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Relation of Wettability of Surfaces to Virus Survival Times

Anthony Pintola
The University of Akron, ajp153@zips.uakron.edu

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Anthony Pintola

Department of Chemical, Biomolecular, and Corrosion Engineering

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Approved:

Bi-min Zhang Newby

Date: 4/26/2021

Honors Project Sponsor (signed)

Bi-min Zhang Newby

Honors Project Sponsor (printed)

Date:

4/26/21

Reader (signed)

Jonathan Matthews

Reader (printed)

Date:

Reader (signed)

Steve Goulding

Reader (printed)

Accepted:

Bi-min Zhang Newby

Date: 4/26/2021

Honors Department Advisor (signed)

Bi-min Zhang Newby

Honors Department Advisor (printed)

Date: 4/26/2021

Department Chair (signed)

Lu-Kwang Ju

Department Chair (printed)

Executive Summary

The COVID-19 pandemic has plagued the world for well over a year now. This pandemic has caused hundreds of millions of infections, including millions of deaths worldwide. Because of how rapidly this virus has spread, and its ability to cause severe infections, it has put severe strains on healthcare systems and supply chains worldwide for personal protective equipment (PPE). The virus is spread via respiratory droplets containing the virus from an infected individual, which enters the body of a healthy individual through mucosal membranes. While virus entering the body through direct inhalation of the virus containing droplets is believed to be the predominately route for COVID-19, some studies have initially indicated that virus could potentially transfer through one's hands when touching surfaces contaminated with the virus and then touching one's eyes, nose and/or mouth. Studies carried out in the early 2020 have reported that COVID-19 virus was stable on surfaces for several hours to days. However, details on how surface properties affect the survival of virus have not been evaluated. This presented a unique opportunity to study surface properties, especially wettability and roughness, to try and determine a relationship to virus survival. In this project, potential relationships between wettability of a surface to the reported COVID-19 survival times on the surfaces are to be evaluated.

In order to gain a useful comparison, surfaces that are touched normally throughout a given day were chosen. The main purpose behind the data analysis was to determine if the surface conditions had a direct correlation to how long COVID-19 is reported to survive, and thus likelihood of virus transmission. This was accomplished by breaking the selected surfaces up into more manageable groupings of surfaces. These groupings included: Personal items, Household items, Food packaging, and Metals. The contact angle of a 10 μL droplet was measured on each surface and plotted with the surface's COVID-19 survival time to roughly

determine if there is a relationship between the contact angle and the virus survival time. The initial analysis as a whole did not show any conclusive trends to indicate there is a relationship between contact angle and COVID-19 survivability. However, the metals group contained the only surfaces that showed a distinct relationship. This group showed an inverse relationship in that as contact angle increased, virus survivability decreased.

This work has had the ability to be beneficial to not only society, but my personal development as an engineer. This work has been very useful for further developing my independence, as the project was individual study. The study also helped improve my ability to objectively thinking. As the time passed during this research, many developments occurred in regards to knowledge on COVID-19 transmissibility. Although this new knowledge would lessen the broader societal benefits, it was still beneficial for being able to complete the work without bias and be able to look to the future for ways to improve the usefulness of this work.

Due to the ever changing landscape of the COVID-19 pandemic we as a society are constantly learning new things every day. As new knowledge is brought forward it is necessary to adapt. This work has many opportunities for future improvement. One immediate change that would be made is to change from virus survivability times to the time it takes for the amount of virus to be low enough to no longer pose risk of infection. Because of qualitative results another improvement for future research would be to quantize physical surface conditions, such as roughness, or how porous a surface is. By making these changes to the work it may provide more insight into how virus survivability, and even transmission, is related to the surface conditions beyond just the wettability.

Introduction

Coronaviruses are a type of virus named after their crown like structure. There are many different types, and some cause disease in humans [1]. A newly identified coronavirus, SARS-CoV-2, also known as COVID-19, has caused a worldwide respiratory illness pandemic. This pandemic has caused 137 million cases of infection and approximately 2.96 million deaths worldwide as of April 2021 [2]. COVID-19 can cause a wide array of symptoms in humans such as: Fever, Chills, Cough, Difficulty breathing, and loss of taste and smell to name a few [3]. These symptoms are also similar to many other respiratory illnesses, such as influenza, however, COVID-19 has a tendency to cause more severe symptoms. These severe symptoms often require hospitalization and even treatment in an Intensive Care Unit (ICU). These severe symptoms have put a massive strain on hospital systems worldwide as well as supply chains for Personal Protective Equipment (PPE).

