Comparison of the Physical Properties and Effectiveness of Medical Swabs for Sampling Biomaterials

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*The COVID-19 pandemic has induced a sharp rise in demand for consumables for laboratory diagnosis and, in particular, for swabs for sampling biomaterials. Test quality depends strongly on swab quality. The aim of this work was to run experimental studies to evaluate the physical and operational properties of fiber-type medical swabs. This study compared swabs from leading manufacturers traditionally regarded as the quality standard on the Russian market in the premium sector: Copan Diagnostics (Italy), Puritan Medical Products (PMP) (USA), and PharmMedPolis (PhMP) (Russia). The following properties were studied: absorption, zeta potential, and surface morphology (by scanning electron microscopy). The techniques for biomaterial collection and release were also considered. Experiments using *Streptomyces pneumoniae* cultures as an example showed that the Copan Diagnostics swab had a recovery rate (RR) of 78.3%, compared with 84.15% for the Puritan Medical Products swab, 87.49% for the PhMP swab, and 93.72% for the HydraFlock[®] swab. The HydraFlock[®] swab was found to be especially effective due to its high ability to absorb water and protein and its high bacterial recovery rate. The second best results were for the PharmMedPolis[®] swab, followed by the Copan swab and the nylon swab from Puritan Medical Products.*

Introduction

The effectiveness of detecting viruses, cells, and proteins depends strongly on the effectiveness of collection of biomaterial, its protection during transportation, and its recovery from nutrient medium. Despite the fact that aspirates, body fluids, and tissue samples are the most effective for primary isolation, samples are often collected using swabs during patient care and testing [1]. This has become particularly relevant during the global COVID-19 pandemic caused by SARS-CoV-2. The pandemic has produced a sharp rise in demand for consumables used for laboratory diagnosis, among which are swabs for collecting biomaterials. The quality of these swabs largely determines the test reliability. As the diagnostic sensitivity of a clinical test depends on the number

of cells collected and released by the swab, there is a constant need for correct sampling to provide reliable and accurate diagnosis.

Swabs from different manufacturers covering a wide price range are now available on the market. Such a wide diversity demands comparative evaluation. Currently available swabs are made of different materials and have different physical properties affecting the efficiency of biomaterial collection and preservation. Two main types of swab materials can be identified: foamed polymer materials with an open porous structure and fiber materials with pronounced capillary effect and good absorption, retention, and release of moisture, microbes, antigens, and nucleic acids. In turn, fiber-type swabs can be subdivided into first-generation swabs with the working part made of spun fibers (viscose, Dacron, cotton) and swabs of the second generation, where flocking techniques are used to apply polymer fibers to the working part, which is at an angle of 90° to the surface of the swab shaft. It is believed that only a small proportion of the organisms collected on traditional spun fiber swabs can be recovered. Rose et al. [2] showed that spun-type swabs extract

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$\geq 30\%$ more *Bacillus anthracis* Sterne spores than viscose and polyester swabs due to trapping of organisms between the fibers. Swab materials of the first type were found to be less effective than those of the second type. They have the lowest levels of biomaterial capture in collecting clinical samples [3]. Apart from the physical structure, recovery is also affected by the chemical composition of the swab material. Dalmaso et al. [4] also reported significant differences between nylon swabs and swabs made of artificial fibers in terms of their ability to recover various bacteria and fungi.

The ideal swab should collect many cells and ensure their release into medium in compliance with the requirements of the manufacturers' instructions for use. As the fibers used in swab heads are in direct contact with the organisms to be extracted from the sampling site, the swab structure also plays an important role. Effective construction of a swab increases the number of diagnostic samples recovered. This is of prime importance given the number of different pathogenic agents producing disease states; effective collection of clinical samples is clearly required for accurate diagnosis. Special methods of application of biopolymer coatings such as alginate or protein to the working area of the swab have been used to improve the collection and stabilization of sensitive organisms [5-8].

The goal of this work was to carry out experimental studies to evaluate the physical and operational properties of fiber-type medical swabs.

Methods

Nylon swabs from three leading manufacturers traditionally regarded as quality standards available on the Russian market in the premium product sector were studied: Copan Diagnostics (Italy), Puritan Medical Products (PMP) (USA), and PharmMedPolis (PhMP) (Russia). HydraFlock[®] swabs from PMP were also tested.

Assessment of absorption. Absorption was tested by measuring liquid uptake by weighing. Swabs were first weighed and then placed in liquid medium (distilled water and 22% bovine serum albumin solution) for 15 s. Apart from moisture retention, absorption by the material itself (fibers at the working end of the swab) was measured. Fibers were cut from the swab surface, weighed, and placed in an Eppendorf tube. Distilled water (0.5 mL) was added to the tube, which was shaken and left for 2 min. The tube was then placed in a centrifuge and spun at 10,000 rpm for 5 min, after which residues were removed by blotting. This procedure was run three times. The fibers were then weighed and the percentage uptake of protein was determined.

Scanning electron microscopy studies of microstructure. Sample collection was evaluated by scanning electron microscopy using a Carl Zeiss EVO 50 instrument to examine the surface morphology of fibers after collecting samples from a suspension of microspheres. The microscope allowed imaging with magnifications of 100 $\times$ to 3000 $\times$ under low and high vacuum. After sample collection, the extent of release of biomaterial was assessed before and after washing in distilled water for 5 s followed by drying. As polymer samples have a tendency to accumulate electrostatic charge, which interferes strongly with high-quality imaging, samples were coated with a gold/palladium conducting layer.

Measurement of the zeta potential. The zeta potential of swab fibers was measured using a Photocor Compact-Z instrument (Photocor, Russia). Fibers were cut from the swab tip, ground, and suspended in KCl with pH changing from 3 to 9. About 200 mg of swab fibers were placed in a cylindrical glass cell for 3 min, after which the measurement was carried out.

