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Cloth Face Masks Containing Silver: Evaluating the Status

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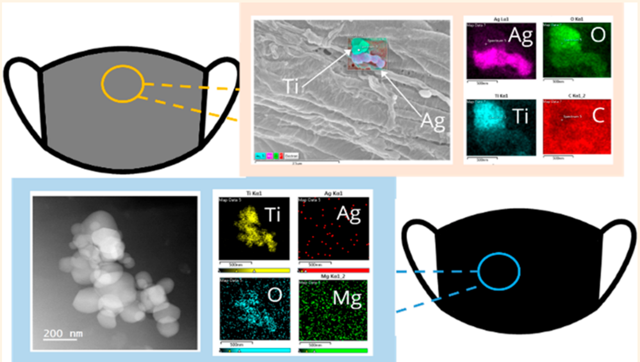
ABSTRACT: Amid the coronavirus disease 2019 pandemic, demand for cloth face masks containing nanosilver has increased. Common product claims such as "antiviral" and "antimicrobial" can be attractive to buyers seeking to protect themselves from this respiratory disease, but it is important to note that filtration capabilities are the main factor to prevent virus transmission and that antimicrobial ability is a secondary protection factor. Silver has long been known to be antibacterial, and growing research supports additional antiviral properties. In this study, 40 masks claiming to contain silver were evaluated for substantiated antiviral and antimicrobial claims using methods available to the public. Criteria for determining the validity of substantiated claims included the use of patented technology, international certification for antimicrobial and/or antiviral textile by ISO or ASTM, EPA pesticide registration, and peer-reviewed literature. Our analysis showed that, of the 40 masks, 21 had substantiated claims. Using scanning electron microscopy (SEM), two of the substantiated face masks (A and B) were examined for silver identification for further confirmation. Mask A uses silver and copper ions attached to zeolite particles; the zeolite particles discovered through SEM were approximately 90−200 nm in diameter. In mask B, particles of silver and titanium at the 250 nm size were found. In conclusion, these certifications or patents are not enough to determine credibility, and stricter regulations by federal agencies on product testing for manufacturers that make claims are necessary to ensure the efficacy of the product advertised, as well as a cloth face mask inhalation standard.



KEYWORDS: *nanoparticles, nanosilver, antimicrobial, coronavirus, COVID-19*

■ INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has created a large demand worldwide for face masks and respirators of all types, including cloth, N95, and surgical. In 2019, the global face mask market was at $1,520.0 million; by 2027, the market is expected to grow to $2,455.4 million.[1] Currently, the Center for Disease Control and Prevention (CDC) in the United States (US) has recommended that nonmedical personnel wear cloth face masks to prevent the spread of COVID-19 as a form of source control as surgical face masks and N95 respirators are considered critical supplies.[2] This has led to both new and existing companies to manufacture reusable cloth face masks, some of which are impregnated or coated with nanoparticles including silver, copper, graphene, and zinc.[3,4] The market of antiviral coatings is currently valued at $0.5 billion US dollars and is expected to grow to $1.3 billion by 2027, with silver coatings predicted to be the most profitable.[5] Many of these nanoparticle-containing masks are marketed toward the prevention of COVID-19 and claim antiviral or antimicrobial properties. However, the claims and performance of many mask products have not been substantiated, potentially leading to confusion and distrust of public health recommendations. Use of nanotechnology in face masks has the potential to impact and prevent the transmission of COVID-19, and it is essential to regulate and evaluate mask products during a time of unprecedented manufacturing.

Silver nanoparticles, also known as nanosilver or termed AgNPs, have primary sizes within the range of 1−100 nm and usually form agglomerates. The antimicrobial properties of silver have been well documented throughout history, including the use by ancient Greek and Roman societies as medicine and to store water.[6] Today, AgNPs are frequently found in healthcare settings, alternative medicine, and household products. In hospitals, nanosilver is used as a Food and Drug Administration (FDA) approved antimicrobial in intubation tubing, hospital curtains, bandages, and medical scrubs. Alternative medicine products containing nanosilver, such as colloidal silver and throat sprays, have countless claims, including the ability to kill over 650 bacteria, fungi, and

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Table 1. Internationally Recognized Certifications for Antimicrobial and Antiviral Treated Textiles[a]

