Supporting Information for
Injectable Slippery Lubricant-coated Spiky Microparticles with Persistent and Exceptional Biofouling-resistance

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**Experimental Methods**

**Fabrication of spiky microparticles (SMP).**

Smooth glass microparticles (~100 μm mean diameter, Shengtuo, China) were used as the base particles. The smooth particles was first deposited onto a kapton tape substrate to form a particle monolayer. The tape was supported by a glass slide. The particles were then sputter coated with a thin ZnO layer (~80 nm) using a ZKDS magnetron sputtering system VTC300. The ZnO layer served as seed layers for ZnO nanospike growth. ZnO nanospikes were grown on particles by incubating the substrate containing particles with aqueous solutions containing 25 mM zinc nitrate hydrate [Zn(NO$_3$)$_2$$\cdot$6H$_2$O, Sigma-Aldrich] and 25mM hexamethylenetetramine (C$_6$H$_{12}$N$_4$, HMTA, Sigma-Aldrich) at 90 °C for 1 h. The substrate containing particles were generally washed with DI water. After reaction, the SMP were separated from the tape substrate by ultrasound and collected. The SMP were washed using DI water for 3 times.

**Microparticles functionalization with TFOS**

Microparticles were functionalized with triethoxy-1H,1H,2H,2H-tridecafluoro-n-octylsilane (TFOS, Sigma-Aldrich). The particles were incubated in anhydrous heptane (Sigma-Aldrich) with 2% TFOS at 80 °C for 12 h. After reaction, the particles were washed for three times with acetone. The particles were then dried under 60 °C.

**Fabrication of microparticles coated with lubricants or corn oil**

Fluorinated microparticles were incubated with lubricant, perfluorodecalin (Sigma-Aldrich) or perfluoropolyethers-90 (Fitlube, Guangzhou) overnight to absorb lubricants on the particle surface. The particles were separated from the excess lubricant via centrifugation at 3000 rcf (Anke, Shanghai). The upper lubricant medium was removed and the particles were re-suspended in DI water. The particles were centrifuged again and washed with DI water for another 5 times to completely
remove unabsorbed lubricant.

Alternatively, microparticles were incubated with corn oil (Sigma-Aldrich) stained by 0.1mg/ml fluorescent hydrophobic dye, Nile red (Sigma-Aldrich) overnight to absorb corn oil on the particle surface. The particles were the washed and collected in a similar procedure as the lubricant coating process.

**Fabrication of lubricant-coated spiky planar substrates (SPS)**

A glass substrate was sputter-coated with a thin ZnO layer (~80 nm). ZnO nanospikes were grown on the substrate by immersing the substrate into aqueous solutions containing 25 mM zinc Zn(NO$_3$)$_2$ and 25mM HMTA at 90 °C for 1 h. The substrate was then rinsed with DI water for 3 times. To reduce cytotoxicity of ZnO, the SPS was coated with a thin layer of aluminum oxide (~20 nm) as a protective layer. Finally, the SPS were functionalized with TFOS at 90 °C for 2 h via chemical vapor deposition (CVD) method. The SPS were washed for 3 times with acetone and dried at 60 °C. Lubricating liquid was then added on top of the SPS-F for at least 5 min. By tilting the surface, the excess lubricant was removed.

**Characterization of particles**

Microparticles were re-dispersed in ethanol, and drop-casted onto conductive substrate and allowed to dry. Samples were sputtering-coated with Au, and imaged with SEM system (Phenom Pro and Zeiss SUPRA 60). Microparticles were also characterized with optical microscopy or fluorescence microscopy (MF52-LED, Mshot).

**Contact angle measurements**

Microparticles were drop-casted on a glass substrate and prepared as a uniform film. Static Contact angle measurement was conducted with Goniometer measuring system to analyze the wetting properties of the microparticle thin film at room temperature. DI water and lubricants including perfluorodecalin and perfluoropolyethers-90 were used as probe liquids.
**Tests of microparticle dispersity in water.**

Microparticles were suspended in DI water and transferred to a 96-wells plate. Particle dispersion at typical area was imaged with optical microscopy.

