

Effect of Varying Dental Implant Coronal Surface Roughness on the Osteogenic Cell Growth in Vitro

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Background

- Surface texturing of dental implants has emerged as a pivotal factor in improving osseointegration and ensuring long-term implant stability.¹
- Nevertheless, it is crucial to maintain a balance as excessive texturing may inadvertently create an environment conducive to bacterial colonization. Prior research demonstrated a critical surface roughness ($Sa \sim 1\mu m$) threshold, equal to or below which bacterial adhesion is not favored over the machined surface.²

Aim

- In this study, we aim to investigate whether the reported $1\mu m$ Sa threshold is equally optimal for promoting osteogenic cell growth by comparing the adhesion and proliferation of human bone marrow-derived mesenchymal stem cells (hBMSCs) to commercial implant coronal surfaces with different morphology and roughness in vitro.

1. Stavropoulos, A., Deproteinized Bovine Bone Xenograft, in Musculoskeletal Tissue Regeneration: Biological Materials and Methods, W.S. Pietrzak, Editor. 2008, Humana Press: Totowa, NJ. p. 119-151. Petrini M, Giuliani A, Di Campli E, Di Lodovico S, Iezzi G, Piattelli A, D'Ercole S. The Bacterial Anti-Adhesive Activity of Double-Etched Titanium (DAE) as a Dental Implant Surface. Int J Mol Sci. 2020 Nov 5;21(21):8315.

2. X. Wang, O. Sanchez, E. Ajami, and HB. Wen. Effect of Varying Surface Properties of Dental Implants on Pathogenic Bacterial Adhesion. Academy of Osseointegration. Phoenix, 2023.

Materials & Methods

12 groups of implants with different surface textures and compositions were tested.

Implant Manufacturer	Implant Size (mm)	Surface Technology on Implant Collar	Method Surface Created	Implant Material	Implant surface #
ZimVie®	4.0 x 13	Machined	Machining	Ti CP4	A
ZimVie	4.0 x 13	Machined	Machining	Ti Alloy	B
Nobel Biocare™	4.0 x 13	TiUltra	Machining	Ti CP4	C
ZimVie	4.0 x 13	Osseotite	Dual acid etching	Ti CP4	D
ZimVie	4.0 x 13	Osseotite	Dual acid etching	Ti Alloy	E
ZimVie	4.0 x 13	MTX	Grit blasting	Ti Alloy	F
Implant Direct®	4.2 x 13	SBM	Grit blasting	Ti Alloy	G
Dentsply Sirona® Astra Tech	4.2 x 13	OsseoSpeed	Grit blasted (TiO blasted) Fluoride-modified	Ti CP4	H
Nobel Biocare	4.3 x 13	TiUnite	Anodization	Ti CP4	I
MiS	4.2 x 13	C1	Sandblasted and acid etched	Ti Alloy	J
Straumann®	4.1 x 12	SLA	Large-grit sandblasted and acid-etched	Roxolid (Zr Ti alloy)	K
BioHorizons®	4.2 x 12	Laser-Lok	Laser machined	Ti Alloy	L

Characterization Methods

- Surface roughness:** The coronal surfaces of the implants were mapped with a Keyence® microscope (VK-X1050) on 4 areas (144 µm x 108 µm) per implant collar. The arithmetical mean height (Sa) of each area was assessed with a MultiFile Analyzer (Keyence).
- Adherent cell measurement:** 5x10⁴ hBMSCs were cultured on the implant coronal surfaces, and their growth was quantified with a cell counting kit (Dojindo® Molecular Technologies) at 1, 3, and 7 days (n=3).
- **Cell differentiation:** 2.5x10⁴ hBMSCs were cultured on the implant coronal surfaces in a non-osteogenic medium. The ALP activity of total adherent cells on the surfaces was measured by ALP Assay Kit (Abcam) at 7 and 14 days. Total protein was detected with Pierce™ Rapid Gold BCA Protein Assay Kit (Thermo Scientific) to normalize the corresponding ALP activity.

Statistical analysis

One-way ANOVA with Dunnett’s multiple comparison tests was performed to determine statistical differences between the groups (GraphPad Prism 8). The p<0.05 was considered significant.