Originally not much was known about the transmissibility of the virus. However, in more recent times it is known to be transmittable through fluid droplets from an infected person(s) [4]. These fluid droplets containing the virus leave the infected person’s body while coughing, sneezing, or even talking, and can land on a variety of different objects and surfaces [5]. A healthy individual could also breathe in the droplets which lead to infection. A healthy individual can also encounter the virus by touching a surface that has been exposed to the respiratory droplets. It has been suggested that the transmission could also occur through openings, such as eyes, mouth, and nose of a human body, when a virus contaminated hand of a healthy individual touches these openings [1]. As members of society, we interact with innumerable surfaces that other individuals have also been in contact with every single day. This presents a unique opportunity for needing an understanding of how long the virus can survive on these surfaces in order to reduce transmission.

In Dr. Newby's research lab there are studies being conducted on various aspects of surface wettability. One of these aspects being researched is in relation to various household surfaces and how easily wettable they are. Given that not only COVID-19, but other viruses transmit through fluid droplets it can be beneficial to understand how easy it is for surfaces we contact every day to be wetted. The wettability of a surface material can be described as the contact angle of the droplet on the surface. The contact angle of the droplet refers to the angle formed between the plane of the surface and the tangent to the droplet edge. The wettability of the surface can then be related to researched literature values for virus survivability time on that surface. This could be a useful relationship for understanding how an individual can approach interactions with the objects they normally encounter.

Methodology

There is an almost endless number of different surfaces that individuals can come in contact with. In order to begin data collection, it was necessary to determine which types of surfaces are common to come in contact with. A secondary factor in determining what surface to test was its availability.

To begin testing each surface had to be properly prepared. Each surface was cleaned off with a micro-fiber cloth and then hit with a spray of compressed air to remove any leftover dust left behind by the cloth. Once the surface was properly prepared it was placed under a digital microscope. The microscopes image output was operated using a program called YAWCAM. The microscope focus was first adjusted visually by viewing the window in YAWCAM. The lighting was then adjusted to further improve the microscope image. Next, a 'respiratory' droplet, which was simulated by a 10 μL water drop was required. This drop was created with a calibrated pipette using DI water. A precise, disposable tip was placed on the end of the pipette and the 10 μL of DI water was drawn in and then deposited carefully onto the sample surface. Once the drop was placed onto the surface the microscope was fine tuned to make sure the edges of the drop were well defined. Next a millimeter ruler was placed on the surface near the drop so that it was visible on the microscope image. Finally, an image of the microscope output was taken and saved for further analysis. This process was repeated five times for each surface. If the surface has absorbent properties, the image was taken as soon as possible to prevent the drop from losing its shape.

Once all of the samples were finished and the images were collected the area of each droplet needed to be determined. This was done via ImageJ software. Using ImageJ, a photo of the desired sample was opened. First the measurements to be taken were selected from the "set measurements" window. The chosen quantities to be measured were area and perimeter. Next a straight line was selected from the tool bar. The line was to be placed along the ruler that was in each image. The line is to serve as a scale to convert pixels to actual lengths. The line was drug from one millimeter mark to the next. After completing the line, the scale needed to be set. Under the "Set Scale" tab the length shown is in pixels, however, the value of known length can be entered, followed by its units (mm). Once entering in the length and units of the drawn line all measurements will now be displayed in millimeters rather than pixels. In order to verify the accuracy of the scale, the line was redrawn along the same scale and the length was viewed to ensure a proper measurement of scale for accuracy of results. After the scale is set the rest of the measurements can be performed. From the tool bar the "oval" was chosen and placed over drop. In some cases where the drop was not a perfect circle or ellipse, the oval was shaped so that portions within the marked region and outside were roughly equal. An example is shown in the figure below.

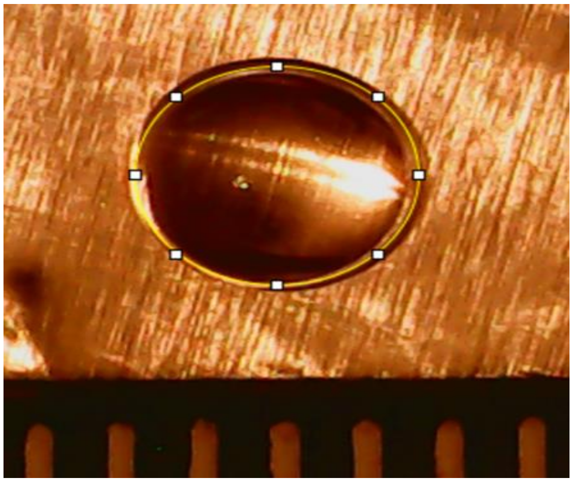

Figure 1: An image representing how the oval is placed when the area of interest is not perfectly circle. Roughly equal areas inside and outside of the contact area are selected via the drawn circle. The example shown is of a droplet on an aluminum surface.

Once the areas were calculated for each sample an average area over the five tests was computed. From there, the radius of the drop was calculated assuming the area represented a two-dimensional circle. The radius was calculated using the following equation:

$$radius(mm) = \sqrt{\frac{Area(mm^2)}{\pi}}$$

Next, the contact angle was determined using the calculated radius for each surface. The contact angle was determined based off of a fitting of theoretical data for a 10 μL drop, to represent a respiratory droplet, and can be found in **Appendix A**. Contact angles were then plotted with COVID-19 survival times as noted in literature.

