

December 2007

Bactericidal activity of extended 9-glycyl-amido-minocyclines

Chang-po Chen
Thomas Jefferson University

Allen R. Zeiger
Thomas Jefferson University

Dr. Eric Wickstrom
Thomas Jefferson University, eric@tesla.jci.tju.edu

[Let us know how access to this document benefits you](#)

Follow this and additional works at: <http://jdc.jefferson.edu/bmpfp>

 Part of the [Medical Biochemistry Commons](#)

Recommended Citation

Chen, Chang-po; Zeiger, Allen R.; and Wickstrom, Dr. Eric, "Bactericidal activity of extended 9-glycyl-amido-minocyclines" (2007). *Department of Biochemistry and Molecular Biology Faculty Papers*. Paper 16.
<http://jdc.jefferson.edu/bmpfp/16>

This Article is brought to you for free and open access by the Jefferson Digital Commons. The Jefferson Digital Commons is a service of Thomas Jefferson University's [Center for Teaching and Learning \(CTL\)](#). The Commons is a showcase for Jefferson books and journals, peer-reviewed scholarly publications, unique historical collections from the University archives, and teaching tools. The Jefferson Digital Commons allows researchers and interested readers anywhere in the world to learn about and keep up to date with Jefferson scholarship. This article has been accepted for inclusion in Department of Biochemistry and Molecular Biology Faculty Papers by an authorized administrator of the Jefferson Digital Commons. For more information, please contact: JeffersonDigitalCommons@jefferson.edu.

Bactericidal Activity of Extended 9-Glycyl-Amido-Minocyclines

Chang-po Chen, Allen R. Zeiger, and Eric Wickstrom*

Department of Biochemistry & Molecular Biology
Thomas Jefferson University, Philadelphia PA 19107, USA

Received July ??, 2007; Accepted September ??, 2007

Abstract—The need for self-protecting polymer or alloy implants resistant to a broad spectrum of bacterial challenges led us to investigate covalent bonding of minocycline (MIN), a tetracycline derivative, to polystyrene beads and to titanium alloy foils by oligoethylene glycol spacers. 9-Hydrazino-acetyl-amido-MIN, and simpler glycylicycline derivatives, retained minimum inhibitory concentration (MIC) against *Staphylococcus aureus* comparable to MIN. However, PEG-glycyl-amido-MIN showed very low activity. Hence, we coupled 9-hydrazino-acetyl-amido-MIN to the aldehyde termini of oligoethylene glycol spacers bonded to polystyrene and titanium alloy surfaces to form acid-releasable hydrazone linkages. 9-Hydrazino-acetyl-amido-MIN was released from the monolayers more rapidly at pH 5.0 than at pH 7.4. ©2007 Elsevier Science Ltd. All rights reserved.

Infections are a devastating complication of medical implant devices that cause significant morbidity. The management of infected implants has serious economic implications. For example, in the United States, treatment of 3500-4000 cases of knee and hip infections every year costs an estimated 150 to 200 million dollars¹. Because of poor vascularity and biofilm formation at the implant sites, such infections have proven difficult to prevent or treat. The local application of antibiotics is a well-known and accepted therapy for such kind of implications²⁻⁴. Current practice includes antibiotic-impregnated bone cement⁵, and antibiotic-containing coating systems⁶⁻⁸. These methods are intended to release antibiotics rapidly and irreversibly, and require a carrier material other than the orthopaedic implant itself to transport the antibiotic materials. Some non-resorbable materials used in the methods even need to be removed after the surgery⁹.

Because of the combination of their many biocompatible properties, titanium and titanium alloys are frequently applied in a wide variety of biomedical devices¹⁰. In our initial studies¹¹ using fine titanium (Ti) particles which had been aminopropylated^{12,13}, we utilized the last resort glycopeptide antibiotic vancomycin (VAN), which acts at the surface of the Gram-positive bacterial cell wall to block peptidoglycan synthesis^{14,15}. Hydrophilic bis(ethylene glycol) spacers were coupled to the solid phase NH₂PrSiO-Ti particles, followed by VAN¹¹. The biological results showed that the VAN-modified Ti particles effectively inhibited the growth of *S. aureus* compared with control Ti particles on which the bacteria grew abundantly¹¹.