certification	how the test is performed	virus/microbes	ref
	Antiviral Property		
ISO 18184:2019 textiles—determination of antiviral activity of textile products	Infects a specimen with virus, waiting 2–24 h, then performing either a plaque assay or TCID50 to determine how much virus is left.	influenza (H3N2, H1N1), feline calicivirus; other viruses can be used	22
ASTM WK73068 new practice for determining the antiviral efficacy of apparel textiles treated with antimicrobial agents intended for the reduction of infectious viral titer using a defined SARS-CoV-2 surrogate	Currently in development. Treated and untreated materials are "inoculated" with a virus and then incubated; then, these materials are compared after a specific amount of time to evaluate the differences in the number of the infectious viral particles.	SARS-CoV-2 surrogates	23
	Antimicrobial Property		
ISO 20743:2013 textiles—determination of the antibacterial activity of textile products	The colony plate count method and ATP luminescence method are used to count the number of bacteria.	bacteria	24
ISO/DTS 23650 nanotechnologies—evaluation of the antimicrobial performance of textiles containing manufactured nanomaterials	under development	bacteria	25
ISO/DIS 20743 textiles—determination of the antibacterial activity of textile products	Currently in development and will replace the ISO 20743:2013. Inoculation of bacteria and using absorption, transfer, and the printing method. Quantitative enumeration of bacteria: colony plate count method, ATP luminescence method.	bacteria	26
ASTM WK31901 new guide for standard test methods and practices for evaluating antibacterial activity on textiles	Resource that includes current ASTM and other industry standard test methods for determining the antibacterial performance of a textile.	bacteria	27
ASTM E3160-18 standard test method for quantitative evaluation of the antibacterial properties of porous antibacterial treated articles	Determines the bactericidal properties of articles which are porous (textiles, paper) and treated with an active biocidal agent. The articles are inoculated with a suspension of microorganisms and then incubated, and any changes in bacterial populations are compared with untreated articles.	bacteria	28

[a]ISO = International Organization for Standardization, ATSM = American Society for Testing and Materials, ATP = adenosine triphosphate, TCID50 = median tissue culture infectious dose.

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viruses.[7,8] Other products on the market claiming to contain nanosilver include toothbrushes, baby blankets, towels, high-efficiency particulate air (HEPA) filters, socks, and T-shirts. Studies conducted by Balagna et al. and Mackevica et al. have confirmed through scanning electron microscopy (SEM) analysis that consumer goods claiming to contain AgNPs did in fact contain nanosilver but not all contained the amount advertised.[9,10]

The antimicrobial effects of AgNPs have extensively been studied[11−14] and have been demonstrated to be effective against several viruses, including human immunodeficiency virus (HIV),[15] chikungunya virus,[16] severe acute respiratory syndrome coronavirus (SARS-CoV),[17] and herpes simplex virus (HSV-2),[18] among others. One potential antiviral mechanism of AgNPs is their binding interaction with viral envelope proteins, inhibiting the virus from binding to the host's cell membranes.[19] In addition, the size of AgNPs are generally thought to influence their antiviral efficiency, although there is still debate on this topic. Gaikwad et al. suggests that AgNPs between 7 and 20 nm in diameter have the capability to disrupt the virus attachment proteins at the lipid envelope, which prevents the virus from interacting with the cell.[20] This size range is supported by Elechiguerra et al., who propose that ∼10 nm is optimal against viruses such as HIV.[21]

To verify antimicrobial efficiency, regulatory agencies such as the International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) provide a variety of certifications for products to ensure the validity of claims made by the manufacturer. These certifications also provide confirmation of antimicrobial and antiviral textiles as summarized in Table 1 through certified laboratories.

The ISO 18184:2019 is of special interest, as this textile certification indicates that the product has demonstrated antiviral capabilities. However, since the ISO 18184:2019 certification only includes specific viruses that have been tested,[22] a certified textile does not necessarily protect against SARS-CoV2 unless explicitly stated.

Another regulatory body which investigates the validity of product claims is the US Environmental Protection Agency (EPA). The US EPA prohibits product manufacturers from advertising antimicrobial claims without proper registration of the product as a pesticide.[29] Referring to regulations 40 CFR 152.6−152.15, a pesticide is considered a substance that is intended to be used to destroy or prevent pests; it is illegal to use unless registered. Antiviral or antibacterial claims on products are also not allowed in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).[30] However, according to 40 CFR 152.25a, articles treated to protect the integrity of the product are not required to be regulated by FIFRA.[31]

Given regulatory differences, it is important to evaluate the current inventory of cloth face masks on the market claiming to contain silver for false and unsubstantiated claims of user protection. Our study can provide evident needs and clear liability issues regarding lack of proper information disclosed with commercial products due to missing regulatory enforcement onto the fast-growing applications of nanotechnology and nanomaterials into consumer products.

■ METHODOLOGY

To find cloth face masks that contain silver or silver nanoparticles and also claim to be antiviral and/or antimicrobial, several methods were used: search engine (Google), peer-reviewed literature, news sources, direct marketing (Facebook advertisements, YouTube), e-commerce sites (Amazon, Etsy), and nano databases (StatNano, The Nanodatabase, Nano.Nature). Keywords used for Google search included: silver antimicrobial and/or antiviral face mask; nanosilver face mask; antimicrobial face mask; antiviral face mask. The methodology for categorization of cloth face masks into substantiated or unsubstantiated antiviral or antimicrobial claims is illustrated in a flowchart as presented in Figure 1.

