfibers and stably retained inside the cloth. At this stage, the presence of water, with which the cloth has been impregnated, will significantly improve soil absorption by the cloth (refer to the following section). The cloth has a thickness of 530 to 550 μm, which also prevents soil from leaching outward from the surface in contact with the fingers during cleaning.

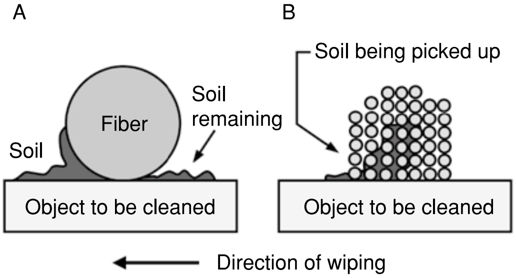

Fig. 3 Schematic diagram illustrating the concept of cleaning by wiping with a cloth with a common fiber diameter vs. Microfiber Cloth CE[6)]

EFFECTIVENESS OF WIPE CLEANING WITH MICROFIBER CLOTH

1 Effectiveness of wipe cleaning using a water-moistened cloth

Liquid soil is easily wiped off, to achieve cleaning, via absorption with a dry nonwoven fabric (dry wiping). In this case, cleanliness is often limited to the so-called "visually clean" level. Furthermore, for organic and/or dry soil adsorbed on the object to be cleaned via intermolecular interactions, dry wiping achieves minimal cleanliness at the microbial level. In such a case, cleaning effectiveness will be greatly improved by first removing liquid dirt via absorption with an environmental cloth (dry wiping) and then finishing by wiping with a cloth impregnated with water as a cleaning medium (wet wiping). Water is a medium for wet cleaning and contributes to basic cleaning performance because it dissolves and disperses many hydrophilic substances. However, impregnating the cloth with excess water may result in water spots on the cleaned object after wipe cleaning. Water droplets remaining on the cleaned surface must always be wiped off as such droplets contain dissolved soil.

Tojo K, et al.[7] compared the cleaning effectiveness of dry wiping vs. wet wiping with Microfiber Cloth CE on stainless steel surfaces contaminated with a specified amount of yeast extract and reported an approximately 10 times higher cleaning effect with wet wiping as compared to dry wiping. They also demonstrated an adequate amount of impregnated water to be up to 0.1 mL/24 cm^2, or even more, and that the same side of the cloth was good for up to 10 repeated uses. In addition, the cloth provided similar wiping effects regardless of the weave direction (lengthwise versus crosswise), which is a feature of Microfiber Cloth CE.

For reference, Toray Industries Inc.'s microfiber cloth for wiping glasses, which is not knitted but rather a woven fabric with a much lower weight per unit area of 68 g/m^2, is not intended for cleaning ME instruments by wiping.

Tojo K, et al.[8] further studied Microfiber Cloth CE for wiping effectiveness with feline calicivirus (dried) attached to stainless steel surfaces and reported a remarkably higher removal rate of 99.9% with wet wiping (2 mL/144 cm^2), versus only 84.2% with dry wiping.

Matsumoto I, et al.[9] examined Microfiber Cloth CE for the removal profile of dried microbes (*Pseudomonas fluorescens*) attached to the surface of polyethylene terephthalate (PET), which is a material constituting ME instrument touch panels. They found that dry wiping barely removed bacterial cells on the PET surface while the microfiber cloth which had been moistened with water (0.8 mL/9 cm^2) removed at least 99.8% of the cells (2.0×10^5 cells/mm^2) in one wiping motion in a single direction (one-way wiping). The wiping was performed in approximately 1 second. Furthermore, the standard deviation of the removal rate after 5 repeated wiping motions was 0.12%. These results support the observation that a water-moistened cloth can provide excellent wiping performance with a high removal rate and excellent reproducibility.