The strategy was then extended to Ti6Al4V alloy pins, widely used for orthopaedic implants¹⁶. We found that VAN could be covalently linked to the Ti6Al4V alloy surface on orthopaedic implants, following oxidation¹⁷. Covalently bound VAN was retained on the surface for an extended period of time and retained significant antibiotic activity¹⁸.

Most implant infections are caused by Gram-positive bacteria¹⁹, but some are caused by Gram-negative bacteria, which are susceptible to broad-spectrum antibacterial agents such as tetracyclines. Bacterial resistance to tetracyclines has curtailed their clinical effectiveness. A minimum of semisynthesis and analoging has been carried out with tetracyclines, compared to other classes of antibiotics, perhaps due to their complex chemistry, chemical liability, and lack of reactivity of the intact naphthacene nucleus.

Glycylicyclines, such as tigecycline, recently approved by FDA²⁰, are active against a broad range of Gram-positive and Gram-negative bacterial strains resistant to tetracycline or doxycycline. Tigecycline, however, lacks functional groups suitable for connecting to a solid support. Minocycline (MIN), on the other hand, allows exclusive 9-nitration, the starting point for glycylicycline extension.

MIN is effective against a broad range of Gram-positive and Gram-negative bacteria²¹, displaying an MIC of 0.12 µg/mL against *S. aureus*²². Against *E. faecalis* and *E. faecium*, by comparison, MIN was found ~8-fold more active than linezolid and 32-fold more than quinupristin-dalfopristin²³. Bulky groups at the 9-position of glycylicyclines usually contribute to activity²⁴, supporting our strategy of coupling moieties to the 9-position of MIN to create new glycylicyclines. We therefore chose MIN as the basis for glycylicycline tethering to solid surfaces.

Keywords: antibiotics, biofilms, implants, orthopedics, spacers

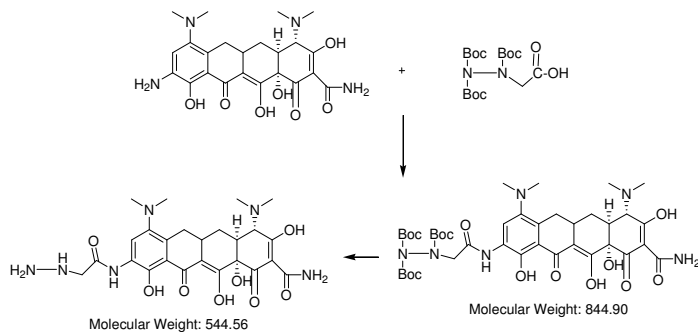
*Correspondence: Dr. Eric Wickstrom, Department of Biochemistry & Molecular Biology, Thomas Jefferson University, Philadelphia PA 19107-5541, USA
voice: 1-215-955-4578; fax: 1-215-955-4580
email: eric@tesla.jci.tju.edu; website: http://tesla.jci.tju.edu

Here we report the design and synthesis of several MIN C9 derivatives and the determination of their minimum inhibitory concentration (MIC). Attachment of the MIN derivatives to polystyrene beads and Ti6Al4V alloy foils via acid-labile linkers was carried out to characterize the bioactivity of the tethered MIN derivatives.

