

## Supplementary Information

### Influence of Particle Size, Shape, and Magnetic Properties on Torque-Driven Biofilm Removal by Magnetic Particles

Vincent Pautu<sup>a</sup>, Laurine Marger<sup>b</sup>, Maja Caf<sup>c,d</sup>, Fabrice Marger<sup>a,b</sup>, Mustapha Mekki<sup>b</sup>, Slavko Kralj<sup>c,d,\*</sup> and Irena Milošević<sup>a\*</sup>

<sup>a</sup>School of Engineering, Architecture and Landscape of Geneva (HEPIA), HES-SO - University of Applied Sciences and Arts Western Switzerland.

<sup>b</sup>University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland

<sup>c</sup>Department for Materials Synthesis, Jožef Stefan Institute, Jamova 39, Ljubljana, Slovenia

<sup>d</sup>Faculty of Pharmacy, University of Ljubljana, Aškerčeva 7, Ljubljana, Slovenia.

\*[irena.milosevic@hesge.ch](mailto:irena.milosevic@hesge.ch) and [slavko.kralj@ijs.si](mailto:slavko.kralj@ijs.si)

#### Characterization of titanium plates

Profilometry revealed a homogeneous, finely rolled surface texture across all Ti Grade 4 plates. The measured roughness parameters were  $R_a = 0.824 \pm 0.030 \mu\text{m}$ ,  $R_q = 1.074 \pm 0.046 \mu\text{m}$ ,  $R_c = 4.462 \pm 0.320 \mu\text{m}$ , and  $R_z = 8.148 \pm 1.130 \mu\text{m}$  ( $n = 9$ ). Shapiro–Wilk tests supported normality for  $R_a$  ( $p = 0.832$ ),  $R_q$  ( $p = 0.147$ ), and  $R_z$  ( $p = 0.366$ ), while  $R_c$  deviated from normality ( $p = 0.011$ ), consistent with isolated micro-peaks inherent to the rolling process. Overall, these data indicate a stable and isotropic surface topography suitable for reproducible biofilm growth and magneto-mechanical experiments.

**Supplementary Table S1:** Surface roughness parameters of cold-rolled titanium Grade 4 plates measured by confocal laser profilometry. Values are reported as mean  $\pm$  standard deviation.

Roughness parameter	Value
$R_a$ ( $\mu\text{m}$ )	$0.824 \pm 0.030$
$R_q$ ( $\mu\text{m}$ )	$1.074 \pm 0.046$
$R_c$ ( $\mu\text{m}$ )	$4.462 \pm 0.320$
$R_z$ ( $\mu\text{m}$ )	$8.148 \pm 1.130$
Number of measurements	$n = 9$

Measurements were performed at five positions per plate using a non-contact confocal laser profilometer. Roughness parameters were calculated according to ISO 4287 and ISO 16610-21.

#### Static water contact angle and normality assessment

Static water contact angle measurements were performed on cold-rolled titanium Grade 4 plates to characterize surface wettability. For each plate, three independent droplets were deposited at distinct locations, and contact angles were measured 10 s after deposition using Young–Laplace fitting. Across the five titanium plates, a total of 15 individual contact angle values were obtained.

The overall static contact angle was  $79.8 \pm 0.8^\circ$  (mean  $\pm$  standard deviation,  $n = 5$  plates), indicating moderate hydrophilicity consistent with native  $\text{TiO}_2$  passivation. Normality of the individual contact angle measurements ( $n = 15$  droplets) was assessed using the Shapiro–Wilk test. The distribution did not significantly deviate from normality ( $W = 0.958$ ,  $p = 0.659$ ), supporting the use of parametric descriptive statistics.

Together with the controlled surface roughness, these wettability characteristics define a stable and reproducible surface baseline suitable for subsequent biofilm formation and magneto-mechanical actuation experiments.

**Supplementary Table S2:** Static water contact angle measurements and normality assessment

Ti plate	Droplet 1 (°)	Droplet 2 (°)	Droplet 3 (°)	Mean ± SD per plate (°)
1	80.30	79.10	79.20	79.53 ± 0.67
2	79.10	79.90	80.80	79.93 ± 0.85
3	80.90	80.30	79.00	80.07 ± 0.97
4	81.20	80.30	79.70	80.40 ± 0.75
5	79.20	78.30	80.10	79.20 ± 0.90
<b>Overall (plates)</b>	—	—	—	<b>79.8 ± 0.8 (n = 5)</b>
<b>Normality test (individual droplets, n = 15):</b> Shapiro–Wilk W = 0.958, p = 0.659				

Contact angles were measured 10 s after droplet deposition using Young–Laplace fitting. Normality testing was performed on individual droplet values (n = 15), while plate-averaged values (n = 5) were used for descriptive reporting.

### Magnetic field characterization

The rotating magnetic field generated by the 2mag MIXdrive device was characterized using an axial Hall probe positioned at the bottom center of each well of a 24-well plate. Measurements were performed across all 24 wells for different combinations of rotation speed and power settings in order to document field scaling and plate-level homogeneity.

Across all tested conditions, the magnetic field increased consistently with both rotation speed and power setting. Average magnetic field values and their standard deviations across the 24-well plate are summarized in Supplementary Table S4.

