Supplementary Materials for

Wirelessly controlled, bioresorbable drug delivery device with active valves that exploit electrochemically triggered crevice corrosion


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("Photo Credit: Jahyun Koo, Korea University ")
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**Fig. S20** *In vivo* biocompatibility studies of bioresorbable Mo-gate. (a) Hematoxylin and eosin (H&E) and (b) T-blue images of stained tissue sections at 5 weeks post-implantation of triggered Mo-gate with a dummy reservoir; a piece of PBTPA. The middle and right images show muscle fascia and muscle layers adjacent to the device, respectively. ("Photo Credit: Matthew MacEwan, Washington University in St. Louis")
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Fig. S22 White Blood Cell (WBC) Count at 5 weeks post-implantation for Mg and Mo device groups (n = 3 per groups).
Supplementary Note 1. Optimization of RF coil design.

In order to optimize the electromagnetic performance of the wireless RF coil, the finite element analysis (FEA) is used to determine the scattering parameters S11, inductance L, and the Q factor of the RF coil (diameter 16 mm) matching with 25 pF capacitor. The simulations (Ansys HFSS 13 User’s guide, Ansys Inc. 2011) use a lumped port to define the S11 and the port impedance (Z). An adaptive mesh (tetrahedron elements) ensures computational accuracy, to yield \( L = \frac{Z_{im}}{2\pi f} \) and \( Q = \frac{|Z_{im}|}{Z_{Re}} \), where \( Z_{Re}, Z_{im} \) and \( f \) represent the real and imaginary parts of the Z and the frequency, respectively.

The resonance frequency of the RF coil is designed to \( \sim 5 \) MHz, which gives magnetic coupling with small parasitic absorption by biological tissues\(^{14}\). A relatively high Q factor \( \sim 15 \) ensures a high induced voltage to achieve a long operating distance\(^{14}\). The optimized harvesting unit generates bias between Mg gate and counter electrode upon activation of an RF transmission coil (80 mm diameter, 3 turns) in proximity\(^{14}\).

To calculate the interference between multiple coils, the three coils use matching capacitors of 19, 23 and 85 pF, respectively, to achieve operating frequencies of 5.14, 9.92 and 14.78 MHz. The values of \( Q \) for these coils are 9, 15 and 15 with corresponding bandwidths of 0.6, 0.7 and 0.9 MHz respectively (fig. S15). The different resonance frequencies, taken together with the physical separation of the coils, minimize mutual interference. In fact, the electromagnetic characteristics (e.g., Q and S11) of the co-integrated harvesters are similar to those of isolated harvesters, consistent with negligible interference effects. The operating frequency of each harvester is
different from the corresponding self-resonance frequency, namely 18, 20 and 28 MHz for 16-, 13- and 8-turn coils, respectively, to ensure the operation stability.

**Supplementary Note 2. Arrhenius scaling of degradation lifetime.**

According to Arrhenius equation,

\[ k_{\text{PBTPA}} = k_0 \times \exp(-E_A/RT) \quad (\text{eq. S1}) \]

where \( k_0 \) is the pre-exponential factor, \( E_A \) is the activation energy, \( R \) is the universal gas constant (=8.314 J·K\(^{-1}\)·mol\(^{-1}\)), and \( T \) is the absolute temperature\(^{18}\), measured degradation rates of the PBTPA (1:1:2.5) at different temperatures (0.5, 0.69, 6.69 and 16.285 mg/day at 23, 37, 60 and 85°C, respectively), yield values of \( k_0 \) and \( E_A \) as 6.9×10\(^{18}\) and 51500 J·mol\(^{-1}\), respectively (Fig. 1). Thus, we can estimate the degradation lifetime of the entire system, which is composed of PBTPA (1:1:2.5) reservoir, is \( \sim \)660 days at body temperature (37°C).

![Arrhenius plot: ln(k) versus 1/T.](image)

**Supplementary Note 3. Electrochemical kinetics of corrosion.**

Electrochemical kinetics relies on Faraday’s law and the Faraday equation is below;
\[ m_{\text{Mg}} = \frac{M_{\text{Mg}} \cdot I}{n \cdot F} \cdot t \]  \hspace{1cm} (eq. S2)

From Supplementary Eq. 2, the total current can be expressed given by;

\[ I = \frac{nF}{M_{\text{Mg}}t} \cdot m_{\text{Mg}} \]  \hspace{1cm} (eq. S3)

where \( m_{\text{Mg}} \) is the mass of the reacted Mg, \( M_{\text{Mg}} \) is the atomic weight of Mg, \( I \) is corrosion current passed, \( t \) is degradation time, \( n \) is number of electrons transferred, and \( F \) is Faraday constant (96,485 coulombs/mole).

