Photo-Induced Surface Charge Activates L-Type Calcium Channels in Neutrophils to Regulate the Osteogenic Microenvironment on Titanium Implants

Chuan Yin[1]*, Zehao Jing[2], Teng Zhang[3], Yongqiang Hao[1]†

Affiliations:

[1] Department of Orthopaedic Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China

[2] Department of Orthopaedic Surgery, Peking University Third Hospital, Beijing, China

[3] Department of Orthopaedic Surgery, Qilu Hospital of Shandong University, Jinan, China

* Corresponding Author:
Dr. Chuan Yin
Email: yinchuan123@pku.org.cn

† Co-corresponding Author:
Prof. Yongqiang Hao
Email: hao_yongqiang@hotmail.com

Abstract

Introduction: Ultraviolet photofunctionalization (UVP) of titanium implants enhances osseointegration, but the underlying immunoregulatory mechanism remains unclear. We hypothesized that photo-induced surface charge activates voltage-gated calcium channels in neutrophils, initiating an electro-immunological pathway for osteogenesis.

Methods: Three-dimensional printed porous Ti6Al4V implants were irradiated with UV light to generate positively charged surfaces characterized by Kelvin probe force microscopy. Primary human neutrophils were cultured on the modified surfaces.

Intracellular Ca^{2+} influx was quantified using Fluo-4 imaging. Nifedipine was used to

block L-type calcium channels (Cav1.2). Conditioned media from neutrophils were applied to mesenchymal stem cells (MSCs) to assess osteogenic differentiation by ALP and RUNX2 expression.

Results: UVP significantly increased surface potential and Ca^{2+} influx in neutrophils,

which was abolished by nifedipine, confirming Cav1.2 activation. Conditioned media from UVP-activated neutrophils enhanced MSC osteogenesis, increasing ALP activity and RUNX2 expression.

Discussion: These results demonstrate that UV-induced surface charge triggers L-type calcium channel activation in neutrophils, bridging photoelectrical surface

modification with immune-mediated bone regeneration.
Significance/Clinical Relevance: Identifying Cav1.2 as a key transducer linking photofunctionalized surfaces and osteoimmune regulation provides a mechanistic basis for designing next-generation immunoactive titanium implants with enhanced clinical osseointegration.

Figures (3 total)

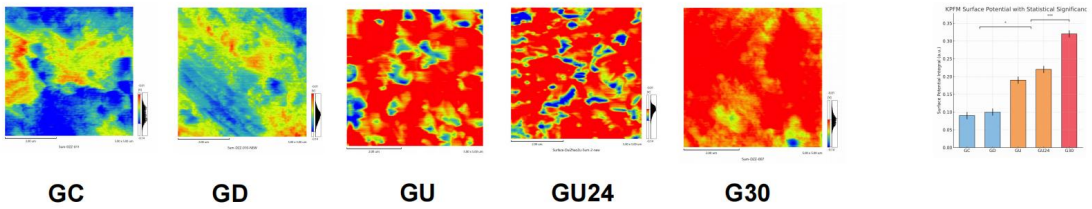

Figure 1. UV photofunctionalization generates a stable positive surface charge on 3D-printed Ti6Al4V implants. Kelvin probe force microscopy (KPFM) shows progressive surface potential increase after UV treatment (GC, GD, GU, GU24, G30).