**Statistical analysis**

T-test was utilized to analyze the difference between two groups, and one way ANOVA among multiple groups. All data were presented as Mean±SD.

**Tests of the adhesions of small molecule (FITC), protein (FITC-BSA) and fluorescent fibrinogen (Fg)**

Fluorescent molecule, fluorescein (FITC, MW=389, Aladdin), FITC conjugated bovine serum albumin (FITC-BSA, MW~66 kDa, Beijing BioDee Biotechnology), and fluorescent fibrinogen (Fg, Solarbio) both at the concentration of 0.1 mg/mL (in PBS, pH 7.4)) were incubated with microparticles at 37°C for 24 h. The microparticles were then washed with fresh PBS for once. Typical microparticles were imaged with fluorescence microscopy at the same exposure time. The fluorescent intensity of microparticles was quantitatively analyzed with Image J.

**Test of protein activity**

Glycose oxidase (GOD, Aladdin) in PBS solution (0.1mg/ml) were incubated with LCSMP (both LCSMP#1 and LCSMP#2) for 24 h. After incubation, the activity of GOD was evaluated by GOD activity detection kit (Solarbio). At the same time, GOD denatured via heating (90 °C, 0.5 h) as negative control.

**Bacteria Culture.**

*Escherichia coli* ATCC25922, GFP-expressing Escherichia coli pUC18, or *Staphylococcus aureus* ATCC6538 (all purchased from REBIO Shanghai) were cultured on Luria-Bertani (LB) broth (Shanghai yuanye Biotechnology) overnight, shaking at 37°C. 1.0 ml solution containing concentrated ATCC25922, pUC18 or ATCC6538 was then withdrawn and diluted with 10 mL fresh LB broth. The bacteria
was cultured for another 8 h. The concentration of bacteria was around 10⁹-10¹⁰ Colony Forming Units/ml with PBS for the following experiments.

**Tests of bacteria adhesion.**

Microparticles were incubated in 150 μl static culture media (in 96-well plate) containing GFP-expressing E. coli or S. aureus at 37°C for 24 h. Prior to imaging, the S. aureus were stained with 10 μg/ml Green fluorescent dye (SYTO-9, Thermo Fisher Scientific). The microparticles were then collected from the culture media and carefully washed with fresh PBS for once. The microparticles were then imaged with fluorescence microscopy at the same exposure time. The fluorescent intensity of microparticles was quantitatively analyzed with Image J.

**Test of bacteria viability**

Lubricant was mixed with culture medium containing either E. coli. or S. aureus. in a ratio of 1:5 (v/v) and LCSMPs were incubated in E. coli. or S. aureus. medium. Those medium was cultured at 37°C for 24 h. The bacteria were then stained with 10 μg/ml SYTO-9 and 10 μg/ml red fluorescent dye, propidium iodide (PI, Thermo Fisher Scientific) at 37°C for 15 min. The fluorescence staining results were imaged with fluorescence microscopy. Bacteria viability was quantified by counting the number percentage of dead bacteria labeled by red fluorescent PI.

**Cell culture**

HeLa cells ( Laboratory Animal Center of Sun Yat-sen University ) were cultured in medium with 90% DMEM (Dulbecco’s Modified Eagle Medium, Gibco), 9% FBS (fetal bovine serum, Gibco) and 1% antibiotics at 37 °C, 95% humidity and 5% CO2. When 90% confluent, the cells were treated with 0.25% trypsin–EDTA (Gibco) and centrifuged at 1000 rpm for 3 minutes. Afterwards, the cells were re-suspended into culture media to achieve densities of 10⁵~10⁶ cells / ml and then applied for experiments.
Tests of cell adhesion

Microparticles were incubated in 150 μl static culture media (in 96-well plate) containing HeLa cells at 37°C for 24 h. Before imaging, the cells were stained with 10 μg/ml Hoechst 33342 (blue fluorescence, Thermo Fisher Scientific). The microparticles were then collected from the culture media and carefully washed with fresh PBS for once. The microparticles was then imaged with fluorescence microscopy. The number of fluorescent cells anchoring on particles was counted.