Fig. 4 shows SEM images of microfiber cloth cross sections after wiping aimed at picking up *P. fluorescens* cells employing one-way wiping as described above. The images represent the cross section from the wiping side (top) to the other side (bottom); **Fig. 4A** through **4D** are magnified views of areas marked with corresponding letters in the cross sectional image. Many adherent bacterial cells are seen on the fibers closest to the wiping side (0 to 50 μm, **Fig. 4A**). Adherent bacterial cells are also seen in the areas close to 200 μm (**Fig. 4B**) and 400 μm (**Fig. 4C**). These observations indicate that bacterial cells have been absorbed and become adherent to sites near 400 μm in depth with approximately 1 second of wiping. However, very few bacterial cells are seen in the deepest area near 550 μm in depth from the wiping side (**Fig. 4D**). This means that bacterial cells did not leach outward onto the fingers of the operator. However, absorbed virus particles reportedly reached the finger side when a similar wiping procedure was repeated 10 times[8].

Microfiber cloth is effective for wiping not only hydrophilic but also oily soil. Amauchi M, et al.[10] examined the wipe cleaning performances of Microfiber Cloth CE, cotton gauze, and non-woven fabric moistened with water (1.0 mL/24 cm^2) on a PET sheet surface contaminated with mineral oil containing adenosine triphosphate (ATP, 34,602 relative light unit [RLU]). The results demonstrated that the amount of ATP remaining after wipe cleaning with a microfiber cloth (77 RLU) was significantly lower than that

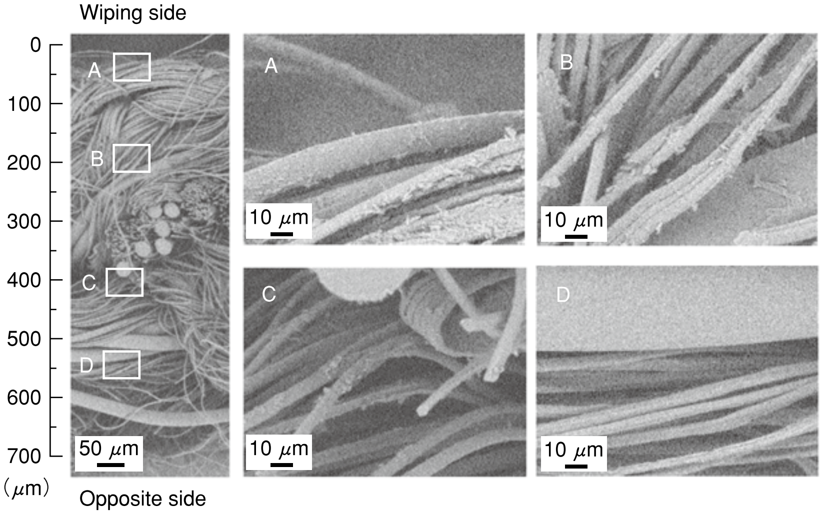

Fig. 4 SEM images of *P. fluorescens* cells trapped in various parts of Microfiber Cloth CE after one-way wiping[9)]
From Ref. 9：Matsumoto Y, et al., reproduced with permission.

with cotton gauze (4,834 RLU) or nonwoven cloth (653 RLU). This finding supports the effectiveness of microfiber cloth for removing sebaceous dirt transferred from the fingers to ME instruments by wipe cleaning. They also investigated the amount of ATP leaching outward onto the finger-contact side and found that Microfiber Cloth CE (27 RLU) was particularly good for preventing this leaching as compared with cotton gauze (1,920 RLU) and nonwoven fabric (396 RLU).

2 Wipe cleaning performance and soil readsorption in one-way vs. back-and-forth wiping

In environmental wipe cleaning, it is a common practice to use the wipe cleaning cloth in a back-and-forth manner and to use the wiping side several times, rather than disposing of the wipe cleaning cloth after using one side in one direction. These practices raise the issue of soil readsorption from the wipe cleaning cloth.

