OsteoFab® Surface Properties: Bacteria Inhibition and Osteoblast Functions

Presented by Thomas Webster, Ph.D., Northeastern University

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Bacteria Inhibition and Promoting Osteoblast Functions on PEKK: A Mechanistic Understanding

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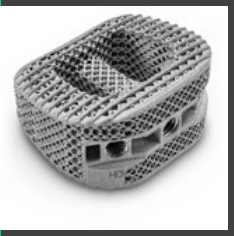
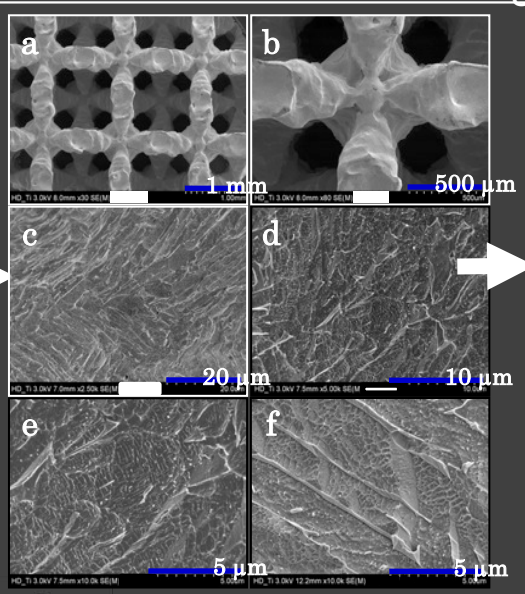
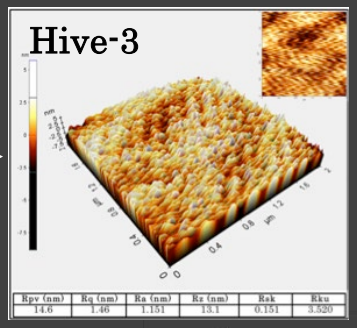
Nanostructured Surfaces Can Control Cell Responses