Results

hBMSCs growth and correlation with surface roughness

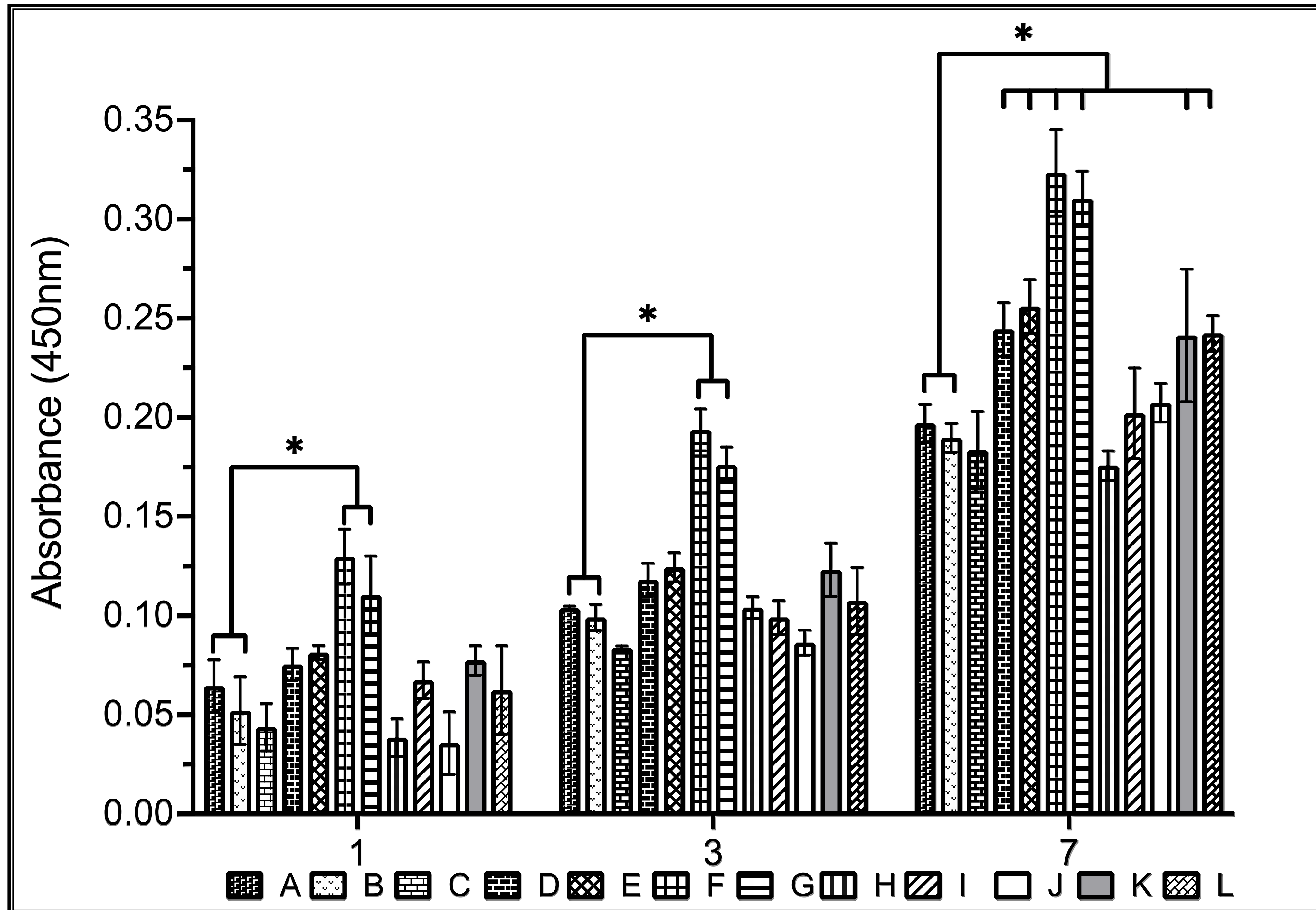


Figure. 1: hBMSCs growth at 1, 3, and 7 days on different implant collar surfaces.