We synthesized [4S-(4 α ,12 α)]-9-H₂N-4,7-bis(Me₂N)-1,4,4a,5,5a,6,11,12a-octahydro-3,10,12,12a-tetrahydroxy-1,11-dioxo-2-naphthacene-carboxamide (9-H₂N-MIN) as described²². Briefly, to an ice-cold solution of MIN·HCl (1 gram, 2.03 mmol) in 9 mL of concentrated H₂SO₄ was added KNO₃ (224 mg, 2.4 mmol). The reaction mixture was stirred at 0°C for about 1.5 hour, and monitored by HPLC on a 150×4.6 mm Phenomenex® Luna phenyl-hexyl 5 μ m column, eluted with 25% CH₃CN in 35 mM Na₂HPO₄, pH 7.5, on a Waters 600 liquid chromatograph (Milford MA USA). When the reaction came to completion, the mixture was slowly poured into 240 mL of ice-cold Et₂O. The precipitate was collected by filtration, and washed with Et₂O three times. The solid was dried overnight under vacuum to give 9-O₂N-MIN·(SO₄)₂. The product was characterized by HPLC, showing a prominent product peak, and MS of the main peak (SELDI-TOF mass spectrometer (Ciphergen, Fremont, CA), calc. 502.47 Da, found 502.5 Da. The dried 9-O₂N-MIN·(SO₄)₂ (1.29 g, 1.8 mmol), 200 mg of 10% palladium on charcoal, and 4.5 mL of 2 N H₂SO₄ in 6 mL of 2-MeOEtOH were mixed and hydrogenated in a Parr apparatus at 40 psi for 1.5 hr. The catalyst was filtered and the filtrate was added dropwise to a mixture of 2-PrOH (210 mL) and Et₂O (150 mL). The yellow solid was collected by filtration, washed several times with Et₂O and dried under vacuum at room temperature overnight to yield 1.16 g of 9-H₂N-MIN·(SO₄)₂ (90% yield). The product was characterized by HPLC and MS: calc. 472.2 Da, found 472.0 Da.

We then converted 9-H₂N-MIN into [4S-(4 α ,12 α)]-9-[(HNAc)NH]-4,7-bis(Me₂N)-1,4,4a,5,5a,6,11,12a-octahydro-3,10,12,12a-tetrahydroxy-1,11-dioxo-2-naphthacene-carboxamide (9-Gly-NH-MIN). To a solution of Boc-Gly (458 mg, 1.2 mmol) in 3 mL Me₂NCHO was added 412 mg of 2-(7-aza-1H-benzotriazole-1-yl)-1,1,3,3-tetramethyl-uronium hexafluorophosphate (HATU) (Applied Biosystems, Foster City CA, USA) (1.1 equivalent) and 311 μ L of iPr₂EtN. The reaction mixture was stirred at room temperature for 30 min, then mixed with 9-H₂N-MIN·(SO₄)₂ (575 mg, 0.95 mmol) in 4 mL Me₂NCHO. After 1 hr at room temperature, the product was precipitated by addition of 2 volumes of ice-cold Et₂O. After sedimentation and removal of supernatant, the precipitate was dissolved in 4 N HCl/dioxane and incubated for 10 min. at room temperature to remove the Boc protecting group. The final product, 9-Gly-H₂N-MIN, was precipitated twice from Et₂O). MS: calc. 529.54 Da, found 530.1 Da.

Next, we prepared [4S-(4 α , 12 α)]-4, 7-Bis(Me₂N)-9-[(HNAc)NH]-4,7-bis(Me₂N)-1,4,4a,5,5a,6,11,12a-octahydro-3,10,12,12a-tetrahydroxy-1,11-dioxo-2-naphthacene-carboxamide (9-hydrazino-Ac-H₂N-MIN) (Scheme 1). To a solution of N,N,N',N'-Boc₃-hydrazinoacetic acid (369 mg, 0.95 mmol) in 3 mL Me₂NCHO was added 397 mg of HATU (1.1 equivalent) and 264 μ l of iPr₂EtN. The reaction mixture was stirred at room temperature for 30 min, then mixed with 9-H₂N-MIN·(SO₄)₂ (600 mg, 0.9 mmol) in 4 mL Me₂NCHO and 1 g of NaCO₃, and stirred for 1 hr at room temperature. It was found that the yellow solution changed to brown. The solid was removed by filtration and the filtrate was applied to a 150×15 mm C₁₈ column (WAT 020594, Waters Associates). The column was washed with H₂O to remove Me₂NCHO. Because of the strong hydrophobicity of 9-Boc₃-hydrazino-Ac-NH-MIN, the impurities in the reaction mixture could be eluted from the C₁₈ column by 20% CH₃CN in aqueous 0.1% CF₃CO₂H. The product was eluted with pure CH₃CN, concentrated by rotatory evaporation, and lyophilized overnight. The dried sample was dissolved in 4 M HCl in dioxane to deprotect the Boc groups. After 10 min, a precipitate was formed. The mixture was kept at room temperature under shaking. The precipitate was collected by filtration and washed with Et₂O three times. The solid product was dried under vacuum to give 510 mg of 9-hydrazino-Ac-H₂N-MIN·(Cl)₂ as a yellow powder (92% yield). The product was characterized by HPLC and MS: calc. 544.56 Da, found 544.6 Da.