Without Drugs, Antibiotics, or Anti-inflammatories

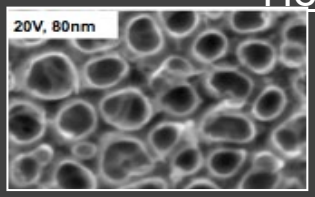
Increased Bone Growth: 3D Printing





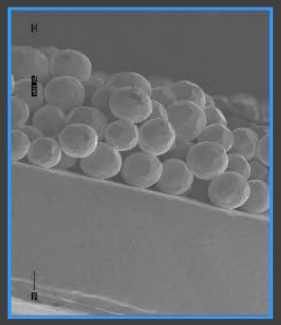


Amputee: Increased Wound Healing

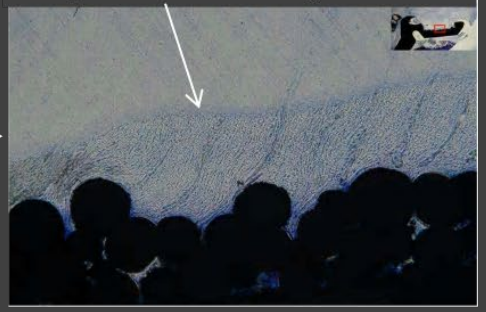


Not Nano vs. Nano

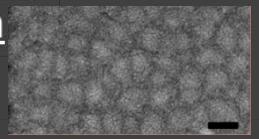
Increased Orthopedic Soft Tissue Growth



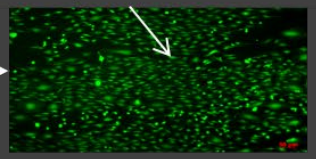
Perpendicular collagen fibers



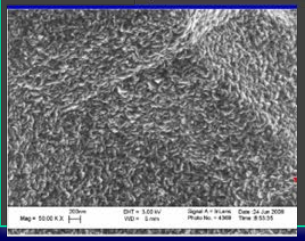
Increased Vascular Endothelialization



Many endothelial cells

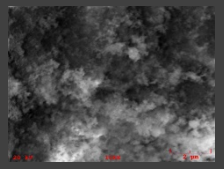


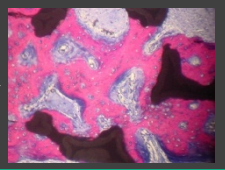
Antibacterial Applications



Few *Staph epi*

Increased Bone Growth



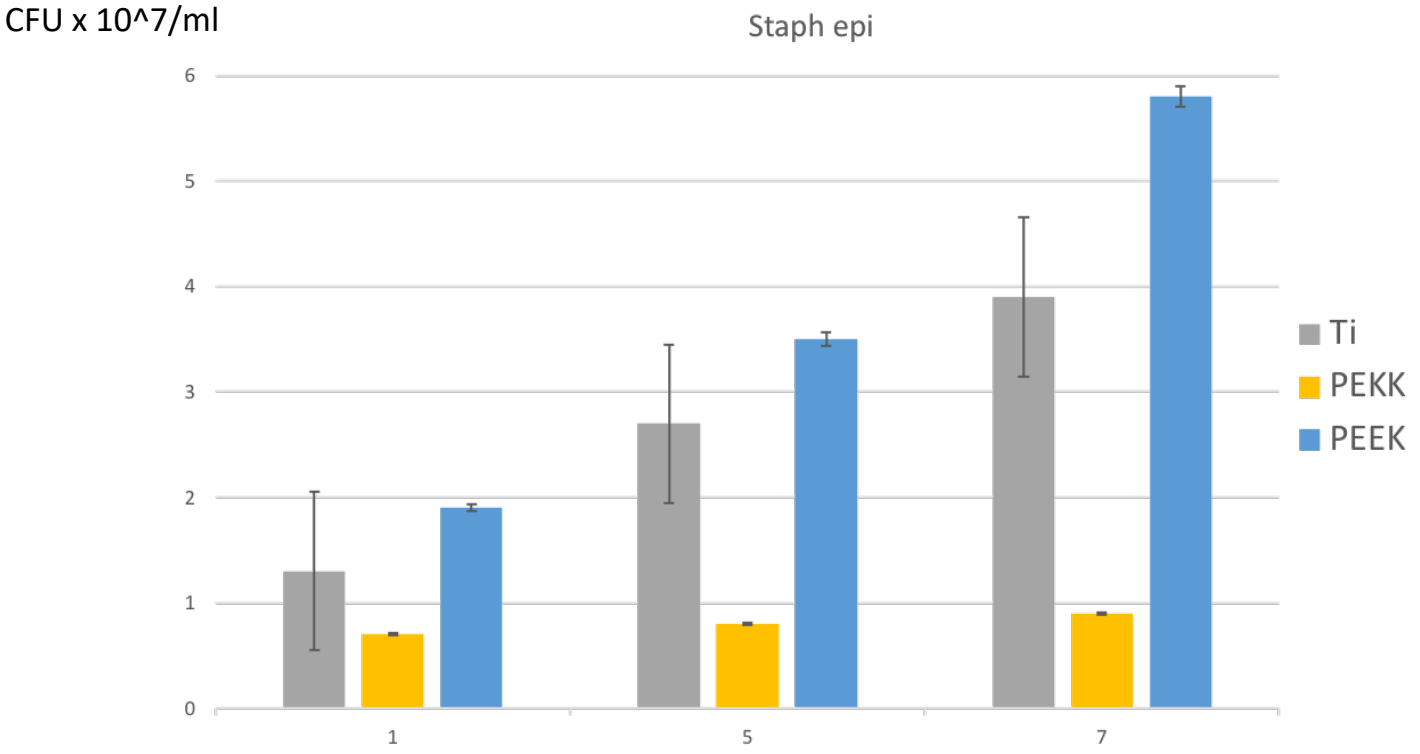


Specific Example:

Oxford Performance Materials

PEKK

Bacteria Results: Colony Forming Units

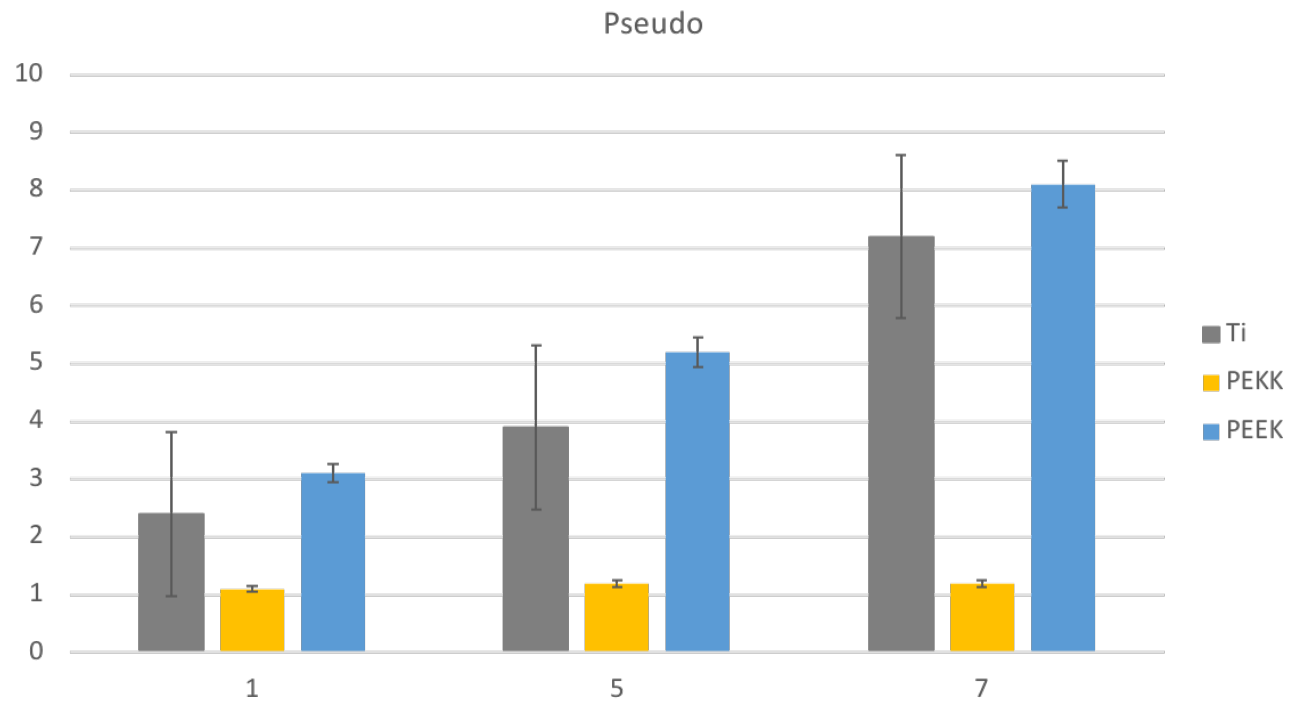


PEKK inhibited bacteria colonization

Data = mean +/- SEM; N = 3; all values significantly different than each other except Ti versus PEEK after 1 day