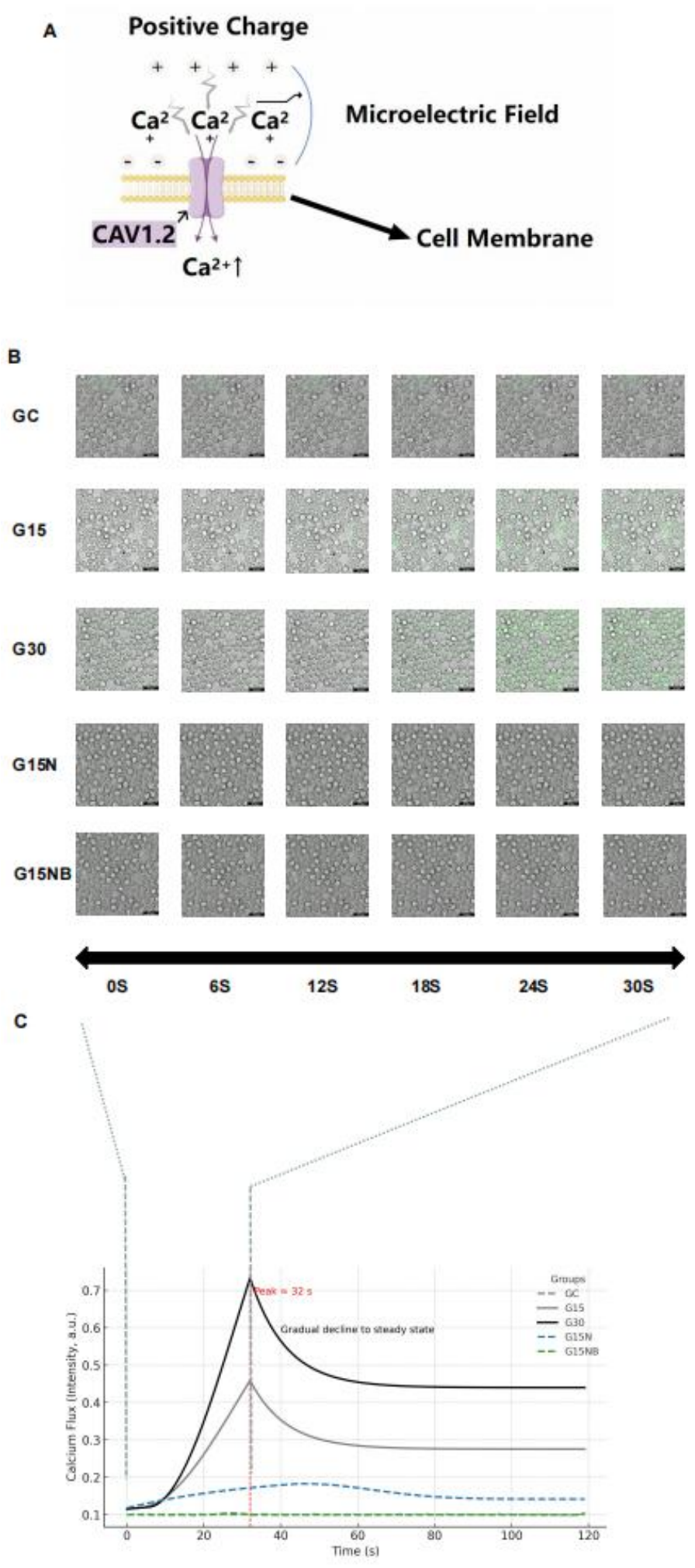

Figure 2. UV-induced surface charge promotes calcium influx in neutrophils through

activation of L-type calcium channels. Time-lapse fluorescence (Fluo-4) reveals Ca^{2+} influx peaks at 32 s in UV-treated group; inhibited by nifedipine.

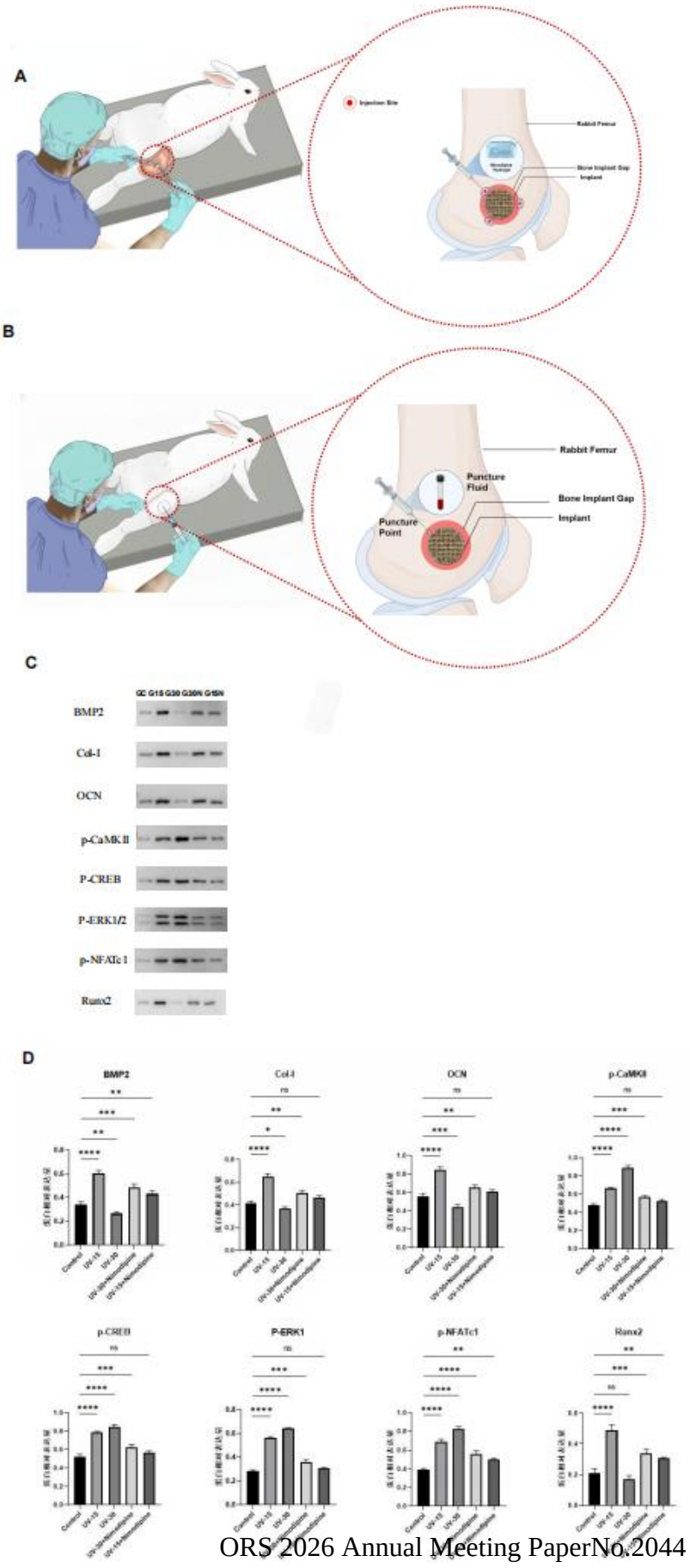

Figure 3. In vivo validation of photo-induced surface charge–mediated osteogenesis. Western blot and quantification show BMP2, Col-I, OCN, and Ca^{2+}-dependent signaling (p-CaMKII, p-CREB, p-ERK1/2, p-NFATc1, Runx2) upregulated in UV group, suppressed by nifedipine.