Scheme 1. Reaction scheme for synthesis of 9-hydrazino-Ac-NH-MIN.

To PEGylate 9-Gly-NH-MIN, we added 1 equivalent of HATU and 1.2 equivalent of iPr₂EtN to 1 mL Me₂NCHO containing 100 mg of O-(N-Fmoc-2-aminoethyl)-O'-(2-carboxyethyl)-undecaethyleneglycol (PEG₁₂ carboxylate) (Merck, Darmstadt, Germany) stirred at room temperature for 30 min, to which 1.1 equivalent of 9-Gly-NH-MIN was added. The reaction mixture was kept at room temperature for 2 hr under stirring. The reaction was stopped by addition of H₂O. Taking the molecular mass (1351 Da) of 9-PEG₁₂-Gly-NH-MIN into consideration, we employed a Sephadex G-25 column (1.7×30 cm) eluted with aqueous 0.5% HOAc to separate the conjugate from the impurities. The eluent corresponding to the first peak was collected,

concentrated and freeze dried. The dried sample was redissolved in H₂O, then characterized by HPLC and MS: calc. 1351.49 Da, found 1351.6 Da. 9-PEG₂₆-Gly-NH-MIN was prepared similarly. The product was characterized by HPLC and MS: calc. 2056.33 Da, found 2056.0 Da.

Measurements of MIC²⁵ for each of the MIN derivatives without PEG (Table 1) showed that 9-Gly-NH-MIN and 9-hydrazino-Ac-NH-MIN retained significant biological activity, compared with unmodified MIN. However, the MIC of the two 9-PEG-MIN derivatives was dramatically elevated. **The bulky PEG modification might have inhibited bacterial uptake of the MIN derivatives, and/or the binding of MIN to the 30S ribosomal subunits, resulting in the loss of bioactivity by the PEG-MIN derivatives. This result argues against permanent PEG tethering of MIN derivatives to medical implants.**

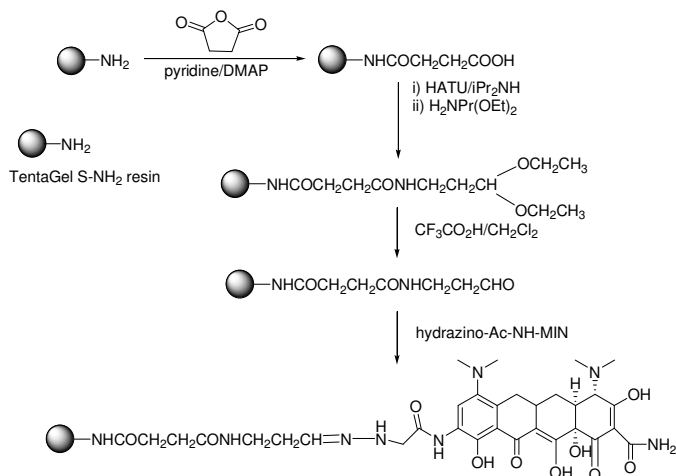
Compound	MIC (found) $\mu\text{g/mL}$	MIC (published) $\mu\text{g/mL}$
MIN	0.125	0.125
9-H ₂ N-MIN	2	1
9-Gly-NH-MIN	2	0.5-1
9-hydrazino-Ac-NH-MIN	2	NA
9-PEG ₁₂ -Gly-NH-MIN	500	NA
9-PEG ₂₆ -Gly-NH-MIN	1000	NA