Bacteria Results: Colony Forming Units

CFU x 10^7/ml

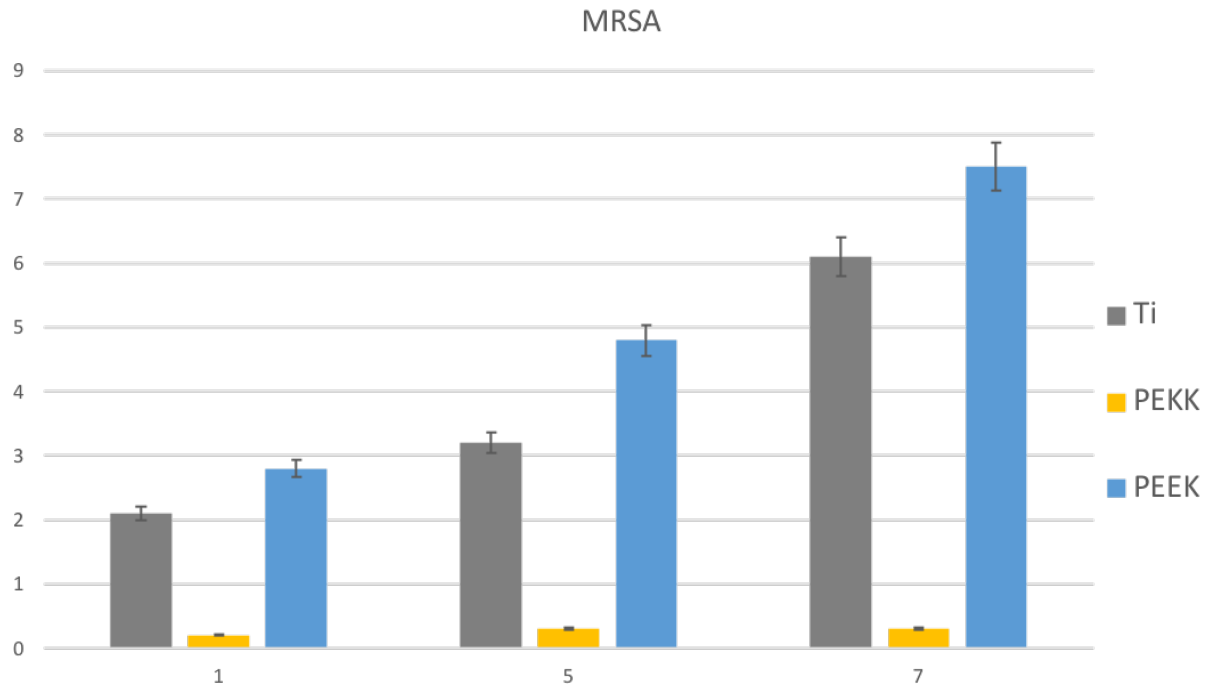


PEKK inhibited bacteria colonization

Data = mean +/- SEM; N = 3; all values significantly different than each other, except Ti and PEEK.

Bacteria Results: Colony Forming Units

CFU x 10^7/ml



PEKK inhibited bacteria colonization

Data = mean +/- SEM; N = 3; all values significantly different than each other.

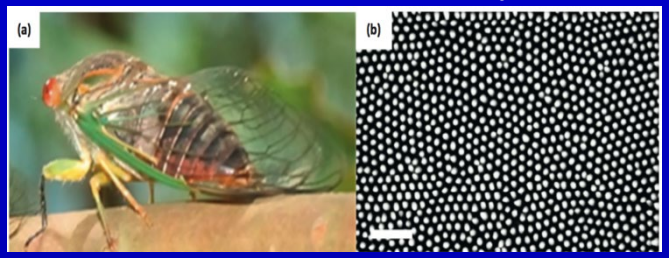
Summary 1:

Results of this study showed:

- Decreased bacteria colonization on PEKK samples compared to PEEK and Ti.
- Impressively, MRSA showed the most drastic decrease on PEKK samples compared to PEEK and Ti.

But Why ????

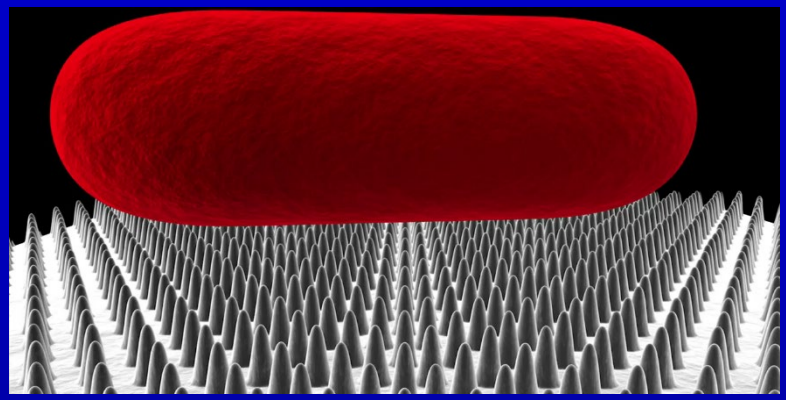
Nanopillars on cicada wings are antibacterial, irrespective of surface chemistry.