Tests of cell viability

Lubricant or corn oil was mixed with culture medium containing HeLa cells in a ratio of 1:5 (v/v) and LCSMPs were incubated in HeLa cells culture medium. The medium was cultured at 37°C for 24 h. The cells were then stained with 10 μg/ml green fluorescent dye, calcein AM (Thermo Fisher Scientific) for labeling live cells, and 10 μg/mL red fluorescent dye, PI for labeling dead cells. Cell viability was quantified by counting the number percentage of both live cells and dead cells.

Characterization of lubricant-coated spiky planar substrate (LCSPS)

The morphology of spiky planar substrates were imaged with SEM. To test the sliding of water or oil droplets on LCSPS, the substrate was tilted with a angle (SA) of 5°. A 5 μl droplet was released onto the substrate surface, and the time–sequence images were captured by the Goniometer measuring system. For the test of bacteria or cell adhesion, the substrate was placed in 96-well plate, and incubated in 150 μl static culture media containing either GFP-expressing *E. coli*, *S. aureus* or HeLa cells at 37°C for 24 h. Before imaging, the *S. aureus* were stained with 10 μg/ml SYTO-9, and HeLa cells were stained with 10 μg/ml calcein AM and and 10 μg/ml PI. The substrate was carefully washed with fresh PBS for once to avoid background signals from suspending solution, and then imaged with fluorescence microscopy.

Assessment of the long-term stability and long-term biofouling-resistance

The as-prepared LCSMP were stored in water at room temperature for at least 14
days. The particles were then applied for experiments. For the assessment of the long-term stability, SMP-F coated with Nile red-stained corn oil was imaged after 14-day storage. For the assessment of long-term biofouling-resistance, the experiments were performed in the similar procedures as described above, except that the incubation time with protein, bacteria or cells was extended to 14 days.

Assessment of the long-term stability and biofouling-resistance on dynamic environment

The as-prepared LCSMP groups (LCSMP#1 and LCSMP#2) immerse in water more than 7 days with the flow rate about 80 r/min and about 1 h with the flow rate >2000 r/min. The particles were then applied for anti-biofouling experiments in the same way as before.

Implantation and retrieval of microspheres

Animal surgeries were performed following the procedures outlined in Ref. 1 and 2. All research and animal experiments described herein were carried out in accordance with the Animal Care and Use Committee at the Sun Yat-sen University. Wild-type C57BL/6 mice (female) were all of specific pathogen-free (SPF) grade and obtained from the Animal Facility of Sun Yat-Sen University. The mice were housed under SPF standard conditions at the Animal Experimental Center of Sun Yat-sen University and free fed a standard sterile pellet diet and water.

The abdomens of immune-competent female C57BL/6J mice were shaved and sterilized using betadine and isopropanol. A 1.0 mm incision was made along the midline of the abdomen and the peritoneal lining was exposed using blunt dissection. The peritoneal wall was then grasped with forceps and a 1.0–2.0 mm incision was made along the linea alba. A volume of 300 μl of microparticles (GMP, LCSMP#1 or LCSMP#2) was then loaded into a sterile pipette and implanted into the peritoneal cavity through the incision. The incision was then closed using 8-0 taper tipped polydioxanone (PDS II) absorbable sutures. The skin was then closed using 5-0 taper tipped polydioxanone sutures. Prior to the surgical procedures, all mice were
anesthetized by an intraperitoneal injection of 3 % sodium pentobarbital solution (1.0-1.5 ml/kg; Merck, USA), along with 0.3 ml of 0.9% saline subcutaneously to prevent dehydration. After one week, mice were euthanized by excess intraperitoneal injection of 3 % sodium pentobarbital solution. In certain instances, 5 ml of ice cold PBS was first injected in order perform an intraperitoneal lavage to rinse out and collect free-floating intraperitoneal immune cells. An incision was then made using the forceps and scissors along the abdomen skin and peritoneal wall. Next, a wash bottle tip was inserted into the abdominal cavity. KREBS buffer was then used to wash out all material spheres from the abdomen and into petri dishes for collection. After ensuring all the spheres were washed out or manually retrieved (if fibrosed directly to intraperitoneal tissues), they were transferred into 96 wells for downstream processing and imaging.