S. aureus subspecies aureus Rosenbach (ATCC 25923) were incubated in Mueller-Hinton broth at 37°C for 14 hr, noting the dilution midway between fully inhibited and uninhibited bacterial proliferation²⁵

Because of the loss of bioactivity of MIN after conjugation with PEG, we selected the acid-labile hydrazone bond to link 9-hydrazino-Ac-NH-MIN to solid surfaces, so that the drug could be released on demand upon acidification of the microenvironment by proliferating bacteria²⁶.

Hydrazone bonds have been widely investigated for targeting drug delivery²⁷. The bond is relatively stable in physiological pH. When the delivered drug was absorbed through endocytosis pathway, the hydrazone could be broken in response to the low pH in cytoplasmic endosomes²⁸. To enable release on demand, the hydrazone bonds should remain largely intact for an effective number of days after implant insertion. For the attachment of antibiotics to the surface of implants by acid-labile linkers, we expect that the antibiotics should remain stably attached on the surface for weeks to months. Due to the reversible property of hydrazone bonds in aqueous solution, the antibiotics attached to implant surfaces could be released gradually at neutral pH, but rapidly at acid pH induced by infection.

We selected TentaGel S-NH₂ polystyrene beads as a model to investigate the release of 9-hydrazino-Ac-NH-MIN from a polymeric surface. The amino groups on



Scheme 2. Reaction scheme for synthesis of PS-Succ-NHPr-hydrazone-9-Ac-NH-MIN.

500 mg of TentaGel S-NH₂ (Fluka 86364, 0.26 mmol/g) resin were transformed to carboxylates by reaction with 1.5 equivalent of succinic anhydride in the presence of 0.1 equivalent of N,N-dimethylaminopyridine (DMAP) catalyst dissolved in 4 mL of pyridine (Scheme 2). The reaction mixture was kept at 50°C with shaking for 3 hr. A ninhydrin test showed no free amino groups available on the surface of the resin beads. The carboxylates on the resin were activated by HATU and iPr₂EtN at room temperature for 30 min, then coupled with H₂NPr(OEt)₂ at room temperature for 3 hr. The resin was washed with Me₂NCHO and CH₂Cl₂, then dried under vacuum. Next, the resin was treated with 50% CF₃CO₂H in CH₂Cl₂ for 30 min to yield aldehyde-modified resin, which was washed with Me₂NCHO and CH₂Cl₂, then dried under vacuum overnight. 9-Hydrazino-Ac-NH-MIN at 0.1 M in CHCl₃ was then reacted with the aldehyde termini to yield the acid-labile hydrazone-linked 9-Ac-NH-MIN polystyrene beads. The resin was washed with **physiological buffer (0.15 M NaCl, 0.01 M Na₂HPO₄, pH 7.4, PBS)**, Me₂NCHO and CH₂Cl₂, then dried under vacuum overnight. PS-Succ-NHPr-hydrazone-9-Ac-NH-MIN resin beads were stripped with 10% HOAc in CH₂Cl₂ to determine the total loading of 9-hydrazino-Ac-NH-MIN, 52 $\mu\text{g/g}$ resin, **by absorbance at 350 nm²⁹**.

The stability of the hydrazone bond was investigated by incubating **5.6 mg aliquots of PS-Succ-NHPr-hydrazone-9-Ac-NH-MIN resin beads** at 37°C under physiological conditions in **1.5 mL of 0.1 M Na₂HPO₄, pH 7.4, and under conditions of anaerobic bacterial metabolism in a confined microenvironment in 0.1 M NaOAc, pH 5.0**. The concentration of the released 9-hydrazino-Ac-NH-MIN in the buffers was determined by absorbance at 350 nm²⁹ (Fig. 1).