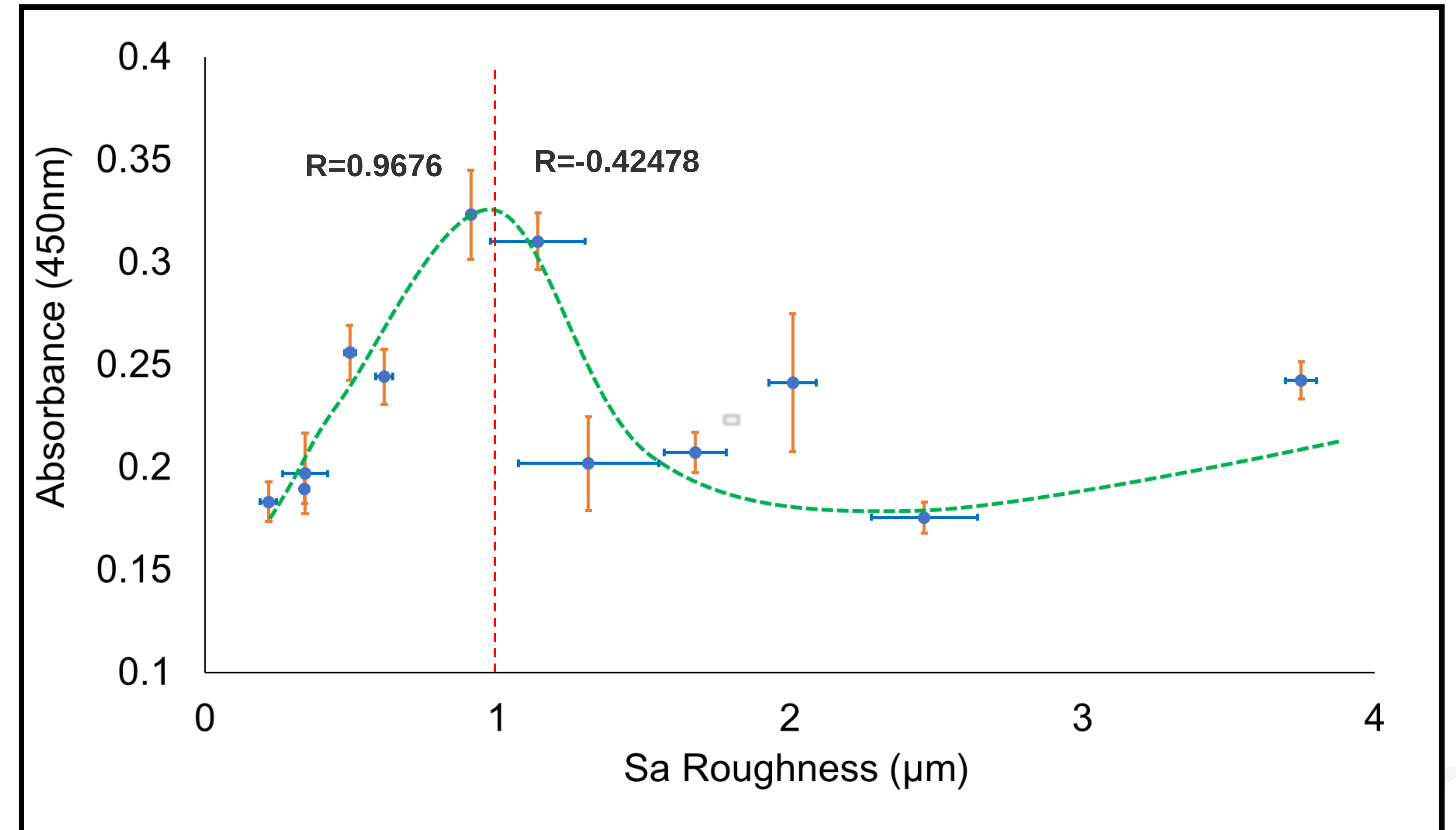


Figure 2: The plot of cell growth and implant collar surface roughness Sa at 7 days. R on the left is the correlation coefficient when Sa roughness is ≤ 1 , and R on the right is when Sa roughness is > 1 .