Results

The surfaces chosen to be investigated were selected based upon being a frequently touched object or surface. The surface also had to have literature values for how long COVID-19 can survive on the surface. The first part of this investigation involved determining the area of the 10 μL droplets on each surface. This involved using ImageJ to convert pixels in the image into usable units, such as millimeters, and then matching the shape of the drop with a circle or ellipse to determine area. The area was then used to determine contact angles for each surface. The results of this analysis can be seen below in **Table 1**.

Table 1: The following table shows the contact angle for each surface across all five tests. The average contact angle and the standard deviation among each surface is also reported. The standard deviation was used as the estimated error in testing.

	Angle 1 (Deg)	Angle 2 (Deg)	Angle 3 (Deg)	Angle 4 (Deg)	Angle 5 (Deg)	Avg Angle (Deg)	Standard Deviation
Plastic Bottle Cap	25.865	30.185	38.919	31.820	26.578	30.673	4.678
Credit Card	58.223	60.662	110.183	81.067	80.796	78.187	18.679
Cardboard Painted	78.407	77.205	89.893	88.315	83.010	83.366	5.094
Cardboard Plain	58.109	57.056	65.897	60.721	58.114	59.979	3.196
Ceramic	15.829	14.571	19.741	14.643	15.398	16.036	1.911
Granite Countertop	10.660	11.640	10.950	10.472	11.444	11.033	0.447
Carbon Steel	108.248	98.625	95.212	98.458	94.686	99.046	4.876
Fake Leather Wallet	4.649	7.022	6.989	4.150	4.178	5.398	1.325
Real Leather	4.988	4.809	5.216	5.743	5.091	5.169	0.316
Paper	114.118	94.572	104.905	100.726	107.621	104.388	6.560
Phone Screen	94.079	96.910	92.244	95.525	92.624	94.276	1.755
Aluminum Foil	96.960	106.386	112.299	110.848	99.699	105.238	6.031
Shoe Sole	103.769	86.003	88.620	96.368	94.869	93.926	6.240
Wood Table Top	50.855	41.683	37.886	35.793	46.666	42.576	5.551
Tile Floor	91.353	89.696	79.652	72.053	96.054	85.761	8.694
Stainless Steel	49.038	47.365	51.649	48.920	48.558	49.106	1.403
Glass	92.639	92.943	92.252	92.346	94.664	92.969	0.882
Silver	33.364	35.290	33.882	31.338	29.512	32.677	2.028
Nickel	95.742	93.708	95.086	92.317	95.976	94.566	1.374
Styrofoam	105.140	104.654	106.060	104.188	105.414	105.091	0.641
Tin	92.229	107.026	110.216	92.264	112.385	102.824	8.803
Porcelain Bowl	49.136	50.704	53.935	47.000	49.095	49.974	2.304
Plastic Phone Case	73.856	62.750	63.467	71.612	68.166	67.970	4.370
Copper	100.497	102.168	104.548	112.248	104.443	104.781	4.028

The next step in the analysis was to determine the contact angle from the data presented above. This was done by converting the areas into radius values and using the theoretical curves shown in **Appendix A** to convert drop radius into contact angle. Once the contact angles for each surface were determined a literature review was conducted to determine how long COVID-19 has been determined to survive on the surfaces. Each surface was plotted with both its contact angle and its researched virus survival time. The plots were grouped based off of how the surface would be viewed during daily interactions. The groupings that were chosen for the surfaces were: Personal Items, Food Packaging, Metals, and Household Surfaces. The results of the comparison between personal materials can be seen below in **Figure 2**.