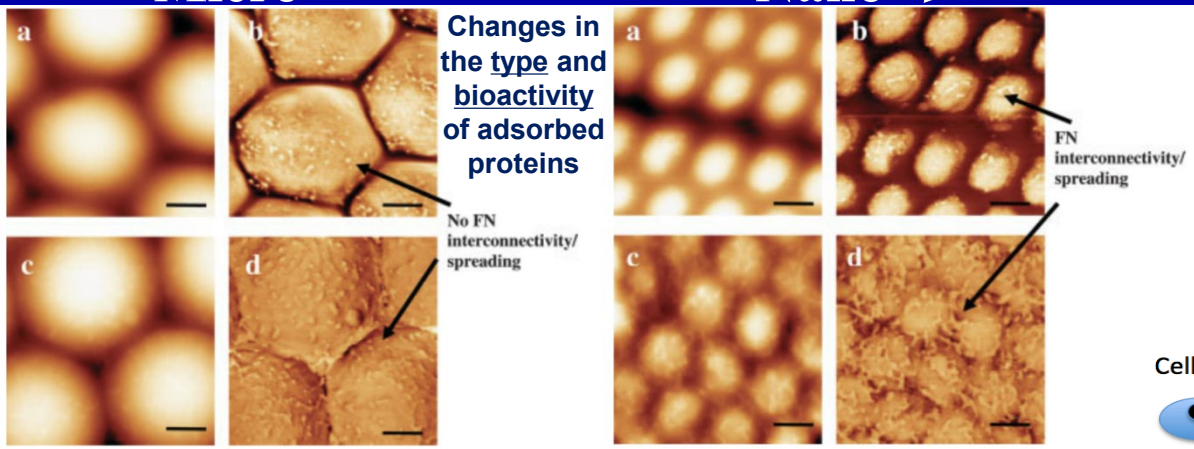
Pogodin et al. Biophysical model of bacterial cell interactions with nanopatterned cicada wing surfaces. *Biophys. J.* 2013, 104, 835-840.

Why ????

Biophysical model of bacterial cell interactions with nanopillars

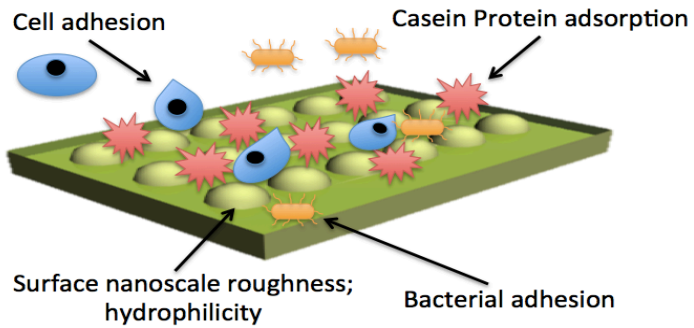


Micro **Nano**



Mechanism: As the bacteria try to attach onto the nanopillar structures, the cell membrane stretches in the regions suspended between the pillars. If the degree of stretching is sufficient, this may lead to no attachment or cell rupture.

Pogodin at al. *Biophysical model of bacterial cell interactions with nanopatterned cicada wing surfaces*. Biophysical Journal, Volume 104, pp. 835-840, 2013.



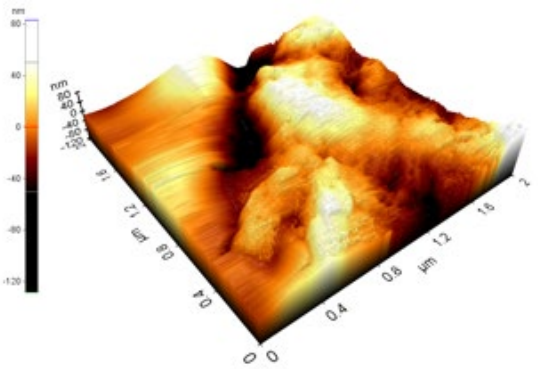
And we have a predictive equation for this:

$$E_s(r_{eff}) = E_{0,s} + \rho \times r_{eff}$$

This predicts the X, Y, and Z nanoscale features to inhibit bacteria, limit inflammation, and promote tissue growth

Surface Characterization: Surface Energy

	Surface Energy/Surface Tension (mN/m)
Ti	62.5
PEEK	16.3
PEKK	35.7
Casein	48.0[a]
Mucin	42-46[b]
Lubricin	40[c]



PEKK surface energy closer to proteins that naturally resist bacteria colonization

[a] Colloid and Interface Chemistry for Nanotechnology, CRC Press, 2014.
[b] B. Nagyová and J.M. Tiffany, "Components responsible for the surface tension of human tears," Journal Current Eye Research 19(1): 4, 1999.
[c] B. Nappone et al, "Adsorption, lubrication, and wear of lubricin on model surfaces: Polymer brush-like behavior of a glycoprotein," Biophysical Journal, 92(5): 1693, 2007.