Corrosion rate based on Mg weight change relies on an equation given by;

\[ \text{Corrosion rate} = \frac{\Delta m_{\text{Mg}}}{\Delta t} = \frac{M_{\text{Mg}}}{nF} \cdot I \]  \hspace{1cm} (eq. S4)

Total current can be sum of passive anodic dissolution current and crevice corrosion current as following;

\[ I = I_{uc} + I_{cc} \]  \hspace{1cm} (eq. S5)

\[ I = jA = j_{uc}A_{uc} + j_{cc}A_{cc} \]  \hspace{1cm} (eq. S6)

and \( A = A_{uc} + A_{cc} \) \hspace{1cm} (eq. S7)

where \( j \) is total current density applied on the gate surface, \( j_{uc} \) is uniform electrochemical etching current density on the exposed surface of the metal gate, \( j_{cc} \) is crevice corrosion current density along with the edge, and \( A \) is anodic area. The amount of degraded Mg is in equilibrium with eq. S5 as follows;

\[ m_{\text{Mg}} = m_{\text{Mguc}} + m_{\text{Mgcc}} \]  \hspace{1cm} (eq. S8)

\[ I = \frac{nF}{M_{\text{Mg}}t} \left( m_{\text{Mguc}} + m_{\text{Mgcc}} \right) \]  \hspace{1cm} (eq. S9)
Furthermore, eq. S3 can be modified to yield an expression for current to explain the relation of current and time as follows;

\[ I = \frac{m_{\text{Mg}} nF}{M_{\text{Mg}} t} = k \frac{1}{t} \]  

(eq. S10)

On the other hand, the current resulting from corrosion can be expressed as Tafel equation as follows;

\[ I = I_0 e^{\frac{2.303 (E-E_0)}{\beta}} \]  

(eq. S11)

where, \( E \) is the electrode potential, \( E_0 \) is the equilibrium potential, and \( \beta \) is the Tafel constant. The Tafel equation for anodic and cathodic reactions in a corrosion system can be combined to generate the Butler-Volmer equation as follows;

\[ I = I_{\text{corr}} \left( e^{\frac{2.303 (E-E_{\text{corr}})}{\beta_a}} - e^{\frac{2.303 (E-E_{\text{corr}})}{\beta_c}} \right) \]  

(eq. S12)

where, \( E \) is the electrode potential, \( E_{\text{corr}} \) is the corrosion potential, \( \beta_a \) is the anodic Tafel constant, and \( \beta_c \) is the cathodic Tafel constant. Equation S12 can be simplified as follows;

\[ I_{\text{corr}} = \frac{1}{R_p} \frac{\beta_a \beta_c}{2.303 (\beta_a + \beta_c)} \]  

(eq. S13)

and \[ R_p = \frac{1}{I_{\text{corr}}} \frac{\beta_a \beta_c}{2.303 (\beta_a + \beta_c)} \]  

(eq. S14)

where, \( R_p \) is polarization resistance. The corrosion rate can be summarized with corrosion current and parameters from Faraday’s law (eq. S3) as follows;

\[ \text{Corrosion rate} = \frac{I_{\text{corr}} K W S}{dA} \]  

(eq. S15)

\[ (m_{\text{Mg}} = \frac{W_0 F}{F}, Q = nFM_{\text{Mg}}, \text{and}) \]
where, $K$ is corrosion rate constant, $W_E$ is equivalent weight, $d$ is density of metal gate, and $Q$ is the charge.

The corrosion rates at the edges and vertex regions are $\sim$10 times higher than that at the central surface regions, i.e. $\sim5.6\times10^{-8}$ mg·mm$^2$·s$^{-1}$ and $\sim4.1\times10^{-9}$ mg·mm$^2$·s$^{-1}$ respectively. These rates follow from estimates of the areas for uniform ($\sim280$ mm$^2$) and crevice ($\sim26$ mm$^2$) corrosion determined from the OM image (1 V for 200 s) and from the etched Mo volume determined with the 3D topology data (fig. S8a).