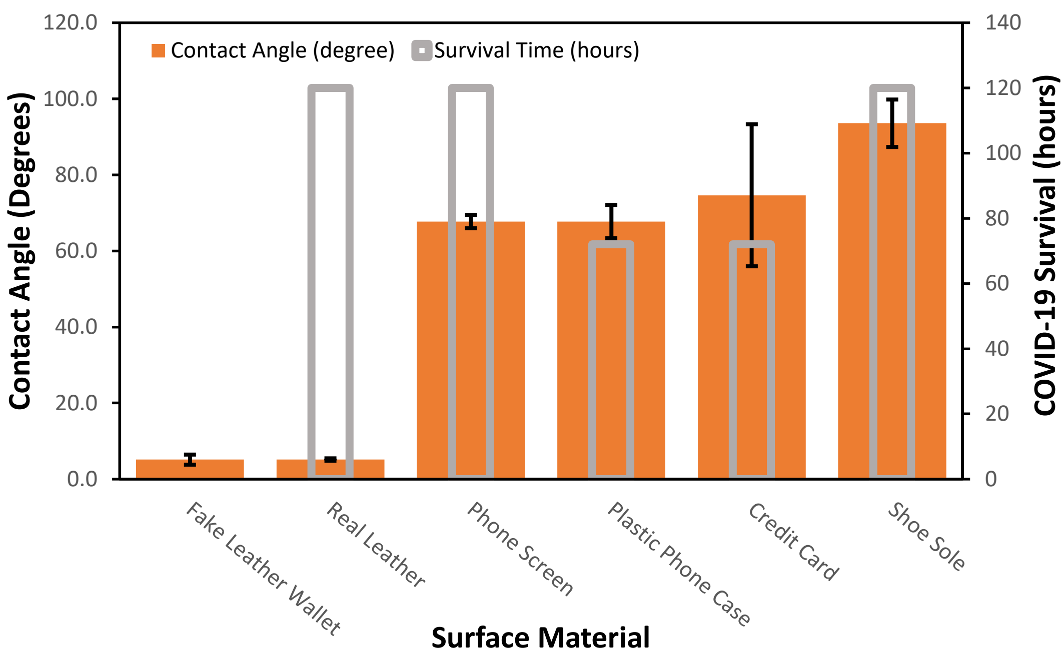

Figure 2: The results of the determined water contact angles (orange bars) and reported literature values for virus survival time (grey bars) for the six surfaces designated as "Personal Surfaces". No obvious correlation between the survival time and contact angle was observed.

All of the personal materials had a researched COVID-19 viral time except for fake leather, or the synthetic compound it is typically made of. Real leather and a phone screen was determined to have a COVID survival time of 120 hours [7,8]. The plastic phone case and credit card, which are often times touched countless times throughout the day were found to have COVID survival times of 72 hours [8]. And lastly, the sole of a shoe, which could carry virus from public floors into homes and vehicles, was found to have a virus survival time of 120 hours [7]. With the surfaces shown in ascending order for droplet contact angle there appears to be no correlation to virus survival time.

The second surface grouping that was chosen was those relating to food. These surfaces could be touched within stores as packaging, from containers when ordering takeout, which is becoming a common practice during the pandemic, or within one's own house when storing food away. The seven investigated surfaces that fit into this category are shown in **Figure 3**.

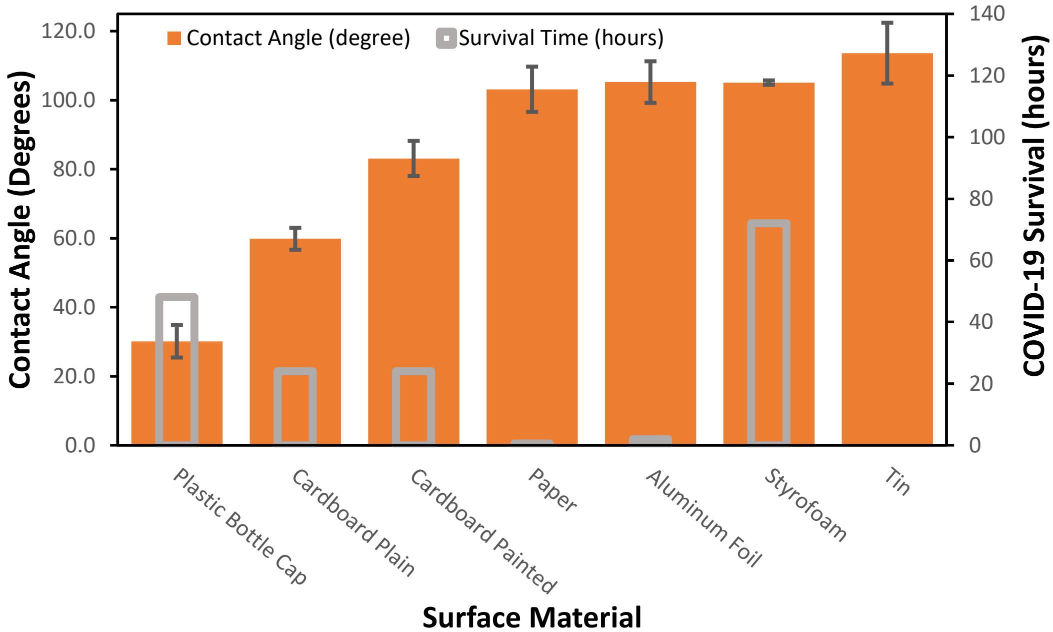

Figure 3: The results of the determined water contact angle (orange bars) and reported literature values for virus survival time (grey bars) for the six surfaces designated as food related surfaces. No obvious correlation between the survival time and contact angle was observed.

The seven surfaces that fit within this category include: plastic bottle cap, plain cardboard, painted cardboard, paper, aluminum foil, styrofoam, and tin. After a review of literature the following virus survival times were found. Plastic bottle caps allow COVID-19 to survive for up to 48 hours [8]. Cardboard, which is used for boxed packaging in stores, and even pizza boxes, was reported to have a virus survival time of 24 hours [8]. Paper was reported to have a virus survival time of 0.5 hours [7]. Aluminum, which is primarily encountered as foil wrapping, has a virus survival time of 2 hours [7]. Styrofoam, which is typically found in take out containers, has a virus survival time of 72 hours [8]. Lastly, tin, which is typically found as a coating on canned goods to prevent corrosion, has a virus survival time of 120 hours [8]. With the surfaces plotted in ascending order of contact angle there appears to be no correlation between virus survivability and contact angle.