Promotion of Selection Protein Adsorption:

Casein Adsorption (intensity)

	ELISA Intensity
Ti	0.1
PEEK	0.1
PEKK	0.6

Mucin Adsorption (intensity)

	ELISA Intensity
Ti	0.2
PEEK	0.1
PEKK	0.8

Lubricin Adsorption (intensity)

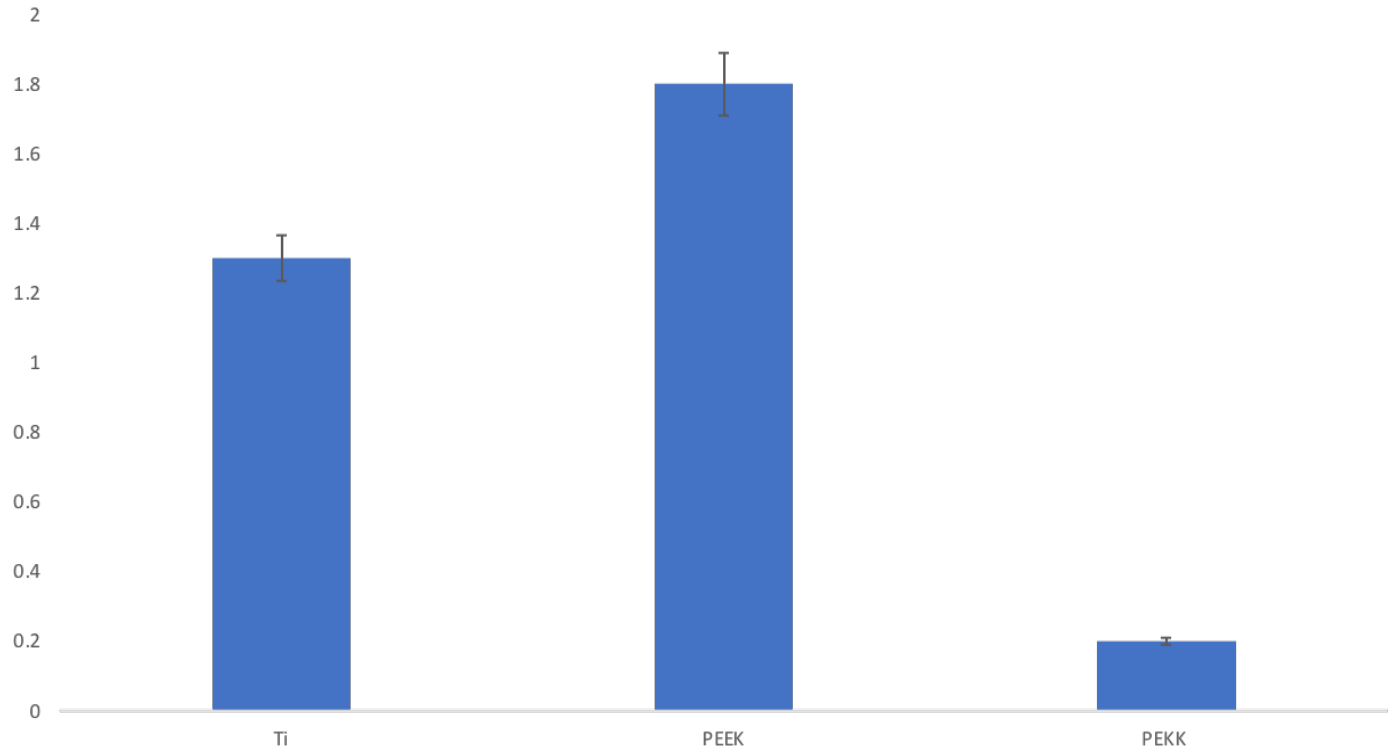
	ELISA Intensity
Ti	0.1
PEEK	0.1
PEKK	0.3

PEKK increased the adsorption of proteins that naturally resist bacteria colonization

