NANO MICRO small

Supporting Information

for *Small*, DOI: 10.1002/smll.201600006

Ultrafast Killing and Self-Gelling Antimicrobial Imidazolium Oligomers

Siti Nurhanna Riduan, Yuan Yuan, Feng Zhou, Jiayu Leong, Haibin Su, and Yugen Zhang**

Supporting Information

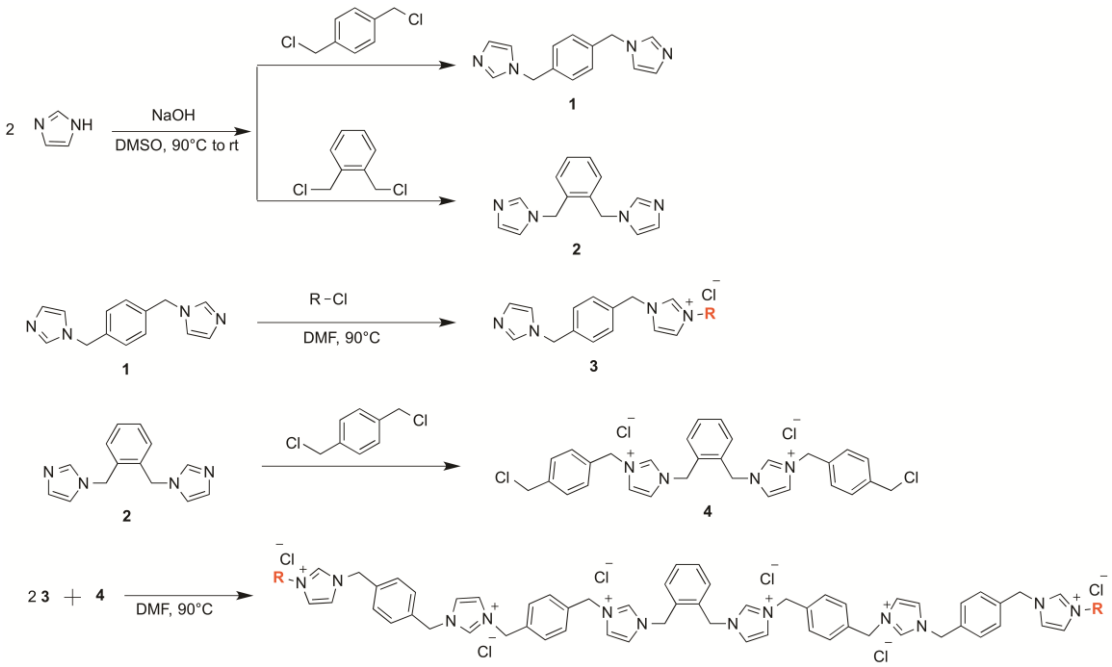
Ultrafast Killing and Self-gelling Antimicrobial Imidazolium Oligomers: Manifestation of Hydrophobic Character of Linear Alkyl Chains

Siti Nurhanna Riduan,[a, #] Yuan Yuan,[a, #] Feng Zhou,[b, #] Jiayu Leong,[a] Haibin Su,[b] Yugen Zhang [a]**

Materials and Methods

Synthesis of Imidazolium Oligomers

All materials were purchased from Sigma Aldrich or Merck, and used as purchased. All manipulations were done without any special precautions to eliminate air or moisture. Synthesis of imidazolium oligomers were adapted from protocols reported previously.[1-2] Nuclear magnetic resonance (NMR) spectra were obtained using a Bruker AV-400 (400 MHz) spectrometer. Chemical shifts were reported in ppm from tetramethylsilane with the solvent resonance as the internal standard.