The third surface grouping that was analyzed were household surfaces. The six surfaces that were tested and fall within this group are: granite countertops, ceramic, wood tabletop, porcelain bowl, tile flooring, and glass. The results of the study can be seen in **Figure 4**.

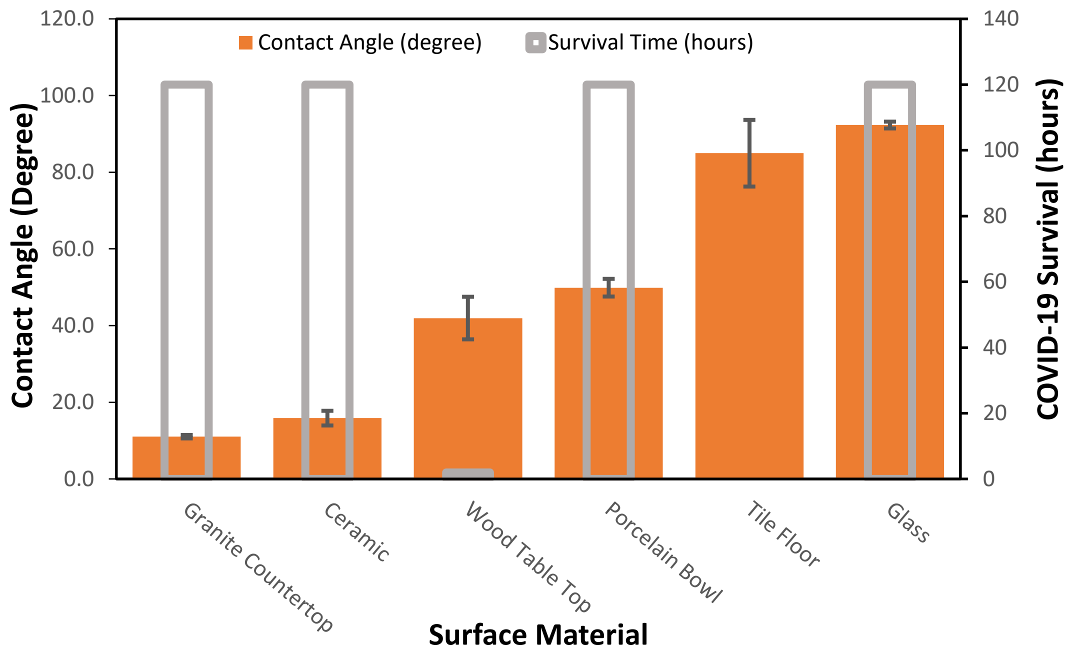

Figure 4: The results of the determined water contact angles (orange bars) and reported literature values for virus survival time (grey bars) for the six surfaces designated as household surfaces. A value for survival time on tile flooring was not obtainable. No obvious correlation between the survival time and contact angle was observed.

Each of the surfaces within this category have numerous daily interactions from working at home on countertops made into desks, to eating, or to even walking around the house. After conducting a literature review the following survival times were found Granite countertops were reported to have a virus survival time of between 120 and 216 hours [7,9]. Ceramic, such as bowls or some restroom fixtures, was reported to have a virus survival time of 120 hours [7]. The bowl, which is typically touched while eating, was reported to have a virus survival time of 120 hours [7]. Lastly the glass, which is primarily touched via dishware and cups, has a virus survival time of 96 hours[7]. When the surfaces were plotted in ascending order of contact angle there appears to be somewhat of a relationship. As contact angle increases, as seen by the orange bars, the virus survivability seems to have a negative trend, as indicated by the grey bars.

The last grouping of tested surfaces was classified as metals. The surfaces within this section are comprised of everything from canned foods, to jewelry, and even household fixtures and appliances. The tested metal surfaces were: silver, stainless steel, carbon steel, nickel, copper, aluminum, and tin. The results of the analysis can be seen below in **Figure 5.**