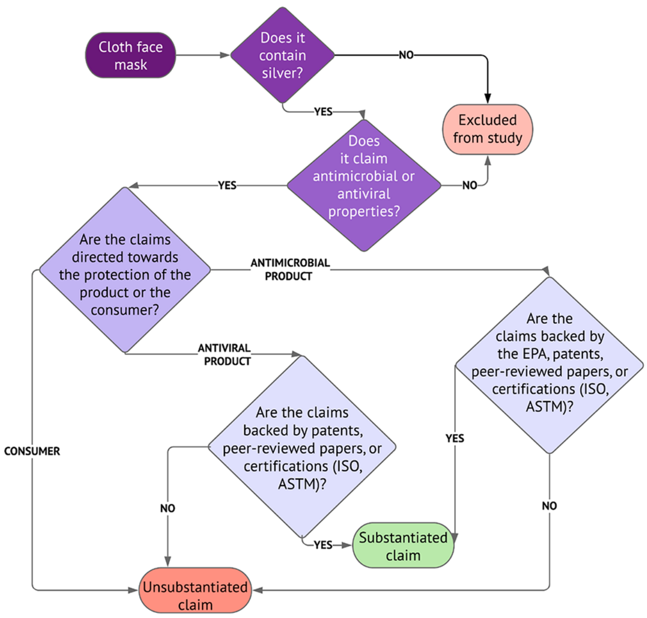

Figure 1. Flowchart of the methodology for categorization of cloth face masks into substantiated or unsubstantiated antiviral or antimicrobial claims.

Face mask products that (1) claimed to contain silver or silver nanoparticles, (2) claimed to be antiviral, to be antimicrobial, or to "kill" COVID-19, and (3) were on the market and available to the public were included in the analysis. The face masks were compiled in an inventory shown in Table 2. These collection methods were created with the perspectives of consumers and how they would access these products.

Substantiated claims as defined by our methodology are face masks that use patented technology, have international certification(s), have peer-reviewed studies, and/or use pesticides registered by the EPA; unsubstantiated claims meet zero of these criteria.

Microscopy Analysis. To confirm the presence of silver, two face masks with substantiated claims defined by this paper were selected for SEM: the Viral Guard Pro and the Everbrand ViralOff. Besides having substantiated claims, these masks were selected through a convenience sample, as they were both readily available from the manufacturers and were popular items in the market. For this study, the Viral Guard Pro mask will be referred to as "mask A" and the Everbrand ViralOff mask as "mask B." Mask A uses AgION technology which has

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Table 2. Cloth Face Mask Inventory

technology	evidence	product	material	claim	market	valid	ref
Silvadur 930 Flex	EPA Reg. No. 464-785,[38] US Patent 10550279[39]	Renfro Nightingale	silver and copper ions, 55% polyester, 28% polyester with copper oxide, 14% nylon, 3% Lycra	antimicrobial	USA	yes	40
Silvadur	EPA Reg. No. 707-313,[41] US Patent 10550279[39]	Jaanuu reusable antimicrobial finished face mask	silver ions, 65% rayon, 30% nylon, 5% Spandex	antimicrobial	USA	yes	42
		Proper Cloth- the everyday mask	silver ions, 100% cotton	antimicrobial	USA	yes	43
		Siftex	silver ions, jersey mesh	antimicrobial	USA	yes	44
		The Pure Mask	silver ions, fleece polyester, polyester	antimicrobial	USA	yes	45
		Corsettery silver infused fabric face masks	silver	antimicrobial	USA	yes	46
	ASTM E3160-18	Chiki Diki antimicrobial face mask	silver ions, 100% polyester, 70% bamboo, 30% cotton	antimicrobial	USA	yes	47
ViralOff (Polygiene)	ISO 18184:2019,[48] Swedish Patent: SE 0400409-9[49]	La Sportiva STRATOS mask	silver ions, 3D mesh fabric, Lycra	antiviral	USA, EU	yes	50
		Squat Wolf	silver ions, polyester, Spandex	antiviral	UAE, USA, UK, AUS, Canada, Middle East, Saudi Arabia	yes	51
		Arface mask	silver ions, nanofiber, nonwoven material	antiviral	UK	yes	52
		Aropec face mask with Swedish Polygiene antivirus and antiodor technology	silver ions	antiviral	UK	yes	53
		Everbrand the ViralOff mask	silver ions	antiviral against SARS-CoV and highly pathogenic avian influenza A (H5N1)	USA	yes	54
		Spira Protekto community mask with ViralOff	silver ions	antiviral	EU	yes	55
AgION	Literature: Bright et al.,[32] EPA Reg. No. 88165-1,[36] US Patent 20100204357[56]	Viral Guard Pro antiviral face mask	silver ions, copper ions, 100% polyester	antiviral, antimicrobial	USA	yes	57
		The Futon Shop Natural Cotton Copper and Silver Infused Face Mask	silver ions, copper ions, 100% cotton	antiviral, antimicrobial	USA	yes	58
HeiQ Viroblock	ISO 18184:2014,[59] ISO 20743:2013,[59] US Patent 8889398[60]	HeiQ Viroblock washable mask	silver, 100% polyester, double layer filter	antiviral	Germany, USA	yes	61
Ionic+ (Silver XT2, X-STATIC)	EPA Reg. No. 70927-1[62]	Mack Weldon silver mask	silver, 84% Supima cotton/10% XT2 polyester/6% Spandex	antimicrobial	USA	yes	63
Sanitized	EPA Reg. No. 3090-220,[64] ISO 18184:2019[65]	Isko Vital+ supreme face cover	silver ions, polymer matrix, cotton	antimicrobial	NA	yes	66
		Foxology viscose and silver face mask British Sanitized T-99 solution	12% silver, 76% viscose, 12% elastane	antimicrobial	UK	yes	67
Silpure	ISO 20743,[68] EPA Reg. No. 88088-3[69]	US Made Safe	50% silver infused and 50% polyester	antimicrobial	USA	yes	70
Silverlon	Literature: Silver et al.,[71] US Patent 7,230,153[72]	Silverlon face mask	99% pure silver plating, 1% silver oxide, nylon material	antimicrobial	USA	yes	73
XSoft	none discovered	Lambs antimicrobial face mask	silver nanofiber	antiviral, antimicrobial	USA	no	74
		Stack Social Silver-Lined Antiviral Mask	silver nanofiber	antiviral, antimicrobial	USA	no	75
Unknown	none discovered	Doc Silver Copper Mask CopperTop Executive 2.0	silver and copper plating	antiviral	USA	no	76
		Boomer nanosilver reusable protective face mask for adults	nanosilver fibers, 65% cotton/35% polyester	anti-COVID-19 (removed claim by FDA request)	USA	no	77
		Changshin Chemical, CO, LTD premium washable Korean mask	nanosilver	antiviral “kills COVID-19”	South Korea, UK	no	78