Tojo K, et al.[11)] compared the wipe cleaning performance of one-way vs. back-and-forth wiping with wet Microfiber Cloth CE using bovine viral diarrhea virus (BVDV) attached to stainless steel surfaces. The results indicated the log reduction value for the BVDV infection titer to be 2.9 (reduction rate of 99.88%) with one-way wiping and 3.8 (reduction rate of 99.98%) with back-and-forth wiping; the mean removal rate was higher for the latter, but the difference in effectiveness between the two did not reach statistical significance ($p=0.27$).

In similar experimental systems, a clean stainless steel surface was wiped with Microfiber Cloth CE that had been used to wipe surfaces contaminated with feline calicivirus or BVDV, and any viral particles readsorbed on the surface after wiping were present at levels below the detection limit[8,11)]. These findings support the supposition that Microfiber Cloth CE does not allow readsorption of virus particles once an object/surface has been cleaned.

In addition, a clean PET sheet surface was wiped with Microfiber Cloth CE, cotton gauze, or nonwoven fabric that had been used to wipe off mineral oil containing ATP as described above[10], and the amount of mineral oil readsorbed was lower for Microfiber Cloth CE (77 RLU) than for either cotton gauze (1,646 RLU) or nonwoven fabric (412 RLU).

It should be noted that the aforementioned experiments on readsorption do not provide information on the time elapsed from the initial wiping until the readsorption experiment.

3 Precautions for wiping procedure

Use of the best wipe cleaning cloth may not achieve good cleaning results, if the wiping procedure is not adequate.

Matsumoto Y, et al.[12] investigated the effects of wiping speed and water absorption into the cloth on the removal of bacterial cells by one-way or back-and-forth wiping with Microfiber Cloth CE using *P. fluorescens* cells (2.7×10^5 cells/mm^2) attached to the PET surface (**Fig. 5A**). With one-way wiping, the residual ratio of bacterial cells on the PET surface was less than 0.4% regardless of the wiping procedure within the ranges of wiping speeds (1.7 to 100 mm/s) and moisture levels (0.1 to 1.0 mL/9 cm^2) examined (**Fig. 5B**).

With back-and-forth wiping, on the other hand, bacterial cells remained along the wiping direction (shown by arrows) and the residual ratio of bacterial cells on the PET surface was 12.5% (**Fig. 5C**). The residual ratio of bacterial cells after back-and-forth wiping tended to be higher as the speed of wiping and the water absorption level increased. In this experimental system, it was confirmed that little bacterial readsorption on the PET surface from the cloth occurred after repetitions of one-way wiping (outward only) up to 10 times[9]. These observations indicate that the change of wiping direction from outward to inward triggers bacterial cell transfer from the cloth to the PET surface. In addition, caution should be exercised to avoid excessive water absorption into the wiping cloth as it may facilitate transfer from the cloth back to the PET surface and lower the cleaning efficiency of back-and-forth wiping.

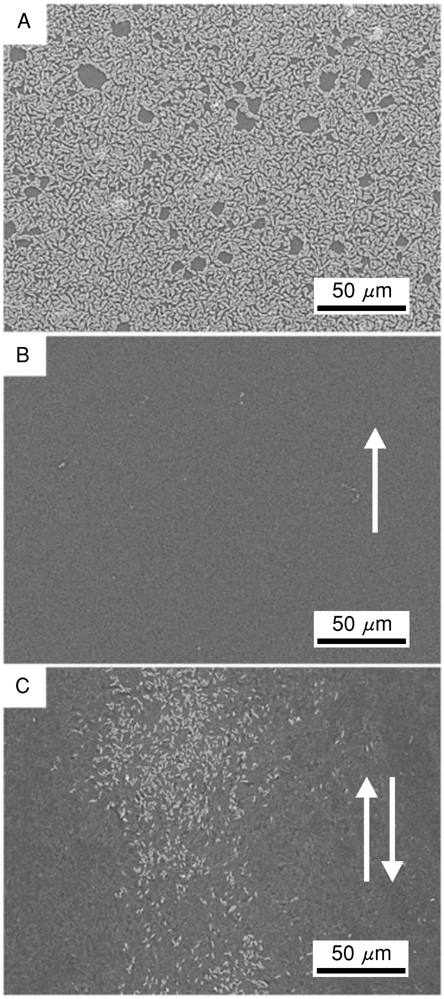

Fig. 5 SEM images of *P. fluorescens* cells remaining on PET surface after one-way or back-and-forth wiping with Microfiber Cloth CE[12]

(A) Before wiping, (B) after one-way wiping, (C) after back-and-forth wiping.
The arrows indicate the direction of wiping.
From Ref. 12 : Matsumoto Y, et al., reproduced with permission.