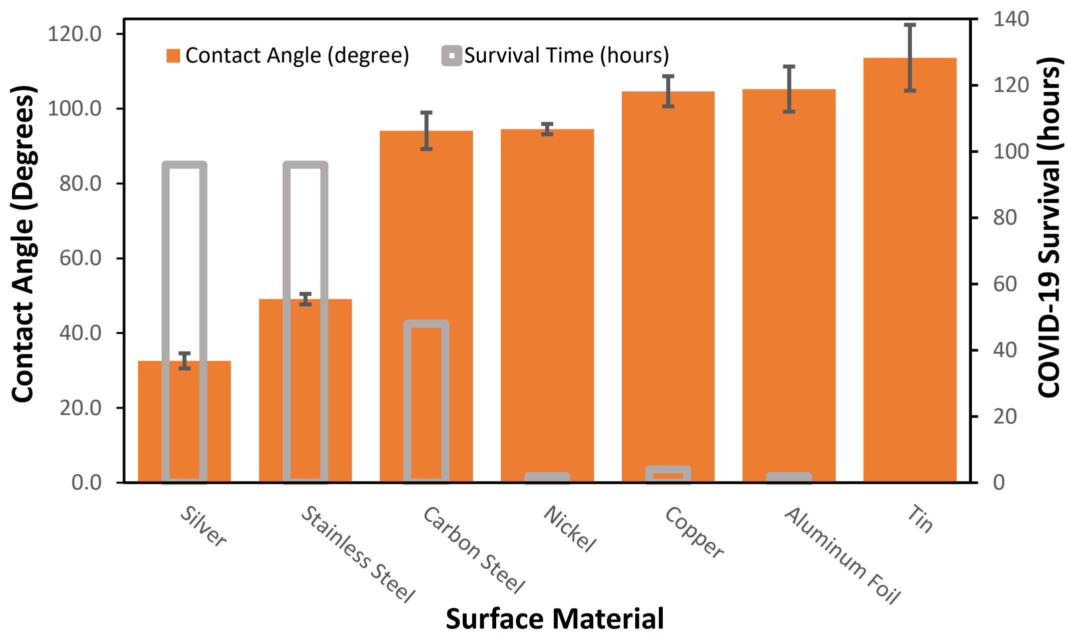

Figure 5 The results of the determined water contact angles (orange bars) and reported literature values for virus survival time (grey bars) for the seven surfaces designated as metals. At this time a value for survival time on tin was not obtainable. A lower contact angle resulted in a longer virus survival time was observed for these metal surfaces.

After conducting a literature review, virus survival times were noted. Silver, which is primarily used in many dining utensils and jewelry, was reported to have a virus survival time of 72 hours [10]. Stainless steel, which is used to make appliances, fixtures, and dining-ware, was reported to have a virus survival time of 72 hours [7]. Carbon steel, which is typically in appliances, tooling, and used in canned goods, was reported to have a virus survival time of 48 hours [10]. Nickel, which is a primary metal in the alloy that are used in coins and household fixtures, was reported to have a virus survival time of 2 hours [10]. Copper, which is a metal primarily used in pennies and some cookware, was reported to have a virus survival time of 4 hours [7]. Lastly, aluminum, which is used to make tooling, appliances, and even food packaging, was reported to have a virus survival time of 2 hours [8]. When these surfaces were plotted in ascending order of contact angle a trend similar to the household surfaces was seen. As contact angle increased, as seen in orange, the virus survivability decreased, as seen in grey.

Analysis

Within the presented data in the figures above a comparison was illustrated between virus survival times and contact angles on the surface. In general there was no relationship noticed between contact angle and survival time. However, with the four categories the surfaces were divided into, a relationship can be seen with the metals. It appears that as contact angle increases, the virus survivability decreases. One important thing to note with the metals is that they were all of a very similar smooth texture, unlike the surfaces within the other categories. It is possible that the physical surface texture also played a role in the accuracy of these measurements, and thus altered the qualitative trends in the figures.

During experimentation, five measurements were chosen to attempt to minimize error. However, it can be seen that some surfaces had a fairly large standard deviation. This may be explained through a visual examination of the actual surface tested. Many of these surfaces that showed higher standard deviations appeared to have textured, non-uniform appearances. This difference in texture across the surface could introduce error in the contact angle depending on the exact location of the drop, as the surface below it is textured slightly different. This could have introduced error in the measured values of contact angle.

Upon completion of the analysis there were some noticeable trends, but also some issues that could be addressed with further research. Even with the trends that could be seen within the metals surface category there is still not enough data on the whole to make a solid conclusion. More surfaces should be tested to see if the trends between contact angle and virus survival time can still be seen. Also, given all of the material groupings, all of the metals had very smooth surfaces that also lacked pores. These surfaces had the most visible relationship between contact angle and virus survivability. Perhaps future research could find a way to quantify surface roughness or porousness and take those variables into account to improve upon the surfaces which are not smooth, such as paper and cardboard for example. Also, more tests per surface could yield higher accuracy by removing the surface texture changes within a small sample size. Lastly, as the pandemic has passed the one year mark much research has pointed to the fact that transmission via surfaces is very low. The research states that while virus particles are detectable for many days, often the amount of virus that is capable of causing infection dies after a very short time [11]. With this new information this study could be updated to include how long it takes for the amount of virus on a surface to drop below the amount that would cause infection. This of course would also require more virology and surface science research as this data is not present on many surfaces currently.