For all conditions, the variation between the lowest and highest field values across the plate remained within approximately 1 to 3 mT, indicating a reasonably homogeneous magnetic field distribution at the scale of the 24-well plate.

All biofilm detachment experiments were performed at 100 % power and 2000 rpm. Under these conditions, the magnetic field at the level of the titanium discs exhibited an average value of  $8.60 \pm 0.94$  mT across the plate. The corresponding well-by-well magnetic field values are reported in Supplementary Table S3.

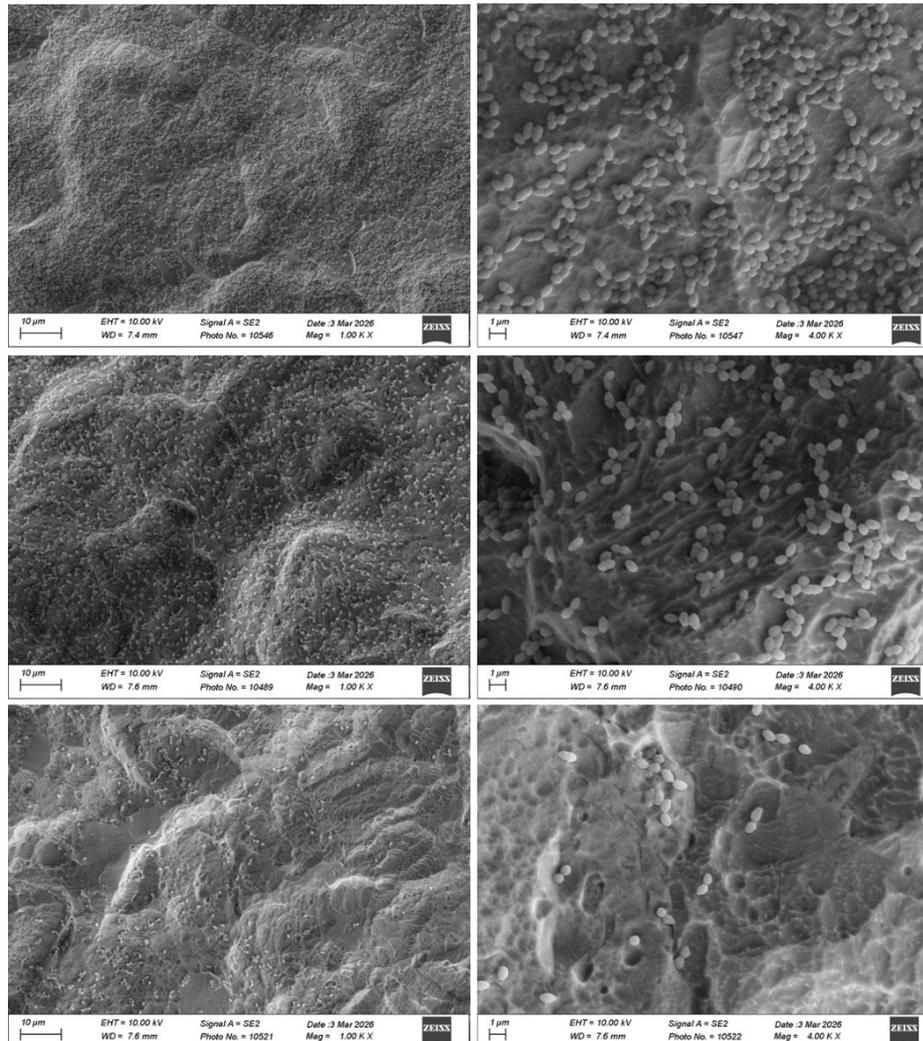
**Supplementary Table S3:** Magnetic field values (mT) measured in each well of a 24-well plate at 100 % power and 2000 rpm using the 2mag MIXdrive device. Measurements were performed at the bottom center of each well using an axial Hall probe.

Field (mT)	1	2	3	4	5	6
<b>A</b>	9.54	8.64	8.80	9.25	7.70	7.20
<b>B</b>	9.49	9.56	10.87	8.87	9.01	7.13
<b>C</b>	9.49	9.86	9.61	7.96	8.20	7.53
<b>D</b>	8.39	7.92	8.32	7.80	7.26	8.04
<b>E</b>						

**Supplementary Table S4:** Average magnetic field values across the 24-well plate as a function of power setting and rotation speed. Values are reported as mean  $\pm$  standard deviation across all 24 wells.

Power (%)	Rotation speed (rpm)	Magnetic field (mT)
50	100	0.63 $\pm$ 0.04
50	600	2.61 $\pm$ 0.21
50	2000	4.02 $\pm$ 0.33
100	100	1.54 $\pm$ 0.15
100	600	5.91 $\pm$ 0.50
100	2000	8.60 $\pm$ 0.94

Standard deviations were calculated across the 24 individual well measurements for each condition.



**Supplementary Figure S1.** SEM images of 24 h *E. faecalis* biofilms grown on titanium discs under control conditions (top row), after treatment with 0.1% chlorhexidine (CHX) for 30 s (middle row), and after 9 min CHX exposure (bottom row). The left column shows images acquired at  $\times 1000$  magnification, while the right column presents the corresponding higher magnification views ( $\times 4000$ ). A progressive reduction in bacterial surface coverage is observed with increasing CHX exposure time, although residual bacterial structures remain visible on the titanium surface.