SchemeS1. Synthetic procedure of IBN-1 Analogues

Representative synthesis of 1,4-bis(N-imidazole-1-ylmethyl)benzene (1): A mixture of imidazole (0.9 g, 13.0 mmol) and sodium hydroxide (0.5 g, 12 mmol) in DMSO (5 mL) was heated to 90°C for 2 h, and then was cooled to room temperature. A solution of α,α'-dichloro-p-xylene (0.99 g, 5.7 mmol) in DMSO (10 mL) was added to the mixture and heated slowly to 40°C for 1 h with constant stirring. The solution obtained was poured into ice-cold water (40 mL). The precipitate was collected, washed with water, and recrystallized from methanol/water to give 1,4-bis(N-imidazole-1-ylmethyl)benzene (**1**) as a white solid (0.95 g,

79 %). ^{1}H NMR ($CDCl_3$): δ 7.55 (s, 2H), 7.13 (s, 4H), 7.10 (s, 2H), 6.89 (s, 2H), 5.12 (s, 4H). MS (GC-MS) m/z 238 (M+).

Similar procedure was used for the synthesis of 1,2-bis(N-imidazole-1-ylmethyl)benzene, α,α'-dichloro-o- xylylene (**2**). ^{1}H NMR ($CDCl_3$): δ 7.45 (s, 2H), 7.38 (d, 2H), 7.12 (s, 2H), 7.08 (d, 2H), 6.80 (s, 2H), 5.03 (s, 4H). MS (GC-MS) *m/z* 238 (M^+).

Synthesis of 3-C6: A mixture of 1,4-bis(N-imidazole-1-ylmethyl)benzene (1) (10 mmol, 2.38 g) and 1-bromohexane (9.8 mmol, 1.375 mL) was stirred in DMF (15 mL) at 90 °C. After overnight stirring, the reaction mixture was allowed to cool before pouring into diethyl ether (50 mL) to isolate the product as a viscous solution. Washing the viscous solution and drying the solution in vacuo to remove DMF would yield the product in quantitative yields. ^{1}H NMR (DMSO-d_6): δ 9.43 (s, 1H), 7.85 (m, 3H), 7.42 (d, 2H), 7. 30 (d, 2H),7.19 (s, 1H), 6.87 (s, 1H), 5.45 (s, 2H), 5.22 (s, 2H), 4.18 (m, 2H), 1.77 (b, 2H), 1.23 (b, 6H), 0.83 (t, 3H).

The same procedure was used to synthesize other analogues **3-C8**, **3-C10**, **3-C12**, **3-C14** and **3-C16**. For longer chains, such as C12 to C16, the product is isolated as a white precipitate.

3-C8: ^{1}H NMR (MeOD): δ 9.21 (s, 1H), 7.76 (s, 1H), 7.65 (d, 2H), 7.45 (d, 2H), 7. 34 (d, 2H),7.12 (s, 1H), 6.98 (s, 1H), 5.43 (s, 2H), 5.27 (s, 2H), 4.23 (m, 2H), 1.90 (b, 2H), 1.32 (b, 10H), 0.89 (t, 3H).

3-C10: ^{1}H NMR (MeOD): δ 9.21 (s, 1H), 7.76 (s, 1H), 7.65 (d, 2H), 7.45 (d, 2H), 7. 34 (d, 2H),7.12 (s, 1H), 6.98 (s, 1H), 5.40 (s, 2H), 5.26 (s, 2H), 4.20 (m, 2H), 1.90 (b, 2H), 1.32 (b, 14H), 0.89 (t, 3H).

3-C12: ^{1}H NMR (MeOD): δ 9.21 (s, 1H), 7.76 (s, 1H), 7.65 (d, 2H), 7.45 (d, 2H), 7. 34 (d, 2H),7.12 (s, 1H), 6.98 (s, 1H), 5.43 (s, 2H), 5.27 (s, 2H), 4.23 (m, 2H), 1.90 (b, 2H), 1.32 (b, 18H), 0.90 (t, 3H).