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Appendix A:

Table 2: The following table shows the results of analyzing images of each sample to determine the droplet area. Twenty-four surfaces were analyzed with five samples each. All of the areas listed are in units of mm^2 and were averaged for each surface to be used in later analysis.

Surface	Area 1	Area 2	Area 3	Area 4	Area 5	Average Area (sq. mm)
Aluminum Foil	10.013	9.356	8.993	9.079	9.811	9.450
Carbon Steel	9.238	7.497	7.839	7.511	7.908	7.999
Cardboard Painted	11.696	11.829	10.583	10.721	11.218	11.209
Cardboard Plain	14.562	14.758	13.282	14.101	14.561	14.253
Ceramic	37.704	40.058	32.078	39.914	38.473	37.645
Copper	9.754	9.637	9.476	8.996	9.483	9.469
Credit Card	14.541	14.111	9.119	11.414	11.442	12.125
Fake Leather Wallet	92.384	68.327	68.565	100.396	99.895	85.913
Glass	8.901	8.223	8.519	8.768	7.911	8.464
Granite Countertop	50.347	47.211	49.368	51.008	47.801	49.147
Nickel	10.106	10.266	10.157	10.379	10.088	10.199
Paper	6.617	7.924	7.068	7.335	6.920	7.173
Phone Screen	7.998	7.652	8.680	7.801	8.318	8.090
Plastic Bottle Cap	26.325	23.513	19.524	22.623	25.807	23.558
Plastic Phone Case	12.219	13.766	13.652	12.498	12.957	13.018
Porcelain Bowl	16.463	16.089	15.378	17.007	16.473	16.282
Real Leather	87.758	90.125	84.934	79.159	86.449	85.685
Shoe Sole	9.528	10.931	10.694	10.058	10.174	10.277
Silver	21.852	20.973	21.607	22.877	23.904	22.243
Stainless Steel	16.487	16.911	15.873	16.516	16.606	16.479
Styrofoam	9.437	9.469	9.377	9.500	9.419	9.440
Tile Floor	10.459	10.600	11.562	12.442	10.082	11.029
Tin	8.656	9.315	9.117	8.506	8.988	8.916
Wood Table Top	16.054	18.568	19.912	20.757	17.096	18.477

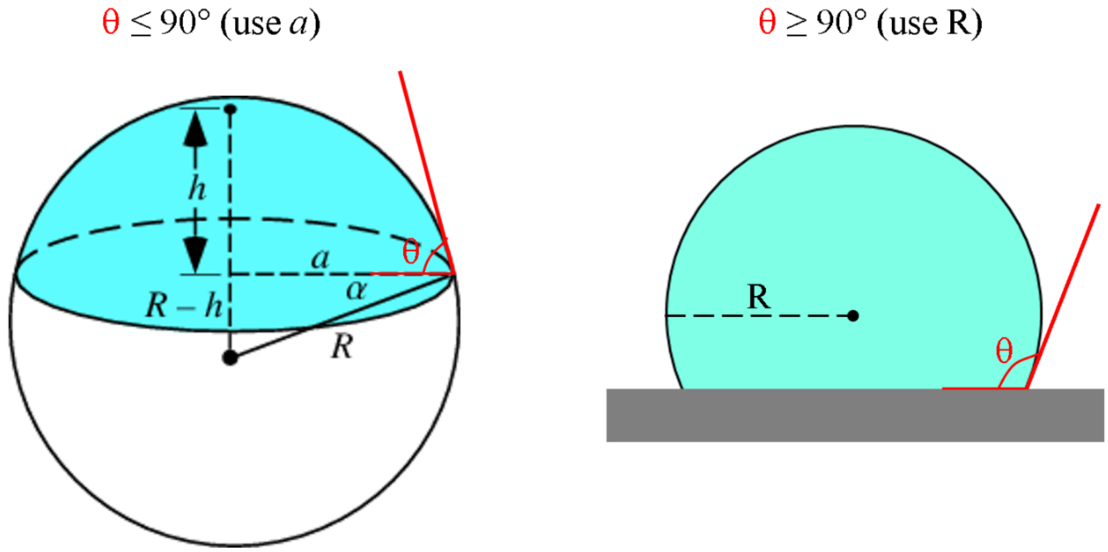

Figure 6: The above figure illustrates the difference between the observed 'radius' of the drops contact with the surface. The image on the left shows the radius is defined as 'a' when the angle is less than 90 degrees. The image on the right shows that when the angle is greater than 90 degrees the observed radius is 'R'.

Table 3: The table shows the theoretical values for drop radii when the contact angle is less than 90 degrees, for a 10 μL drop, as defined in ***Figure 6****.*

a (mm)	θ (deg)
11.342	0.5
5.262	5
4.171	10
3.636	15
3.294	20
3.046	25
2.852	30
2.694	35
2.559	40
2.441	45
2.335	50
2.238	55
2.149	60
2.065	65
1.984	70
1.907	75
1.832	80
1.757	85
1.684	90

Table 4: This table shows the theoretical radii values when the contact angle of the droplet is greater than 90 degrees for a 10 μL drop.