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Table 2. continued

technology	evidence	product	material	claim	market	valid	ref
		Turmerry antimicrobial silver infused face mask 100% cotton cloth 3 layer mask	nanosilver, 100% cotton	antimicrobial	USA	no	79
		Emmi-dent Emmi oral and nasal mask, temporary mask with nanosilver	nanosilver, cotton	antiviral, antimicrobial	Germany	no	80
		Ella & Cherry London Hygimask washable face mask, tested and certified with antimicrobial nanosilver coating	nanosilver	antimicrobial	UK	no	81
		Aero Tech Designs Cyclewear silver nano reusable face mask - antibacterial with removable filter	nanosilver, 100% graphene, 71.2% cotton, 25.1% viscose, 3.7% nylon	antiviral	USA	no	82
		Bort- Swiss Orthopedic Supply, LLC copper, silver infused cotton face mask	silver, copper, cotton	antimicrobial	USA	no	83
		Paradise City Group Hawaii nano face cover mask with fluid resistant nanosilver - copper filter	nanosilver, copper	antimicrobial	USA	no	84
		Megapump Supplements Ireland antiviral and antibacterial face protective masks	colloidal silver	antiviral	EU	no	85
		Silver Safe Products LLC Silvertize antimicrobial face mask	99.9% pure silver	antimicrobial, protects against COVID-19	USA	no	86
		Just Silver Apparel Deluxe 10% silver face mask	silver fiber	antimicrobial	UK	no	87
		Dermagate silver ion barrier face mask	silver ion, 99.9% pure silver-coated, nylon	antimicrobial	Canada	no	88
		The Big Bloomers Company washable face mask with silver fiber	10% silver fiber, 78% polyamide, 12% elastane	antimicrobial	UK	no	89
		Protective & reusable Silver iON face mask	silver ions, 77% cotton, 8% wool, 15% silver, modal graphene cotton	antimicrobial	UK, EU	no	90
		Jane Group Johnston Prams antimicrobial face mask	silver ions, 35% cotton, 65% polyester	antimicrobial	UK	no	91
		Tru47 pure silver mask - pleated	silver ions	antimicrobial	USA	no	92

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been shown to deactivate several viruses including SARS-CoV, *Haemophilus influenzae*, feline calicivirus, and adenovirus using silver ions attached to zeolites.[32] Zeolites containing silver have antimicrobial capabilities through a silver-ion exchange mechanism.[33,34] AgION is also used as an antimicrobial in Fosshield technology, which is approved by the FDA to be used in the SpectraShield 9500 N95 surgical respirator and is also registered as a pesticide with the EPA.[35,36] Mask B has three layers that use ViralOff, which has an ISO 18184:2019 antiviral textile certification. Both masks have patents.

One layer from each mask was used for SEM and energy-dispersive X-ray spectroscopy (EDS) analysis. The layer of face mask chosen for SEM was where the silver is claimed to be used. SEM analysis (JSM-6500F, JEOL, Peabody, MA, USA) was used to examine the size, shape, surface morphology, and agglomeration or aggregation of the nanosilver.[37] EDS (model 51-XMX1015, Concord, MA, USA) at 10.0 kV was used to confirm the use of silver. For mask B, the layer used was the material closest to the face; for mask A, both the outer and inner layers were viewed. The patches were cut into 3 mm × 3 mm dimensions and then mounted on a pin with conductive tape. The sides of the pin were then wrapped with copper tape to reduce the static charge of the fabrics. A gold coating of 50 nm was used on the samples to improve conductivity; therefore, gold was excluded from analysis.