Cell staining

The retrieved microparticles were fixed in 4% paraformaldehyde overnight, and then samples were washed twice with KREBS buffer (Solarbio), permeabilized for 0.5 h using a 0.1% Triton X-100 solution (Aladdin), and subsequently blocked for 1 hour using a 1% BSA solution (Shanghai yuanye Biotechnology). Next, the spheres were stained with 10 μg/ml Hoechst 33342 (blue fluorescence, Thermo Fisher Scientific). The microparticles were then carefully washed with fresh PBS for once and imaged with fluorescence microscopy.

S1. Supporting information for the test of small molecule & protein adhesion.

The ZnO nanospikes on particle surface possessed intrinsic weak fluorescence.
The intrinsic fluorescence of particles was used as the background fluorescence signal for quantitating the fluorescent intensities of particles in the experiments. An example of the intrinsic fluorescence of SMP was shown below.

Figure S1.1. Microscopic images are showing the background fluorescence of ZnO material on SMP surface. (a) Optical microscopy image of the SMPs. (b) Fluorescence microscopy image of the SMPs. The fluorescence was weak and almost invisible. (c) Fluorescence microscopy image of the SMPs with increased image brightness/contrast to make the fluorescence of SMPs visible. Scale bar: 50 μm.
Figure S1.2. Testing small molecule and protein (FITC and FITC-BSA) adhesion. Optical and fluorescence images are showing the adhesion of FITC (a) or FITC-BSA (b) and (c) fluorescent fibrinogen (all with green fluorescence) on different types of microparticles. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 100 μm.
Whether LCSMPS changed protein conformation or activity was evaluated. Glycose oxidase (GOD, Aladdin) was employed as representative protein for tests, which is an enzyme that could catalyze the decomposition of glucose. Since the change of protein conformation would easily affect the catalysis ability of the GOD, this allows facile detection of the occurring of protein conformation change. GOD in PBS solution (0.1mg/ml) were incubated with LCSMP (both LCSMP#1 and LCSMP#2) for 24 h. After incubation, the activity of GOD was evaluated by GOD activity detection kit (Solarbio). The results indicated that the GOD activity was not significantly altered (< 5%) compared to GOD without incubation with LCSMPs, suggesting the protein conformation of GOD was minimally changed by LCSMPs. In contrast, we employed GOD denatured via heating (90 °C, 0.5 h) as negative control. The results found that GOD activity was almost eliminated by heating.

Figure S1.3. Statistical analysis of glucose oxidase (GOD) relative activity. Error bar represents the mean ± SD. N=3.
S2. Supporting information for the test of bacteria adhesion.

**Figure S2.1.** Testing bacteria adhesion. Optical and fluorescence images are showing the adhesion of E. coli (a) or S. aureus (b) on different types of microparticles. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 100 μm.
Figure S2.2. Optical and fluorescence images are showing the viabilities of *E. coli.* (a) and *S. aureus* (b) (live bacteria stained with green fluorescence and dead bacteria stained with red fluorescence) incubated with media containing lubricants for 24 h. The optical microscopy image and fluorescence image were separately shown. Scale bar: 30 μm.

