Surface Treatment of Non-woven Polypropylene Used in Personal Protective Equipment to Reduce SARS-CoV-2 Spread

Justin Gangwish, Abhishek Bhattacharjee, Roberta Sabino, Vignesh Manivasagam,
Yan Vivian Li, Ketul Popat, Melissa Reynolds, and Susan James, Colorado State University

Introduction:
The CDC recommends healthcare personnel who work with COVID-19 patients wear personal protective equipment (PPE) to protect themselves from infection. While PPE prevents infection, it can also encourage the spread of disease between patients through contact transmission**(Fischer et al., 2015; Reddy et al., 2019)**. Polypropylene (PP) is commonly used to make isolation gowns and N95 masks**(Kilinc, 2015; Lam et al., 2019; Vozzola et al., 2018)**. Recent evidence has shown that PP, provides SARS-CoV-2 viability up to 72 hours**(van Doremalen et al., 2020)**. While new materials for PPE could be investigated to decrease the viability of SARS-CoV-2, it will take years to fully investigate, design, and manufacture novel materials. Alterations to current PPE materials, would be much faster, and our research group has already developed a method for incorporating a potentially viricidal biological polymer, hyaluronic acid, into plastics**(Bui et al., 2019; Li et al., 2014; Zhang et al., 2006)**. Furthermore, we have developed two cost effective methods to increase spike protein adhesion to nonwoven PP. The methods used to alter the nonwoven PP are non-toxic **(Bui et al., 2019; Jiang et al., 2014; Reznickova et al., 2019; Santos et al., 2016)**.

Methods:
Plasma Grafting PEG onto Nonwoven PP Treatment: The nonwoven PP filtration layer used in disposable face masks (Makena) was activated with oxygen plasma (PlasmaEtch) then PP samples were placed in a 25g/L solution of PEG (MW 3,350 kDa, Sigma Aldrich) in 200 proof ethanol for 15 minutes allowing the PEG to adsorb to the activated surfaces. Adsorbed PEG was grafted to the surface with a 300 second oxygen plasma treatment. Excess PEG was removed by methanol and ethanol rinses. Sham PEG controls underwent the same process except the shams were submerged only in ethanol rather than a PEG/ethanol solution after the plasma activation step.
Hyaluronic Acid Complexed with Cetyltrimethylammonium (HA-CTA) Spray Treatment: HA-CTA powder was dissolved in 200 proof ethanol at 0.4% (w/v). The HA-CTA/ethanol solution was sprayed onto the nonwoven PP layer at 25 PSI using an airbrush (Powermate). The solution sprayed at 0.1 ml/cm^2. A 2% (v/v) solution of toluene diisocyanate (TDI, Sigma Aldrich) in xylenes was prepared and the dry HA-CTA sprayed PP material was allowed to crosslink in the vapor above 10 ml of the TDI/xylene solution at 60 °C for 1 hour. The crosslinked samples were dried then hydrolyzed in a 0.2 M NaCl in DI/ethanol (1:1, v/v) solution.
Control Samples: Control samples were untreated, but opened and stored in ambient conditions to reflect storage conditions for the treated samples.

Material Evaluation:

Contact Angle Goniometry: PP fabric contact angles were assessed for hydrophilicity by examining the absorption rate of a droplet of water on the surface over 5 minutes. Contact Angle was taken on days 1 and 28 after treatment.

X-ray Photoelectron Spectroscopy (XPS): A PHI-5800 spectrometer with a monochromatic Al-K X-ray source operated at 15 kV was used to analyze the surface chemistry.

Spike Protein Adsorption: Samples were stored in ambient conditions for 14 days to simulate a brief period of storage before testing. SARS-CoV-2 spike protein (Sinobiological) adsorption was evaluated using an enzyme-linked immunoassay (ELISA) (Sinobiological).

Samples were evaluated for chemical groups with attenuated total reflectance-fourier transform infrared spectroscopy, for water vapor transmission according to ASTM D6701-16, and for Young's modulus and ultimate tensile failure according to ASTM D3882, however these results are omitted for brevity.