Because silver was not found through SEM-EDS analysis for mask A, transmission electron microcopy (TEM) analysis (JEM-2100F, JEOL, Peabody, MA, USA) and EDS were performed to further search for particles which were smaller than 100 nm. For preparing samples to be analyzed using TEM, 22.80 mg of the polyester fiber face mask was first burned into ash using thermal gravimetric analysis (TGA) combustion (TGA Q500 V20.13); 79.5% of the mass was burned away. The remaining mass was then crushed between two microscope slides and then dispersed into approximately 3 mL of 99% isopropyl alcohol. This solution was then sonicated and drop-casted onto a gold 400 mesh carbon-coated grid and allowed to dry for 24 h before TEM analysis.

■ RESULTS AND DISCUSSION

Cloth face masks meeting the criteria for inclusion were compiled into Table 2. Of the 40 masks, 21 masks were found to have substantiated claims while 19 masks had unsubstantiated claims.

Several themes were found throughout the inventory of face masks. Many products used the same patented technology (ViralOff, Silvadur, Sanitized, Ionic+, AgION) and combined use of different nanoparticles including copper, graphene, activated charcoal, and zinc, in addition to various applications of silver, territory differences, and marketing similarities. Silver came in several forms and variations including silver ions, nanosilver, colloidal silver solution, silver fiber, and silver coatings. One notable marketing trend was the preference of describing products as "silver ion" based on nanotechnology verbiage.

The two commercially available face masks chosen for SEM analysis to verify the existence of silver can be seen in Figures 2−6.

Silver was not detected in mask A. When analyzing the fabrics, contents, and structures of the face masks, zeolites approximately 90−200 nm in diameter were observed in the fabric structure using SEM analysis as presented in Figure 2. The manufacturer of this mask uses a technology named AgION in solution to coat the masks; it is claimed that silver and copper ions are attached to the zeolites.

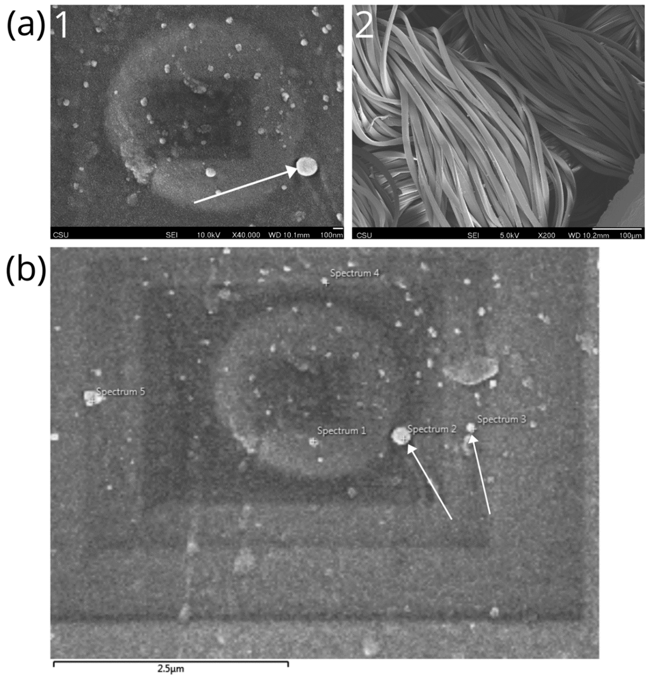

Figure 2. Microscopy analysis of the Viral Guard Pro (mask A) face mask. (a) SEM images: 1 - aluminum oxide zeolite example marked with an arrow with a scale bar of 100 nm at 10 kV; 2 - the structure of the fabric with a scale bar of 100 μm at 5.0 kV. (b) SEM-EDS analysis mapping sites with a scale bar of 2.5 μm. Zeolites are marked with arrows.

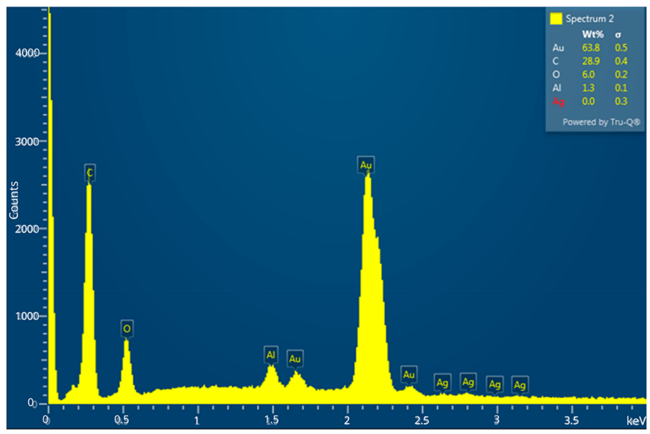

Figure 3. Elemental analysis of the particle in Figure 2b labeled spectrum 2. Oxygen, aluminum, and carbon were found. Gold (Au) was used as a coating, so it is excluded from analysis.