Cell culture studies. Cell culture studies used *Streptococcus pneumoniae*. Cultures were investigated in 30 samples. Statistically significant differences between mean values were identified using the Tukey-Kramer Honestly Significant Difference test [9]. Cultures were incubated for 24 h at $37 \pm 1^\circ\text{C}$. Several well-isolated colonies were then selected and transferred to a tube in which 5 mL of 0.85% sterile saline (pH 6.8) was placed. The turbidity of the bacterial suspension was adjusted to 0.5 McFarland standard units ($1.5 \cdot 10^8$ cfu/mL). To ensure absorption and adhesion of bacteria to the swab head, the test swab was placed in a glass tube containing 5 mL of bacterial suspension ($\sim 10^7$ cfu/mL) for 10 s. Swabs were removed from the bacterial suspension and held in air for 60 s, transferred to dilution medium and shaken for 15 s to release bacteria. Viable organisms were then diluted in dilution medium (A). Viable organisms were quantitated by plating samples on nutrient medium (B) in duplicate.

Bacteria were cultured in 5% CO₂. Dilution medium was 0.85% physiological saline; nutrient medium, blood agar.

The results were used to compute the RR:

$$\text{RR} = \frac{\text{Coefficient of dilution} \times A}{\text{Coefficient of dilution} \times B} \times 100\%.$$

Results

The ability of the swabs tested in this work to absorb water ranged from 18.8% to 21.3%. Within the test

group, the HydraFlock[®] swab provided the best water absorption, followed closely by the PhMP swab (Table 1).

The ability to absorb protein was worse than the ability to absorb water and ranged from 17.4% to 19.3%. In this case, the HydraFlock[®] swab was found to be the most effective, while the Copan swab was the least effective. As shown by these experiments, the type of fiber and its

properties were the main factors determining the absorption of liquids.

Figure 1 shows SEM images of the fiber-type swabs studied in this work.

Capture and release of polymer spheres was studied and evaluated qualitatively using a model system to simulate bacteria. The HydraFlock[®] swab had good sphere-collecting ability. However, as a result, it also released a

Fig. 1. SEM images of swab tips: a, c, e) Copan; b, d, f) PhMP.

TABLE 1. Comparison of the Capacities of Samples for Absorbing Water and Protein

Sample name	Water absorption, %		Protein absorption, %
	Sample	Fiber	Sample
HydraFlock®	21.3	613	19.3
Nylon PMP	19.6	537	17.9
Nylon Copan	20.1	585	17.4
PharmMedPolis®	20.8	592	18.7

smaller number of than the other samples. Imaging at magnification 1000× showed that HydraFlock® swab fibers became frayed into 20-30 separate fine filaments 10-30 µm long. The other three samples shared similar morphology and consisted of nylon fibers.

Figure 2 shows the relationship between the zeta potentials of the swab fiber samples and the acidity of the medium. The zeta potentials of the HydraFlock®, Nylon PMP, and PharmMedPolis® samples were all negative, gradually decreasing with increasing pH, while in the case of the Nylon Copan sample increases in pH produced a transition from positive (pH 3-6) to negative (pH 6-9) zeta potential.

Correct collection, storage, and transportation of biomaterials must not be underestimated as important components of the healthcare system. Thus, assessing the operating properties of swabs is necessary to understand what problems may arise when swabs are used to obtain clinical samples for laboratory analysis. Despite the fact that the use of direct exudates and fluid aspirates

is the most effective, collection of samples using swabs is widely employed because of the high level of convenience and practicality of this technique. Assessment of the operating properties of swabs includes testing absorption, collecting capacity, moisture retention, and the zeta potential. All these parameters have direct effects on the collection and release of bacteria and the ability to maintain viability during transportation to the laboratory. Absorption of water includes two components: unbound water coating the fibers and bound water which soaks into the material or is in some other way retained on the surface. This parameter is determined by the chemical composition, microstructure, and polarity of the surface.

Another factor is that synthetic fibers have poor hydrophobic properties, so the leading swab manufacturers have developed and introduced special technologies to improve this parameter. The water-absorbing capacity of swabs plays the leading role in extracting bacteria and other microorganisms; it is maximized by means of capillary effects, while water retention is needed to prevent dehydration. Our studies demonstrated a clear relationship between the zeta potential of samples and the pH of the medium and yielded very different values for samples from different manufacturers. This may be related to differences in the chemical composition of the fibers and in the processing of their surfaces. The sign of the zeta potential is indicative of the nature of the electrostatic potential close to the particle surface. If the zeta potential is sufficiently large, the short-acting attractive van der Waals forces are overcome. Swab fibers with higher zeta potential values lead to repulsion; this, in turn, may reduce capture of bacteria.

Analysis of SEM images demonstrated morphological and structural differences between different swabs. The following characteristic feature of the HydraFlock® swab should be noted: the fiber tips are frayed, ensuring thereby effective collection of microorganisms. The other fiber samples (Nylon PMP, Nylon Copan, and PharmMedPolis®) shared similar morphology.

Experimental studies showed that different swab samples had different RRs. For example, for *Streptococcus pneumoniae*, the Copan Diagnostics swab provided RR = 78.3%; the Puritan Medical Products swab, RR = 84.15%; the PhMP swab, 87.49%; the HydraFlock® swab, 93.72%. The key result of this study was to produce a rating of swabs. The HydraFlock® swab had the greatest overall effectiveness due to its high water- and protein-absorbing capacity and a high level of retrieval of bacteria. It was followed in the rating by the PharmMedPolis® swab, the Copan swab, and the nylon swab from Puritan Medical Products.

Fig. 2. Relationship between the zeta potential of the studied swab fiber samples and the acidity of the medium.

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