Figure S2.3. Statistical analysis of bacteria viability. Error bar represents the mean ± SD. N=4.
Figure S2.4. Optical and fluorescence images are showing the viabilities of *E. coli* (a) and *S. aureus* (b) (live bacteria stained with green fluorescence and dead bacteria stained with red fluorescence) incubated with media containing LCSMPs for 24 h. The optical microscopy image and fluorescence image were separately shown. Scale bar: 100 μm.

Figure S2.5. Statistical analysis of bacteria viability. Error bar represents the mean ± SD. N=4.
S3: Charcaterization of lubricant-coated spiky planar substrate (LCSPS)

Figure S3.1. Time-sequence images for a water or oil drop sliding down fluorinated spiky planar substrates or lubricant-coated spiky planar substrates.
**Figure S3.2.** Optical and fluorescence images are showing the attachments of bacteria including *E. coli*. (a) and *S. aureus* (b) (stained with green fluorescence) to different substrates. The sample substrate was indicated as the area “1”, and the bottom surface of the well was indicated as the area “2”, and the substrate boundary was highlighted with dashed line in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 30 μm.
Figure S3.3. Optical and fluorescence images are showing the attachments of cells (stained with green fluorescence) to different substrates. The images were either focused on the substrate top surface or on the well bottom surface. The sample substrate was indicated as the area “1”, and the bottom surface of the well was indicated as the area “2”, and the substrate boundary was highlighted with dashed line in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 30 μm.
S4. Supporting information for the test of cell adhesion.

**Figure S4.1.** Testing cell adhesion. (a) Optical and fluorescence images are showing the adhesions of HeLa (nucleus stained with blue fluorescence) on different types of microparticles. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 100 μm.

**Figure S4.2.** Optical and fluorescence images are showing the viabilities and spreading profile of HeLa (live cells stained with green fluorescence and dead cells stained with red fluorescence) incubated with media containing lubricants or oil for 24 h. The optical microscopy image and fluorescence image were separately shown. Scale bar: 30 μm.
Figure S4.3. Statistical analysis of cell viability. Error bar represents the mean ± SD. N=4.

Figure S4.4. Optical and fluorescence images showing the viabilities and spreading profile of HeLa (live cells stained with green fluorescence and dead cells stained with red fluorescence) incubated with media containing LCSMPs for 24 h. The optical microscopy image and fluorescence image were separately shown. Scale bar: 100 μm.

Figure S4.5. Statistical analysis of cell viability. Error bar represents the mean ± SD. N=4.
S5. Supporting information for assessment of long-term biofouling-resistance.

**Figure S5.1.** Testing protein and cell adhesion after 14-days incubations. (a) Optical and fluorescence images are showing the long-term adhesion of FITC-BSA (a) or S. cell (b) on different types of microparticles. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 100 μm.
**Figure S5.2.** Testing bacteria adhesion after 14-days incubations. (a) Optical and fluorescence images are showing the long-term adhesion of *E. coli* (a) or *S. aureus* (b) on different types of microparticles. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image and merged image were separately shown. Scale bar: 100 μm.
S6. Supporting information for assessment of long-term biofouling-resistance. (in flow environment)

Figure S6.1. (a) and (b) Optical, fluorescence images and statistical analysis showing the adhesions of FITC-BSA on different types of microparticles, respectively. The particle boundary was outlined with white dash lines in the merged images. The optical microscopy image, fluorescence image were separately shown. (c) and (d) Optical, fluorescence images and statistical analysis showing the adhesions of HeLa (nucleus stained with blue fluorescence) on different types of microparticles, respectively. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image were separately shown. Scale bar: 100 μm.
Figure S6. (a) and (b) Optical, fluorescence images and statistical analysis showing the adhesions of *E. coli* or *S. aureus* (both stained with green fluorescence) on different types of microparticles, respectively. The particle boundary was outlined with white dashed lines in the merged images. The optical microscopy image, fluorescence image were separately shown.