Correlation of Protein Adsorption to Minimized Bacteria Colonization

Staph epi and Casein: Colony Forming Units

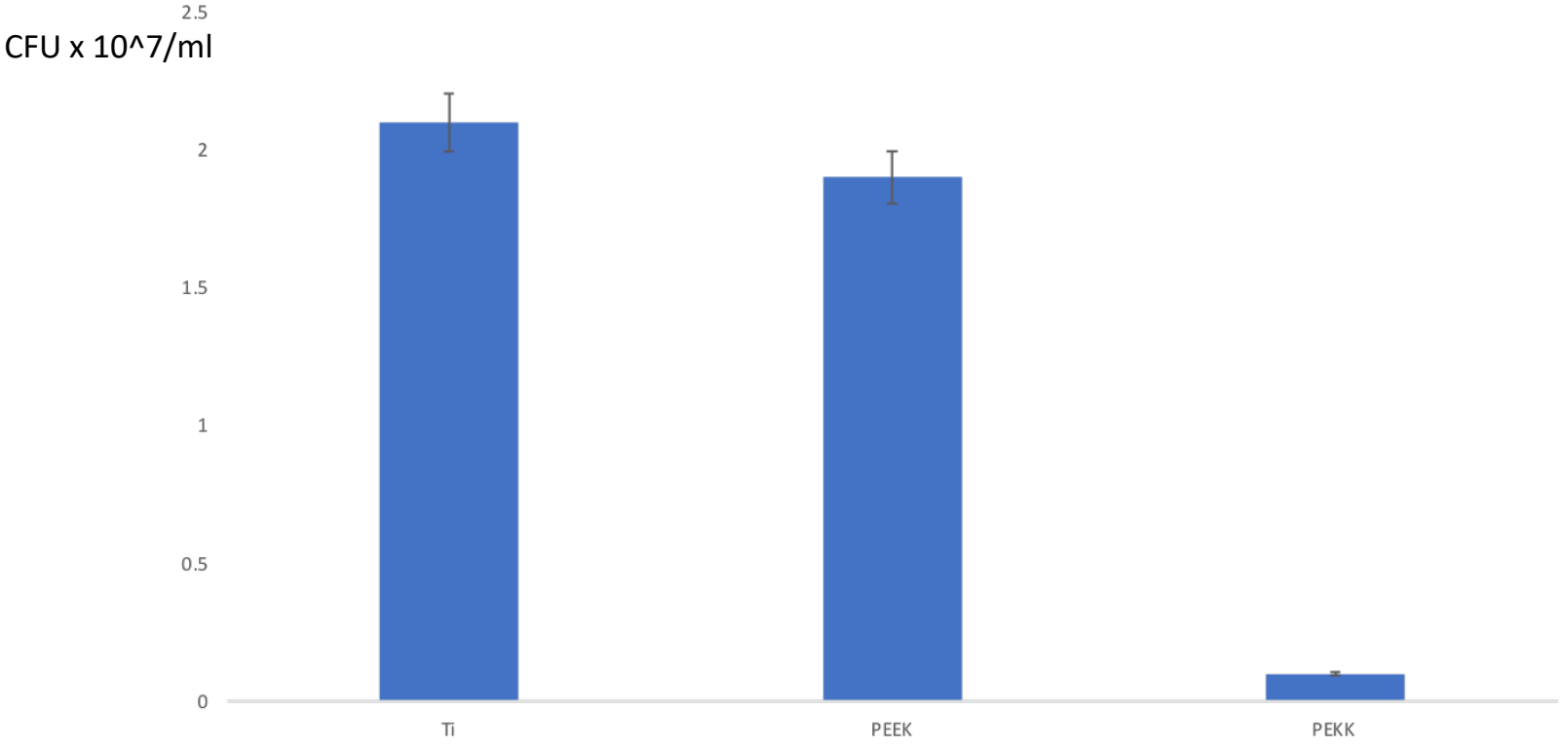
CFU x 10^7/ml



Data = mean +/- SEM; N = 3; all values significantly different than each other

Correlation of Protein Adsorption to Minimized Bacteria Colonization

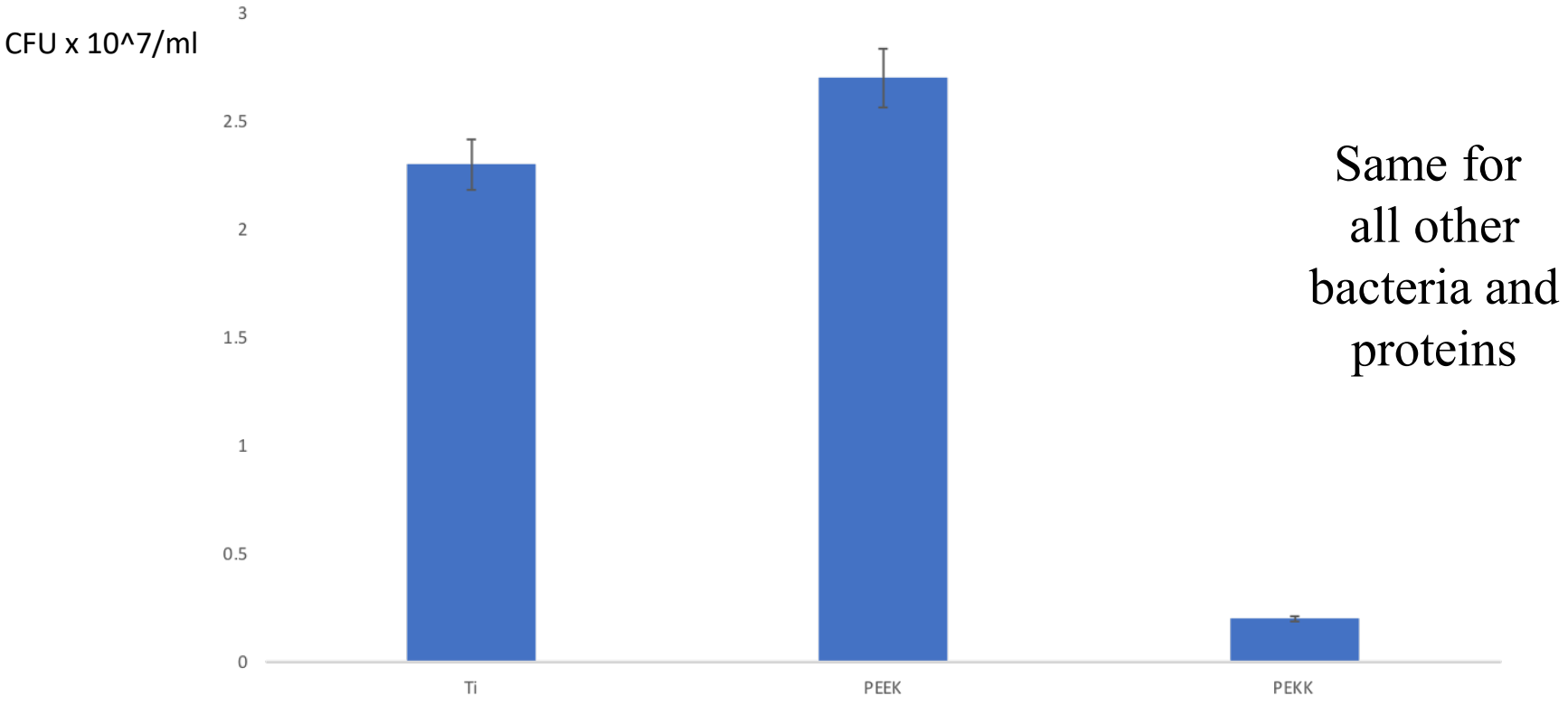
Pseudo and Casein: Colony Forming Units



Data = mean +/- SEM; N = 3; all values significantly different than each other.

Correlation of Protein Adsorption to Minimized Bacteria Colonization

MRSA and Casein: Colony Forming Units