Silver particles were detected in the mask B fabric though SEM analysis. EDS analysis on the mask fabric confirmed the presence of silver particles, as well as titanium. The manufacturer of the ViralOff technology has claimed that the reaction of silver chloride and titanium dioxide creates antiviral properties.[93] The detected particles of silver and titanium were both approximately 250 nm in diameter; agglomerations of silver were found in the fabric, while titanium particles existed in both agglomerations and as individual particles.

Because silver was not detected in mask A through SEM-EDS analysis, TEM analysis was used on a sample of face mask which underwent TGA combustion. TEM of the TGA ash was

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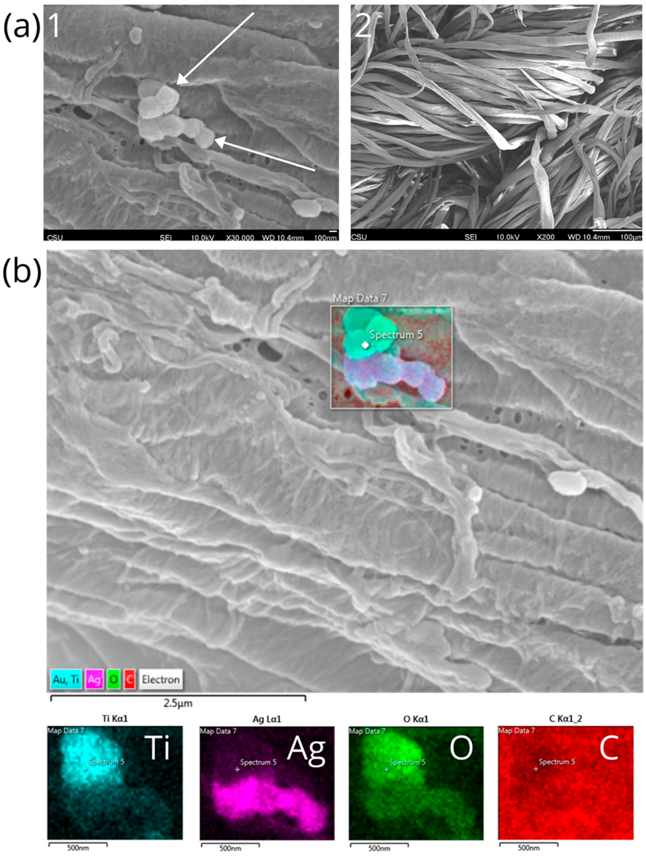

Figure 4. Microscopy analysis of the Everbrand ViralOff (mask B) face mask. (a) SEM images: 1 - a silver and titanium agglomeration marked with arrows with a scale bar of 100 nm; 2 - the structure of the fabric with a scale bar of 100 μm. (b) SEM-EDS analysis. Silver (Ag), oxygen (O), titanium (Ti), and carbon (C) were found with scale bars of 500 nm. Gold (Au) was used as a coating, so it is excluded from analysis.

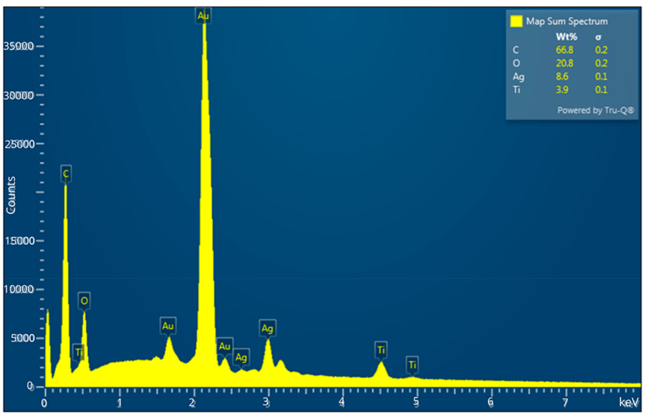

Figure 5. Elemental analysis of the agglomeration in Figure 4b.