- All the tested coronal surfaces supported the growth of hBMSCs with a significant increase in cell number over time (Fig.1).
- All the textured surfaces performed similarly to machined surfaces except for F and G (Sa~1μm) at 1 and 3 days, demonstrating significantly increased cell growth.
- Cell growth was significantly increased on all the textured surfaces except for H, I, and J at 7 days.
- At 7 days, a strong positive correlation ($R=0.97$) was seen between cell proliferation and Sa roughness values, confirming increased cell growth with increasing Sa to ~1μm. However, increasing Sa to $>1\mu\text{m}$ was negatively correlated with cell growth ($R=-0.42$) (Fig.2).

Results

hBMSCs differentiation (ALP activity) and correlation with surface roughness

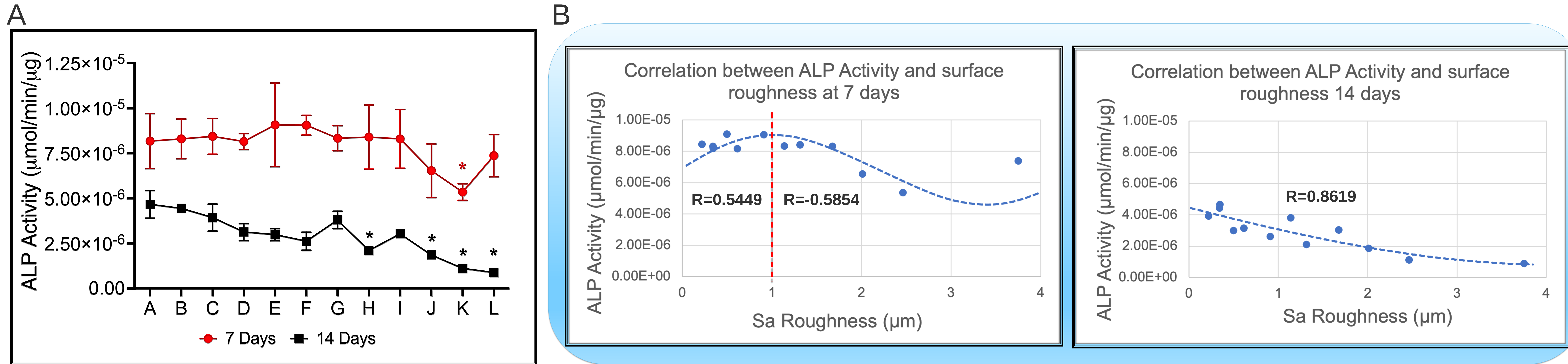


Figure 3: (A) ALP activity of hBMSCs in response to different surfaces at 7 and 14 days. (B) Correlation between ALP activity and surface roughness at 7 and 14 days.

- hBMSCs on all surfaces showed higher ALP activity at 7 days than 14 days.
- At 7 days, no statistical differences in ALP activity was observed between groups, except for K which demonstrated significantly lower ALP activity when compared to A and B. At 14 days, H, J, K, L showed significantly lower ALP activity compared to A and B. (Fig. 3A)
- At 7 days, there is a positive correlation between increased surface roughness ($Sa \leq 1 \mu m$) and ALP activity ($R=0.5449$). Whereas, with continuously increased roughness Sa to $>1 \mu m$ was negatively correlated with ALP activity ($R=-0.5854$). At 14 days, roughness Sa was negatively correlated with ALP activity. (Fig. 3B)

Discussion & Conclusion

- Improving peri-implant tissue health by texturing the surface, especially on the coronal region, is essential for enhancing osseointegration and long-term implant stability.
- However, excessive texturing can create a bacteria-friendly environment. Previous research found that a surface roughness threshold of $Sa \sim 1\mu m$ or lower is unfavorable for bacterial adhesion.
- In this study, textured surfaces with an optimum threshold Sa roughness of $1\mu m$ were shown to support maximum cell growth. Cell growth was positively correlated to Sa roughness of textured collar surfaces with $Sa \leq 1\mu m$; however, increasing Sa roughness to $>1\mu m$ decreased cell growth. The threshold was also proven to favor osteogenic cell differentiation at early time points in vitro.
- Within the limitations of this study, combined with our previous findings², suggest a novel perspective to understand implant surface properties to optimize both osseointegration and antibacterial characteristics for enhanced implant success.