R (mm)	θ (deg)
1.684	90
1.616	95
1.560	100
1.513	105
1.473	110
1.441	115
1.414	120
1.393	125
1.376	130
1.363	135
1.354	140
1.347	145
1.342	150

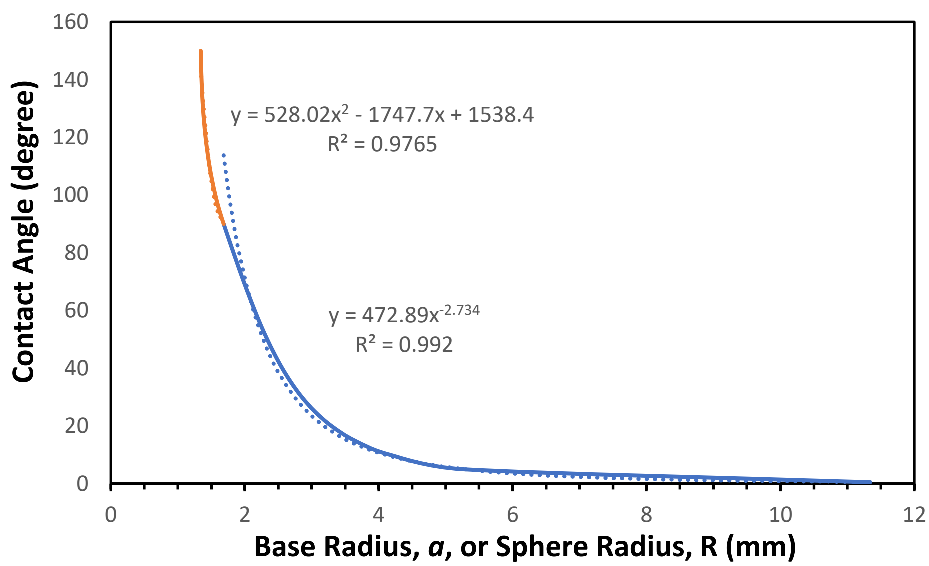

*Figure 7: The above figure depicts a plot of the values presented In **Table 2** and **Table 3**. The orange line depicts the values for a contact angle greater than 90 degrees and the blue line represents data with a contact angle less than 90 degrees. The plot for contact angles greater than 90 degrees was fitted with a quadratic equation. For contact angles less than 90 degrees a power function was fitted to the data. These fittings were used to convert the experimental radii into contact angles for analysis.*

*Table 5: The following table displays the data values used to create **Figure 2** in the Results section. The error bars are represented by +/- one standard deviation as shown below. The standard deviation is calculated based off of the five tests on each surface.*

Surface	Contact Angle (degree)	Survival Time (hours)	Standard Deviation for Contact Angle
Fake Leather Wallet	5.135	0	1.325
Real Leather	5.153	120	0.316
Phone Screen	67.727	120	1.755
Plastic Phone Case	67.727	72	4.370
Credit Card	74.637	72	18.679
Shoe Sole	93.571	120	6.240

*Table 6: The following table displays the data values used to create **Figure 3** for the food related surfaces in the Results section. The error bars are represented by +/- one standard deviation as shown below. The standard deviation is calculated based off of the five tests on each surface.*

Surface	Contact Angle (degree)	Survival Time (hours)	Standard Deviation for Contact Angle
Plastic Bottle Cap	30.105	48	4.678
Cardboard Plain	59.839	24	3.196
Cardboard Painted	83.097	24	5.094
Paper	103.156	0.5	6.560
Aluminum Foil	105.238	2	6.031
Styrofoam	105.088	72	0.641
Tin	113.620	0	8.803

*Table 7: The following table displays the data values used to create **Figure 4** for the household surfaces in the Results section. The error bars are represented by +/- one standard deviation as shown below. The standard deviation is calculated based off of the five tests on each surface*

Surface	Contact Angle (degree)	Survival Time (hours)	Standard Deviation for Contact Angle
Granite Countertop	11.018	120	0.447
Ceramic	15.862	120	1.911
Wood Table Top	41.963	2	5.551
Porcelain Bowl	49.884	120	2.304
Tile Floor	84.961	0	8.694
Glass	92.313	120	0.882

*Table 8: The following table displays the data values used to create **Figure 5** for the metal surfaces in the Results section. The error bars are represented by +/- one standard deviation as shown below. The standard deviation is calculated based off of the five tests on each surface*

Surface	Contact Angle (degree	Survival Time (hours)	Standard Deviation for Contact Angle
Silver	32.566	96	2.028
Stainless Steel	49.072	96	1.403
Carbon Steel	94.075	48	4.876
Nickel	94.548	2	1.374
Copper	104.651	4	4.028
Aluminum Foil	105.238	2	6.031
Tin	113.620	N/A	8.803