Same for all other bacteria and proteins

Data = mean +/- SEM; N = 3; all values significantly different than each other.

Summary 2:

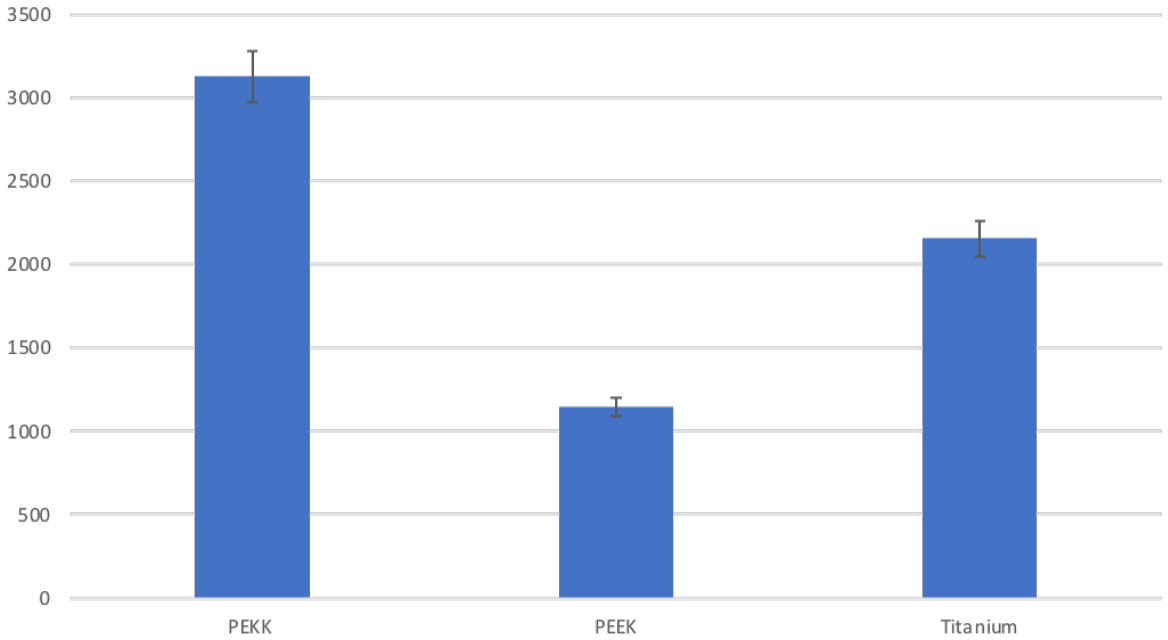
Results of this study showed that:

- The surface energy of PEKK increased the adsorption of key antibacterial proteins: mucin, casein, and lubricin.
- The increased adsorption of these proteins decreased bacteria colonization.
- The “mechanism of action” for decreased bacteria colonization on PEKK is related to its optimal surface energy which enhanced the adsorption of endogenous antibacterial proteins.