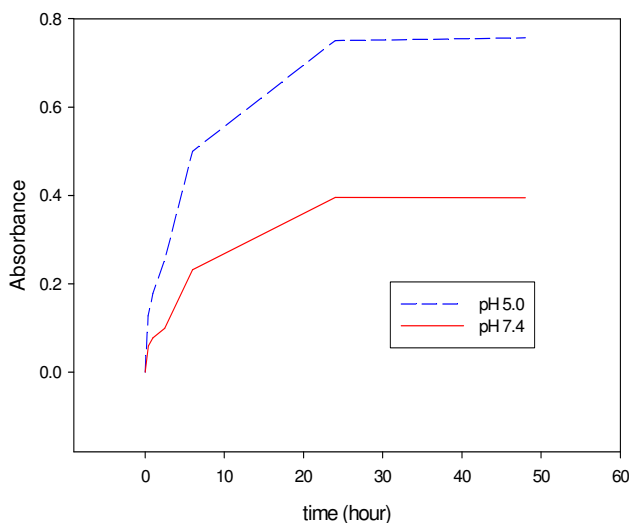


Figure 1. Release of 9-hydrazino-Ac-NH-MIN from PS-Succ-NHPr-hydrazono-9-Ac-NH-MIN resin beads as a function of pH. Solid line: 0.1 M Na_2HPO_4 , pH 7.4. Dashed line: 0.1 M NaOAc, pH 5.0.

The time course of 9-hydrazino-Ac-NH-MIN release from the beads showed much faster release at pH 5.0 than at pH 7.4. After 24 hr at pH 5.0, released MIN reached $36.7 \mu\text{g/mL}$, or 54% of the MIN loading measured after coupling (Fig. 1). That value is 18 times greater than the MIC of $2 \mu\text{g/mL}$. After 24 hr at pH 7.4, released MIN reached $18.8 \mu\text{g/mL}$, or 27.6% of the MIN loading measured after coupling. The leveling of the A_{350} trace after 24 hr is probably the result of the instability of hydrazino-MIN. Hence, the hydrazone bond is not stable enough to keep 9-hydrazino-Ac-NH-MIN on the surface for an extended period of time.

We also attached 9-hydrazino-Ac-NH-MIN to the surface of Ti6Al4V foil. We prepared $\text{H}_2\text{NPrSi-O-Ti6Al4V}$ alloy foil as described previously for Ti6Al4V pins¹⁷. The amine was then coupled with 4 equivalents of glyoxylyl-8-amino-3,5-dioxaoctanoic acid in the presence of HATU/ $i\text{Pr}_2\text{EtN}$ in Me_2NCHO . 9-Hydrazino-Ac-NH-MIN at 0.1 M in CHCl_3 was coupled to the surface of the aldehyde-PEG-NHPrSi-O-Ti6Al4V foil for 4 hr to yield Ti-O-SiPrNH-PEG-hydrazono-9-Ac-NH-MIN. The foil was washed with CH_2Cl_2 , Me_2NCHO and double deionized H_2O , then dried under vacuum overnight. On the surface of a one cm^2 Ti6Al4V foil with a maximum monolayer loading of 200 pmol^{30} , as we found for VAN¹⁸, the amount of strippable MIN would be too low to measure by UV absorbance.