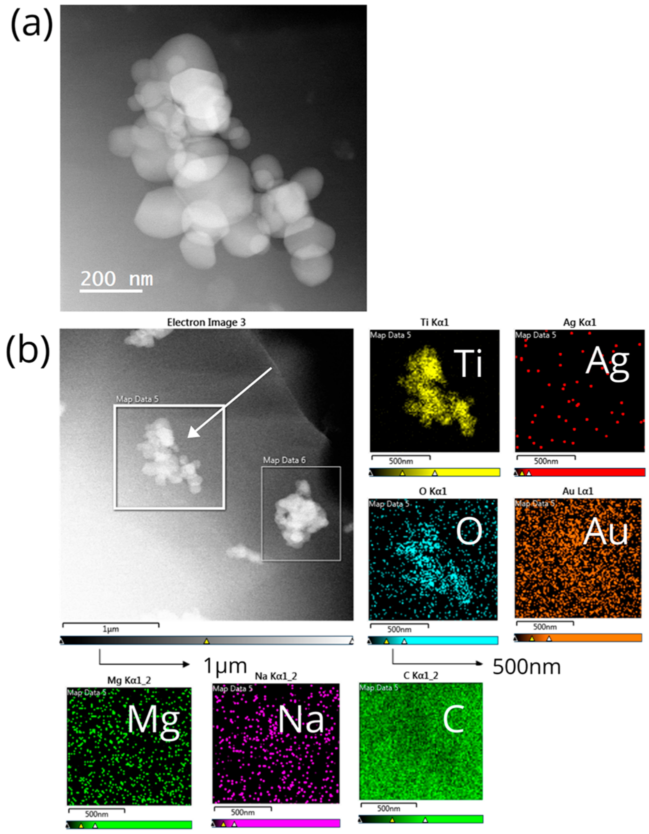

Figure 6. Microscopy analysis of TGA ash of the Viral Guard Pro (mask A) face mask. (a) TEM image of the titanium agglomeration used for analysis. The scale bar is 200 nm. (b) TEM-EDS analysis of the agglomeration marked with an arrow. Oxygen (O), titanium (Ti), carbon (C), silver (Ag), magnesium (Mg), and sodium (Na) were analyzed with scale bars of 500 nm. Gold (Au) was excluded for analysis because of the use of a gold grid. No silver was detected, and carbon was found in the background.

also unable to confirm the presence of silver, but other elements, such as aluminum, silica, magnesium, yttrium, ytterbium, sodium, oxygen, chlorine, and titanium, were found (see the Supporting Information). Titanium dioxide was also detected in the TGA ash in the 50−250 nm diameter size range, as seen in Figure 6.

Comparison of Masks A and B. Although the technology used in both masks has substantiated antiviral claims according to the methodology used in this paper, silver was only detected in mask B. This could be because of the differing use of technology and claims in each mask; mask A claims to use silver ions, while mask B uses silver particles and is ISO 18184:2019 certified. The Beijing Institute of Epidemiology Testing Standard verifies that the ViralOff technology can inactivate the viruses SARS-CoV and H5N1 with an effectiveness of 99% within 2 h. Mask A, in contrast, does not have an ISO or ASTM certification but is registered with the EPA, patented, and has one peer-reviewed paper.[32] Additional research is needed to determine conclusively whether silver ions are used in mask A.

The fact that mask A was not found to contain silver is important. This suggests that either there are no antiviral properties of the mask or that the antimicrobial properties contained are not related to the silver because the silver contained in the mask is at such a low concentration. The authors speculate whether this means the technology of the mask works but the Web site or business is untrustworthy.

Both masks were found to contain titanium dioxide, which has also been demonstrated to act as an antimicrobial agent,[94] but this finding is negligible according to mass-based analysis. This amount of titanium and other elements found in mask A are a small amount of the actual mass used in the mask. Regarding the silver element contained in the masks, as stated in the pesticide registration form for AgION technology, the amount of product in powder form recommended to be used in fibers is at least 0.1% of the commercial product weight (such as fabric for cloth mask) and is not to exceed 5%.[36] The registration form also reports that, among the 0.1−5% additives (AgION technology powder), 22% of the additive is silver and 78% as "other" by weight, so the mass amount of silver element found is very low and can be negligible for reporting. For mask B, the patent states that the mass amount of elemental silver per product or article is between 5 and 80 mg, also demonstrating that the amount of elements in the mask is small when compared to the overall weight of the mask product.[49] Because of the specific mass of elemental silver required in mask B, it has resulted in a higher amount of silver contained in mask B than mask A. This explains our findings where silver nanoparticles are clearly found in mask B, yet the silver element was not detectable in mask A. Although the mass of silver is low, the number of these silver nanoparticles impregnated into the fabric of mask B was high and should not be negligible when considering the number metric for interpretation.

The Importance of Silver in Face Masks. Nanosilver face masks provide several opportunities for use in the current COVID-19 pandemic and for future respiratory virus prevention. During a crisis, medical personnel could wear cloth masks or these silver masks over N95s to preserve and protect the surface of the N95 for reuse or extended use when face shields are not available, although this method is currently not approved with National Institute for Occupational Safety and Health (NIOSH).[95,96] Under normal circumstances, N95s are disposable after one use, but as respiratory pandemics come with personal protective equipment (PPE) shortages, medical personal can re-wear respirators using a disinfection protocol.[97] Some nanosilver masks are also useful in that bacteria or viruses are neutralized on the fabric (depending on the technology—see Table 1) within 2 h, in addition to aerosol transmission control provided by cloth masks. It is important to note that filtration capabilities are the main factor to prevent the virus transmission. The silver coating helps to decrease the contamination by touching the mask and increasing the inactivation of the virus.