This study further compared the effectiveness of back-and-forth wiping as a function of the time to switch (waiting time) from one-way (outward) wiping to back-and-forth (inward) wiping. As the waiting time increased from 0 to 60, 300, and 600 sec, the residual ratio of bacterial cells on the PET surface decreased sequentially from 53.8 to 19.9, 15.9, and 4.1%, respectively. Matsumoto Y, et al. pointed out that the "elapsed time" after wiping of bacterial cells until irreversible adsorption on the fiber surface of the cloth is a critical factor that governs bacterial readsorption behavior with inward wiping.

USE OF WIPE CLEANING MATERIAL IMPREGNATED WITH A CHEMICAL AGENT

Although chemical-free wipe cleaning is much desired, as mentioned in the first section of this article, wipe cleaning with a chemical agent is preferred for some objects in medical practice.

If the object to be cleaned is suspected of harboring bacteria or viruses, healthcare workers would want to use a wiping cloth impregnated with a disinfectant, from the viewpoint of infection prevention. Nonwoven fabric wipes impregnated with chlorine-based oxidant possessing cleaning and bactericidal effects, such as sodium hypochlorite ($NaClO$) and sodium chlorite ($NaClO_2$), show improved wiping performance for proteinaceous soil on hard surfaces, as compared to wipes impregnated with water[13,14]. Because the cleaning performances of $NaClO$ and $NaClO_2$ are nearly the same, in terms of the removal of both proteins and bacterial cells[15〜17], wipes impregnated with these chlorine-based oxidants also seem to be effective for the removal of bacterial cells. The presence of chlorine at a certain efficacy level in the nonwoven fabric wipe impregnated solution also rapidly reduces the number of viable bacterial cells on the wipe[14]. In this regard, PET, the material of which Microfiber Cloth CE is made, is less reactive with $NaClO$ and $NaClO_2$ than with other fiber materials[14,18]. Therefore, PET material has the advantage of being less prone to the loss of an effective chlorine concentration after impregnation with a chlorine-based oxidant.

Additionally, wipes impregnated with complex chlorine-based disinfectant/detergent that releases hypochlorous acid have recently come into widespread use. These products have also been reported to inactivate various bacteria and feline calicivirus attached to hard surfaces[19,20]. The effectiveness of a chlorine-based oxidant in combination with Microfiber Cloth CE is anticipated to be a focus of future research.

On the other hand, impregnating nonwoven fabric wipes with ethanol for disinfection purposes significantly reduces the removal efficiency of protein by wipe cleaning[13,14]. This is due to the reduced solubility of proteins in ethanol solution. When wipe cleaning material impregnated with ethanol is used for environmental disinfection, it first requires the use of water-moistened wipes to remove (clean off) organic soil as thoroughly as possible, prior to wipe cleaning to achieve disinfection.

EFFECTIVENESS AND ASSESSMENT OF WIPE CLEANING IN MEDICAL PRACTICE

Hatakeyama T, et al.[21] compared the wipe cleaning effectiveness of wet Microfiber Cloth CE and 5 different environmental cloths impregnated with quaternary ammonium salt, by applying a wiping test, on infusion pumps and syringe pumps used in clinical settings with ATP (+ adenosine monophosphate : AMP) serving as the indicator. The results demonstrated that only Microfiber Cloth CE achieved a level of cleanliness not exceeding 500 RLU, which is the target control level for noncritical medical instruments, in wiping tests conducted after a wipe cleaning operation. The cleaning effect was significantly higher than those of other environmental cloths. Furthermore, it was also confirmed that after a 10-day reuse test（by washing with water after each use）the cleanliness level was sustained at a level below 500 RLU.