S7. Supporting information for the mechanism of LCSMP dispersion and whether the air layer exists between particles and water

S7.1 The mechanism of LCSMP dispersion

According to simulation model established in *Nature* 2015, 517, 596-599., we employed Derjaguin–Landau–Verwey–Overbeek (E_DLVO) theory to explain the anomalous dispersity of SMP-F and LCSMPs. The total interaction potential ($V_{E\_DLVO}$) between the SMP-F was calculated to be: $V_{E\_DLVO} = V_{vdW} + V_{DL} + V_{HB}$, where $V_{vdW}$, $V_{DL}$ and $V_{HB}$ are represent van der Waals, electrical double layer and hydrophobic interactions, respectively. Compared with fluorinated glass microparticles (GMP-F), the fluorinated spiky microparticles (SMP-F) dispersed in water without forming
aggregations. It is mainly attributed to that the $V_{\text{vdW}}$ and $V_{\text{HB}}$ are greatly decreased for spiky particles compared with the smooth spheres. The contact area between different spiky particles is drastically reduced due to the presence of nanospikes.

The total interaction potential ($V_{\text{E DLVO}}$) between the LCSMPs was calculated to be: $V_{\text{E DLVO}} = V_{\text{vdW}} + V_{\text{DL}} + V_{\text{LL}}$, where $V_{\text{vdW}}$, $V_{\text{DL}}$ and $V_{\text{LL}}$ are represent van der Waals, electrical double layer and lubricant-lubricant interactions, respectively. Similarly, for the Lubricant-coated spiky microparticles (LCSMP), the $V_{\text{vdW}}$ and $V_{\text{LL}}$ are greatly decreased. This is also contributed to the drastic reduction in the contact area for different LCSMPs due to the presence of nanospikes. The reduction of attractive interactions between the particles allows the LCSMPs to be dispersed in water without aggregation.

**S7.2 Whether the air layer exists between particles and water**

According to *Nature* 2015, 517, 596-599., the wetting of corrugated surfaces is often attributed to a Cassie–Baxter wetting model. The air shell is present only when hydrophobic hedgehog particles are in the water-based medium. This is due to water has a large contact angle with the superhydrophobic surface. In contrast, hydrophilic hedgehog particles in organic solvent have no air shells. This is because organic solvent could still easily wet the hydrophilic surface with a small contact angle. Therefore, the existence of air shell is more dependent on whether the contact angle between the medium and the material surface, rather than relating to the existence of nanospikes. If the medium has a large contact angle with the material surface, then the air shell would exist; and if the contact angle is small, the air shell would not exist.

In our case, the lubricants could completely wet (*Figure S7*) the fluorinated surface of the SMP-F with ultra-low contact angle ($<10^\circ$). Water could also completely wet the lubricant surface with very small contact angle ($<10^\circ$). Therefore, no air shell would exist after the particles were coated with lubricant either on the nanopike-lubricant interface of the lubricant-water interface.
Figure S7 (Please also see figure 2b in the manuscript) Lubricant#1(a) or lubricant#2 (b) drops on fluorinated spiky microparticles films.

In addition, According to Nature 2015, 517, 596-599, the anomalous dispersity of hedgehog particles is mainly attributed to the reduction of the van der Waals and hydrophobic-hydrophobic interactions. The presence of the double electric layer at the air–water interface leaded to the increase of electrostatic repulsion. However, the increase of electrostatic repulsion by air shells only plays a secondary role on the anomalous dispersity. Therefore, in our lubricant case, air shell does not contribute to the anomalous dispersity or anti-biofouling properties of the LCSMPs.

S8. Supporting information for the mechanism of anti-biofouling of LCSMP.