To determine bacterial viability on Ti6Al4V foil substrates, control Ti6Al4V alloy foils and Ti-O-SiPrNH-PEG-hydrazono-9-Ac-NH-MIN alloy foils were sterilized by incubation with 70% EtOH, and washed five times with autoclaved PBS. *S. aureus* subspecies aureus Rosenbach were cultured in Mueller-Hinton broth at 250 rpm, 37°C for 14 hr. Using a 0.5 McFarland standard, the bacteria were diluted to 1×10^4 cfu/mL in Mueller-Hinton broth. The sterilized

Ti6Al4V foils were cultured with the *S. aureus* at 37°C for 24 hr, after which the pH was still 7.3-7.4. For Ti6Al4V foil, we immersed the MIN-bonded foil in the minimum volume of $200 \mu\text{L}$ of broth. The foils were washed three times with PBS to remove loosely adherent bacteria, and assessed for bacterial adhesion and viability by staining with the Live/Dead@BacLight™ viability kit, which fluorescently labels viable bacteria green and dead bacteria red. After labeling, the Ti6Al4V alloy foils were washed three times with PBS to remove nonspecific stain and visualized by confocal laser fluorescence microscope on a Fluoview 300 (Olympus, Melville, NY). Challenge by *S. aureus*, however, showed live bacteria on all foil samples. At physiological pH, the concentration of 9-hydrazino-Ac-NH-MIN that could be released into the medium was insufficient to inhibit the growth of *S. aureus*. Even if all the attached monolayer of MIN were released into the broth, the resulting MIN concentration of $1.2 \mu\text{g/mL}$ would have been below the MIC of $2 \mu\text{g/mL}$. The flat foil has much less surface area than the porous resin beads.

For the construction of medical implants with covalently bound broad-spectrum antibiotics for self-protection against Gram-negative colonization, we designed and synthesized three MIN derivatives. Conjugation of long hydrophilic PEG spacers with MIN at the C9 position resulted in dramatic loss of bioactivity, which argued against the utility of permanent linkage of MIN to the surface of medical implants by PEG spacers.

Knowing that 9-hydrazino-Ac-NH-MIN showed reasonable antibiotic activity, we attached it to the surfaces of polystyrene beads and Ti6Al4V foils by an acid-labile hydrazone bond that would permit release of free 9-hydrazino-Ac-NH-MIN to enter bacteria, triggered by bacterial acidification of the implant microenvironment. The release kinetics showed a clear difference between the rates of 9-hydrazino-Ac-NH-MIN released at pH 7.4 and pH 5.0. However, the hydrazone bond may not be stable enough for long term medical implant application. We are also considering methylmaleimide³¹ linkers to enable this strategy.

We thank Dr. Richard Wassell for assistance with mass spectroscopy. This work was supported in part by DoD grant DAMD-17-03-1-0713.

- (1)Toubes, E.; Segreti, J. *Curr Infect Dis Rep* **2002**, *4*, 433-438.
- (2)Garvin, K. L.; Hanssen, A. D. *J. Bone Joint Surg.* **1995**, *77A*, 1576-1588.
- (3)Duggan, J. M.; Georgiadis, G. M.; Kleshinski, J. F. *Infect. Med.* **2001**, *18*, 534-541.
- (4)Zimmerli, W.; Trampuz, A.; Ochsner, P. E. *N Engl J Med* **2004**, *351*, 1645-54.
- (5)Haddad, F. S.; Masri, B. A.; Campbell, D.;