Hatakeyama T, et al.[22] further investigated the residual ATP level changes on syringe pumps, which were returned to the ME center after being used for assessment, during their repeated routine usage following the introduction of Microfiber Cloth CE at their medical institution. The results demonstrated a gradual ATP decrease over time；the ATP level after one and a half years was less than 1,000 RLU, which is the target control level for healthcare workers after hand washing, indicating that the use of Microfiber Cloth CE also contributed to infection control[14]. Also, the ATP level after wipe cleaning with wet Microfiber Cloth CE was around 100 RLU, achieving a level comparable to the target control level for steel tools and other materials used in the operating room. The practical results reported above indicate that, on a daily basis, the introduction of Microfiber Cloth CE effectively maintained the cleanliness of medical instruments at a higher level than could previously be achieved.

As Microfiber Cloth CE is currently being used routinely in clinical practice, cost effectiveness is now an issue. In general, environmental cloths cost 10 yen or less per sheet, while Microfiber Cloth CE costs more than 200 yen per sheet, making the price 20 to 30 times higher than that of the former. However, Microfiber Cloth CE is used in various applications, from an alternative to nonwoven cloth to its usage for maintenance of medical instrument details, based on being cut into small pieces, making it difficult to unconditionally assess the cost. Hatakeyama T, et al.[22] stated that the use of environmental cloths alone for achieving and maintaining the cleanliness already achieved by the introduction of Microfiber Cloth CE will require more environmental cloths, which raises concerns about increased costs.

Yamafuji T, et al.[23] evaluated the reusability of Microfiber Cloth CE, specifically, the wiping performance of washed/recycled Microfiber Cloth CE on artificial contaminants and their cleanability. The results demonstrated that wiping performance and cleanability after 60 repeated washes/reuses were both similar to those of unused products. Although disposable use（single use）is regarded as being desirable for Microfiber Cloth CE from the viewpoint of infection control, the authors consider this product to also be useful as a cloth for environmental maintenance/cleaning, depending on the object to be cleaned and its usage, based on the results indicating the potential for washing and reuse.

Microfiber Cloth CE has also been used for wipe cleaning of lenses on medical optical instruments due to the product's intrinsic features. In recent years, it has begun to be applied to wiping lenses on cameras used for endoscopic surgery. However, for use in the operating room, microfiber cloths must fulfill requirements, such as prior sterilization and radiographic compatibility to assure medical safety. New microfiber cloth products that meet these requirements are now commercially available from Toray Industries, Inc.

CONCLUSION

With the advent of Microfiber Cloth CE, wipe cleaning procedures have advanced from wiping with conventional nonwoven fabric to wipe cleaning that can achieve cleanliness at the microbial level. Particularly, the use of a moistened cloth impregnated with water has been proven to provide very high wiping effectiveness. However, the actual situation is not that simple and the use of Microfiber Cloth CE by itself does not immediately provide the desired level of cleanliness. Effective wipe cleaning procedures must be established by selecting an appropriate wipe, cloth, and impregnating solution depending on the object to be cleaned and the type of soil requiring removal. Other issues include prevention of slight "readsorption" seen with back-and-forth wiping. Repeated one-way wiping is recommended based on current knowledge. It should be noted that the data presented in this article do not necessarily apply to all products that are referred to as being comprised of microfibers. There is no doubt that product design with full consideration of wipe cleaning performance is essential. In the future, various interfacial phenomena should be elucidated for their impacts on wipe cleaning with Microfiber Cloth CE and, furthermore, wipe cleaning procedures/conditions need to be established for the optimal prevention of readsorption.

CONFLICTS OF INTEREST

The author declares no conflicts of interest assosiated with this manuscript.

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＜Received on September 17, 2019＞