Mechanisms of Greater Osseointegration

Greater Osteoblast Adhesion

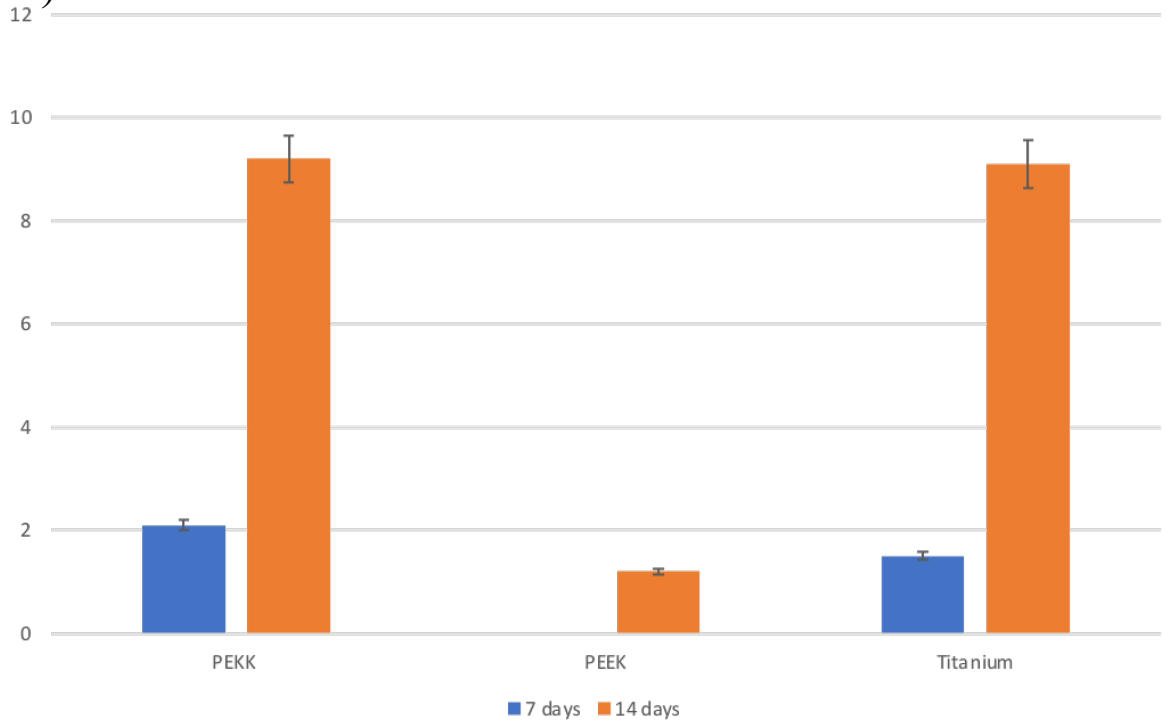
Osteoblast density (cells/cm^2)



Data + mean +/- SEM; N = 3; all values are statistically ($p<0.01$) different.
Time = 4 hrs; Seeding density = 3500 cells/cm^2.

Greater Osteoblast Mineralization

Calcium deposition (micrograms/sample)



Data + mean +/- SEM; N = 3; all values are statistically ($p<0.01$) different at the same time points. All values at 14 days are greater ($p<0.01$) than after 7 days on each respective sample. Seeding density = 50,000 cells/cm^2.

Mechanism of Action:
Calcium and Protein Adsorption

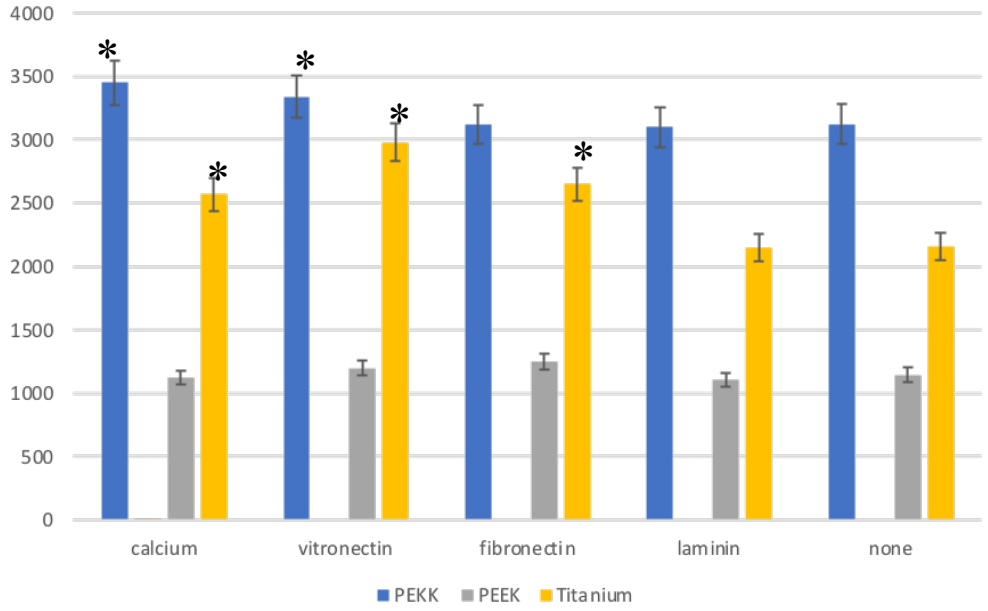
Samples	Calcium adsorption (micrograms)	Vitronectin (ELISA intensity)	Fibronectin (ELISA intensity)	Laminin (ELISA intensity)
PEKK	0.4	0.2	0.3	0.4
PEEK	0	0	0	0
Titanium	0.7	0.4	0.5	0.2

PEKK increased the adsorption of proteins that naturally promote osteoblast functions

Data + mean +/- SEM; N = 3; all values are statistically ($p<0.01$) different from the ELISA assay.

Mechanism of Action: Correlation of Calcium and Protein Adsorption to Osteoblast Adhesion

Osteoblast density (cells/cm^2)



Data + mean +/- SEM; N = 3; * $p<0.01$ compared to the same protein/calcium to none (control) on the same sample. Seeding density = 3,500 cells/cm^2. Proteins and calcium pre-coated at 100 micrograms/ml.

Summary 3:

Results of this study showed:

- Greater osteoblast adhesion and calcium deposition on the PEKK samples compared to PEEK and Ti.

- Increased initial calcium and select protein adsorption on PEKK compared to PEEK and Ti as the main mechanism of action which promoted osteoblast density.

Taken together, PEKK demonstrated optimal surface properties to both inhibit bacteria and promote osteoblast functions.

Thank you!

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