Protein absorption onto substrate surface have been known to occur dependent on the following four types of interactions: 1) ionic or electrostatic interaction, 2) hydrogen bonding, 3) hydrophobic interaction (largely entropically driven), and 4) interactions of charge-transfer or particle electron donor/acceptor type. For a lubricant surface which is omniphobic and in liquid mobile state, it tends to have little ionic/electrostatic, hydrogen bonding, and donor/acceptor interactions with proteins. In addition, since it could repel most of the oil-like and hydrophobic solvent and molecules, it would have little hydrophobic interaction with protein molecule as well. Therefore, protein molecule could not adhere to the lubricant surface, and could be easily sheared away by dynamic flow, or even diffuse into medium under under a static condition.

Mammalian cells adhesion onto substrate surface is mediated by integrin, a type of protein ligand embedded on cell membrane. The binding of integrin on substrate initiates the contact of cells with substrate, mediates the reassembly of actin network
of cells and facilitates the formation of focal adhesions. Since the lubricant surface could effectively repel protein adhesion, it is unfavorable for cell attachment on its surface and hence effectively prevent the adhesion of mammalian cells. In addition, as shown in Fig 5c and Fig S4.2~S4.5, the mammalian cells could maintain high viability with the presence of lubricant and LCSMPs. This suggested the anti-adhesion mechanism of lubricant surface is mainly through the prevention of cell attachment, rather than through the mechanism by killing the cells.

The adhesion of bacteria on substrate surface is largely relying on adhesin present on bacterial surface, which is mainly consisting of proteins and polysaccharide molecules. The adhesins initiate the contact of bacterial with substrate and facilitate the adhesion of bacteria and eventually the formation of biofilms. Similarly, the lubricant surface could effectively repel the attachment of adhesins since it does not allow robust adhesive interactions with the protein or polysaccharide molecules of adhesins. Therefore, the lubricant surface could effectively prevent the attachment of bacteria. In addition, as shown in Figure 4c and Figure S2.2 ~ S2.5, the cultured bacteria could maintain high viability with the presence of lubricant and LCSMPs. This suggested the anti-adhesion mechanism of lubricant surface is mainly through the prevention of bacteria attachment, rather than through the mechanism by killing the bacteria.

Reference:
1. Vegas, A. J.; Veiseh, O.; Doloff, J. C.; Ma, M.; Tam, H. H.; Bratlie, K.; Li, J.; Bader, A. R.; Langan, E.; Olejnik, K. Combinatorial hydrogel library enables identification of materials that mitigate the foreign body response in primates. Nat. Biotechnol. 2016, 34 (3), 345-352.
2. Veiseh, O.; Doloff, J. C.; Ma, M.; Vegas, A. J.; Tam, H. H.; Bader, A. R.; Li, J.; Langan, E.; Wyckoff, J.; Loo, W. S. Size-and shape-dependent foreign body immune response to materials implanted in rodents and non-human primates. Nat. Mater. 2015, 14 (6), 643-652.
3. Norde, W. Adsorption of proteins from solution at the solid-liquid interface.
Adv. Colloid Interface Sci. 1986, 25, 267-340.

4. Mermut, O.; Phillips, D. C.; York, R. L.; McCrea, K. R.; Ward, R. S.; Somorjai, G. A. In situ adsorption studies of a 14-amino acid leucine-lysine peptide onto hydrophobic polystyrene and hydrophilic silica surfaces using quartz crystal microbalance, atomic force microscopy, and sum frequency generation vibrational spectroscopy. J. Am. Chem. Soc. 2006, 128 (11), 3598-3607.

5. Li, Q.; Lau, K. A.; Sinner, E.-K.; Kim, D. H.; Knoll, W. The effect of fluid flow on selective protein adsorption on polystyrene-block-Poly (methyl methacrylate) copolymers. Langmuir 2009, 25 (20), 12144-12150.

6. Penna, M. J.; Mijajlovic, M.; Biggs, M. J. Molecular-level understanding of protein adsorption at the interface between water and a strongly interacting uncharged solid surface. J. Am. Chem. Soc. 2014, 136 (14), 5323-5331.