Health Effects of Silver. There is evidence that silver nanoparticles can pose adverse effects on health in both animals and humans. The main routes for exposure are dermal, respiratory, and oral. Overexposure in rats to AgNPs includes neuroinflammation, cytotoxic response to the lungs, accruing of AgNPs in the brain, and argyria.[98−100] Inhalation of silver particles is a concern with masks that have been impregnated with silver, and the US EPA released a report in the past confirming that silver can be absorbed into the lungs.[101] Additionally, a study by Calderón et al. shows that there are some airborne particles which are released from nanoparticle impregnated products, even when the nanoparticles are embedded inside the fibers.[102] For occupational exposures, the NIOSH Bulletin for nanosilver gives an exhaustive review of the health effects of nanosilver and suggests a recommended exposure limit (REL) of 0.9 $\mu g/m^3$ 8 h exposure for respirable silver particles that are less than 100 nm in size.[103] More research is needed to make a conclusive statement on the safety or risk of AgNPs in masks.

Limitations of Consumer Products and Silver Impregnated Face Masks. There are several potential problems with AgNP face masks. One concern is user compliance that consumers may disregard maintenance instructions and intended duration of use, or otherwise not wear the mask as intended. Another concern is that cloth masks are not considered medical devices and do not provide the same protection as N95 respirators even if the mask is shown to have antiviral or antimicrobial properties;[104] consumers could have a false sense of protection. For evaluating cloth face masks, filtration is the primary factor for consumers to be concerned with, and antimicrobial features second. Moreover, the filtration of cloth face masks varies with the type of fabric used, and poor filtration is an indicator of a mask that does not work. Similarly, fit to the face is also important, as filtration of particles is diminished up to 60% if gaps between the face and the mask are present.[105]

To test the claims of manufacturers, Rengasamy et al. evaluated claims of commercially available dust masks by using a protocol similar to the NIOSH certification test. It was found that the filtration performance of the dust masks was not comparable to NIOSH certified devices, and the authors support the need for regulation and verification of mask product claims.[106] Similarly, advertisements of products may not reveal all information: Nowack et al. determined that 53% of products that contain silver registered by the EPA likely contain AgNPs, yet only 7% of manufacturers advertised their product as containing nanoparticles.[107] There are currently ample silver face masks on the market with unsubstantiated or faulty antiviral claims, and consumers need to be educated when choosing a mask on how to check for proper certifications and claims if buying for protective use.

According to our analysis listed in Table 1, three future certifications currently under development can help the public discern substantiated claims for antimicrobial cloth face masks. Table 1 lists applicable ISO and ASTM certifications, and the three future standards are ASTM WK73068, ISO/DTS 23650, and ISO/DIS 20743, each of which focus on antimicrobial testing of textiles. Special interest is given to ISO/DTS 23650, as this standard is the only antimicrobial standard specific to nanomaterials.

Although these certifications focus on antiviral or antibacterial properties of textiles, another consideration is that, even if these masks are made from fabric that is verified as antimicrobial, these certifications do not consider exposure to nanoparticles or cloth fibers which could potentially be released during mask wearing. A standard protocol for proving the safe use of masks impregnated with nanoparticles or nanofibers could be added to an existing standard or act as a stand-alone certification for cloth face masks. This new standard should include nanoparticle and fiber release tests, which can aid in gathering more comprehensive information regarding the benefits and potential risks in using these nanotechnology-enabled mask products.

Furthermore, the Consumer Product Safety Commission (CPSC) under the Consumer Product Safety Act is charged with protecting the public from unreasonable risks of injury or death associated with the use of the thousands of types of consumer products under the agency's jurisdiction. Based on our study results, CPSC may develop educational frameworks for manufacturers that will aid the current lacking enforcements for testing new products and further develop voluntary standards with other organizations such as ASTM. Scientific research is needed to evaluate technology-enabled products to provide informative analysis results for both manufacturers and consumers to move toward safe and sustainable business practices. Finally, the Federal Trade Commission and its

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Bureau of Consumer Protection shall be aware of the gap of missing appropriate federal regulations in supporting consumers and manufacturers with products incorporating the latest technologies.

In conclusion, the potential for AgNPs in health and hygiene products is immense, where the cloth facial mask is an exceptional candidate. However, in order to be useful, safe, and capable of reducing the potential exposure to viruses, it is necessary to implement well-defined evaluation parameters and quality-control protocols to improve product quality and consumer trust. A database or test center would benefit consumers by providing transparency and assurance that the face mask purchased has substantiated claims.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.chas.1c00005.

Additional elements found in face mask A are presented in SI Figures S1 and S2 (PDF)

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■ ABBREVIATIONS

AgNPs, silver nanoparticles; SEM, scanning electron microscopy; TEM, transmission electron microscopy; EDS, energy-dispersive X-ray spectroscopy; TGA, thermal gravimetric analysis; SARS-CoV, severe acute respiratory syndrome; SARS-CoV2, severe acute respiratory syndrome coronavirus 2; COVID-19, coronavirus disease 2019

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