- McGraw, R. W.; Beauchamp, C. P.; Duncan, C. P. *Journal of Bone & Joint Surgery - British Volume* **2000**, *82*, 807-12.
- (6)Loll, P. J.; Axelsen, P. H. *Annual Review of Biophysics & Biomolecular Structure*. **2000**, *29*, 265-89.
- (7)van de Belt, H.; Neut, D.; Schenk, W.; van Horn, J. R.; van der Mei, H. C.; Busscher, H. J. *Acta Orthopaedica Scandinavica*. **2001**, *72*, 557-71.
- (8)Frazier, D. D.; Lathi, V. K.; Gerhart, T. N.; Hayes, W. C. *Journal of Biomedical Materials Research* **1997**, *35*, 383-9.
- (9)Montali, A. *Injury* **2006**, *37 Suppl 2*, S81-6.
- (10)Liu, X.; Chu, P. K.; Ding, C. *Materials Science and Engineering R: Reports* **2004**, *47*, 49-121.
- (11)Jose, B.; Antoci, J., V.; Zeiger, A. R.; Wickstrom, E.; Hickok, N. J. *Chemistry & Biology* **2005**, *12*, 1041-1048.
- (12)Puleo, D. A.; Kissling, R. A.; Sheu, M. S. *Biomaterials* **2002**, *23*, 2079-87.
- (13)Jennissen, H. P. *Ann N Y Acad Sci* **2002**, *961*, 139-42.
- (14)Walsh, C. *Nature* **2000**, *406*, 775-81.
- (15)Kahne, D.; Leimkuhler, C.; Lu, W.; Walsh, C. *Chem Rev* **2005**, *105*, 425-48.
- (16)Zreiqat, H.; Akin, F. A.; Howlett, C. R.; Markovic, B.; Haynes, D.; Lateef, S.; Hanley, L. *J Biomed Mater Res A* **2003**, *64*, 105-13.
- (17)Edupuganti, O. P.; Antoci, V., Jr.; King, S. B.; Jose, B.; Adams, C. S.; Parvizi, J.; Shapiro, I. M.; Zeiger, A. R.; Hickok, N. J.; Wickstrom, E. *Bioorganic & Medicinal Chemistry Letters* **2007**, *17*, 2692-2696.
- (18)Antoci, V., Jr.; King, S. B.; Jose, B.; Parvizi, J.; Zeiger, A. R.; Wickstrom, E.; Freeman, T. A.; Composto, R. J.; Ducheyne, P.; Shapiro, I. M.; Hickok, N. J.; Adams, C. S. *Journal of Orthopaedic Research* **2007**, *25*, 858-866.
- (19)Schierholz, J. M.; Beuth, J. *Journal of Hospital Infection*. **2001**, *49*, 87-93.
- (20)van Ogtrop, M. L.; Andes, D.; Stamstad, T. J.; Conklin, B.; Weiss, W. J.; Craig, W. A.; Vesga, O. *Antimicrob Agents Chemother* **2000**, *44*, 943-9.
- (21)Zhanel, G. G.; Homenuik, K.; Nichol, K.; Noreddin, A.; Vercaigne, L.; Embil, J.; Gin, A.; Karlowsky, J. A.; Hoban, D. J. *Drugs* **2004**, *64*, 63-88.
- (22)Sum, P. E.; Lee, V. J.; Testa, R. T.; Hlavka, J. J.; Ellestad, G. A.; Bloom, J. D.; Gluzman, Y.; Tally, F. P. *J Med Chem* **1994**, *37*, 184-8.
- (23)Milatovic, D.; Schmitz, F. J.; Verhoef, J.; Fluit, A. C. *Antimicrob Agents Chemother* **2003**, *47*, 400-4.
- (24)Barden, T. C.; Buckwalter, B. L.; Testa, R. T.; Petersen, P. J.; Lee, V. J. *J Med Chem* **1994**, *37*, 3205-11.
- (25)NCCLS *Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically; Approved Standard*; 5th ed.; National Committee of Clinical Laboratory Standards: Wayne PA, 2000; Vol. NCCLS document M7-A5.
- (26)DeLand, F.; Wagner, H. N., Jr. *J Lab Clin Med* **1970**, *75*, 529-34.
- (27)Ulbrich, K.; Subr, V. *Adv Drug Deliv Rev* **2004**, *56*, 1023-50.
- (28)Van Dyke, R. W. *Subcell Biochem* **1996**, *27*, 331-60.
- (29)Hasan, T.; Khan, A. U. *Proc Natl Acad Sci U S A* **1986**, *83*, 4604-6.
- (30)Puleo, D. A. *Journal of Biomedical Materials Research* **1997**, *37*, 222-228.
- (31)Drummond, D. C.; Daleke, D. L. *Chem Phys Lipids* **1995**, *75*, 27-41.