Results and Discussion

Contact Angle Goniometry: Figure 3 shows the control samples and PEG, PEG sham, and HA samples for day 1 and day 28. Controls are shown as reference. The PEG treated PP samples had consistently lower contact angles than the control PP from day 1 to day 28**, while** The sham samples were never significantly different than the controls**.** The HA treated PP samples had consistently lower contact angles compared to the control from day 1 to day 28**.**

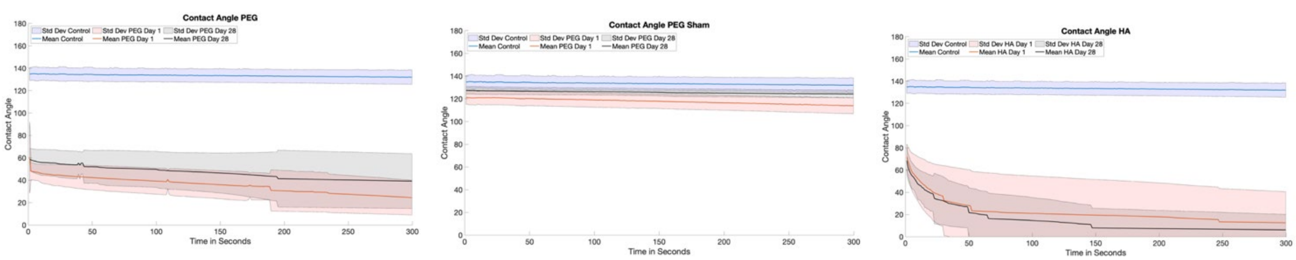

Figure 1: Contact Angle of PEG, PEG sham, and HA samples at day 1 (red) day 28 (black) with control reference (blue). Solid lines represent the mean while shading is standard deviation.

X-ray photoelectron spectroscopy (XPS): Day 28 results are seen in table 1. The PEG sample and sham samples continued to maintain significantly higher carbon to oxygen ratios compared to the control over the 28 day study.

Sample	Carbon	Oxygen	Nitrogen	Silicon	Others
PEG	73.81	24.56	0	0.99	0
Sham	68.69	24.33	0	6.98	0
Control	93.09	4.21	0	2.69	0
HA	60.45	32.23	3.36	0.96	2.83(Na)

Table 1: Elemental composition of day 28 PP samples.

Spike Protein Adsorption: All samples had significantly higher adsorption of the spike protein compared to the control samples. Figure 2 shows the SARS-COV-2 spike protein adsorption. The significantly greater rates of spike protein adsorption indicate the HA and PEG treatments may be effective ways to treat nonwoven PP to further retain live SARS-COV-2. By preventing the live virus from detaching from a facemask or other PPE material that has SARS-COV-2, surface transmission of

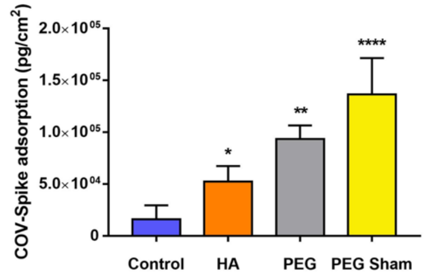

Figure 2: Spike protein adsorption on nonwoven PP substrates. Asterisk indicates significance (p=0.05)

the virus may be greatly reduced. Interestingly the most

effective method at adsorbing the spike protein was the

PEG sham treatment. This indicates that the addition of active oxygen groups on the surface may be the most ideal way to trap SARS-COV-2 on the surface of PP, however the other treatment groups were also effective in increasing adsorption.

Discussion: All three treatments of the non-woven PP demonstrated increased spike protein adsorption indicating they may help reduce the spread of COVID-19. Interestingly, the PEG sham sample had the greatest protein adsorption indicating the introduction of oxygen through plasma treatment as confirmed by XPS may help reduce COVID-19 transmission. While the ELISA results are promising, further study using live SARS-CoV-2 virus is warranted, especially because plasma treatment is a simple and low-cost process that may help

reduce transmission of SARS-CoV-2.

Authors: Justin Gangwish [a], Abhishek Bhattacharjee [a], Roberta M. Sabino [a], Vignesh K. Manivasagam [b], Yan Vivian Li [a,c,d], Ketul C. Popat [a,b,d], Melissa Reynolds [d,e,f], and Susan James [a,b,d]

a. School of Advanced Materials Discovery, Colorado State University, Fort Collins
b. Department of Mechanical Engineering, Colorado State University, Fort Collins
c. Department of Design and Merchandising, Colorado State University, Fort Collins
d. School of Biomedical Engineering, Colorado State University, Fort Collins
e. Department of Chemistry, Colorado State University, Fort Collins, f. Department of Chemical and Biological Engineering, Colorado State University, Fort Collins

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