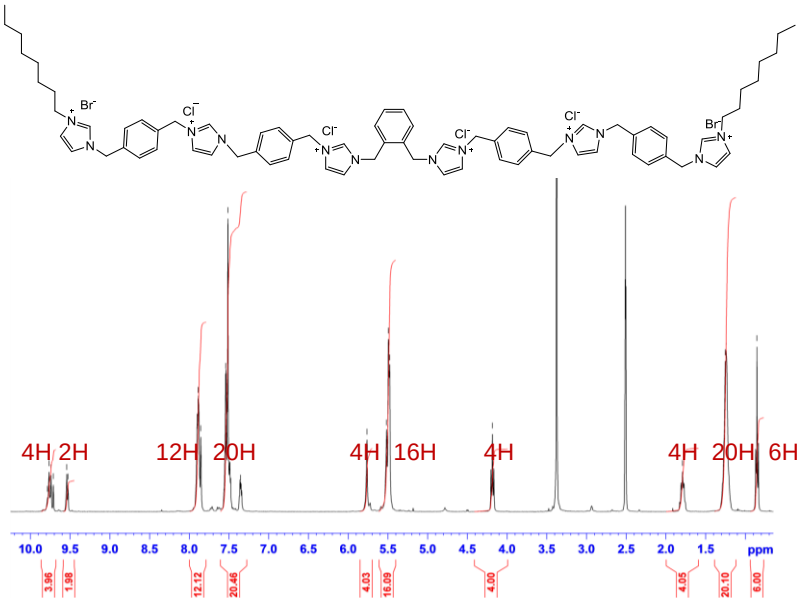
3-C14: ^{1}H NMR (DMSO-D6): δ 9.27 (s, 1H), 7.80 (m, 3H), 7.38 (d, 2H), 7. 31 (d, 2H),7.17 (s, 1H), 6.89 (s, 1H), 5.39 (s, 2H), 5.20 (s, 2H), 4.11 (m, 2H), 1.77 (b, 2H), 1.25 (b, 22H), 0.85 (t, 3H).

3-C16: ^{1}H NMR (DMSO-D6): δ 9.28 (s, 1H), 7.80 (m, 3H), 7.38 (d, 2H), 7. 32 (d, 2H),7.18 (s, 1H), 6.90 (s, 1H), 5.39 (s, 2H), 5.20 (s, 2H), 4.15 (m, 2H), 1.78 (b, 2H), 1.23 (b, 26H), 0.85 (t, 3H).

3-Cy: ^{1}H NMR (DMSO-D6): δ 9.28 (s, 1H), 7.80 (m, 3H), 7.38 (d, 2H), 7. 31 (d, 2H),7.17 (s, 1H), 6.90 (s, 1H), 5.40 (s, 2H), 5.20 (s, 2H), 4.03 (m, 2H), 0.91-1.79 (m, 11H).

Synthesis of 4: A,α'-dichloro-p-xylene (2.63 g, 15.0 mmol) was dissolved in 25 ml DMF and heated to 90 ^{o}C. Then 1,2-bis(N-imidazole-1-ylmethyl)benzene (714 mg, 3.0 mmol) was dropped to the solution and the mixture was stirred at 90 ^{o}C for 8 h. After cooling down the organic phase was collected by decantation and the insoluble part was discarded. The solvent in the organic phase was removed under vacuum and the white solid obtained was purified by re-precipitation (1.61 g, yield 91%). 1H NMR ($(CD_3)_2SO$): δ 9.78 (s, 2H), 7.89 (s, 4H), 7.37-7.56 (m, 12H), 5.76 (s, 4H), 5.51 (s, 4H), 4. 78 (s, 4H).

Synthesis of IBN-1 analogues: A mixture of **3-C8** (862 mg, 2 mmol) and **4** (588 mg, 1 mmol) in DMF (20 ml) was stirred at 90 ^{o}C for 15 h. After cooling down, the reaction mixture was centrifuged and the solution decanted. The precipitates were washed with DMF thoroughly and further purified by re-precipitation from methanol. C8 was obtained as white solid (1.10 g, yield 76.2%). 1H NMR ($(CD_3)_2SO$): *δ* 9.78 (s, 4H), 9.58 (s, 2H), 7.87-7.92 (m, 12H), 7.36-7.54 (m, 20H), 5.78 (s, 4H), 5.50 (m, 16H), 4. 19 (t, 4H), 1.79 (m, 4H), 1.24 (m, 20H), 0.85 (t, 6H).



The same procedure was used to synthesize other analogues **IBN-C6, C8-C16, Cy**.
IBN-C6: ^{1}H NMR (MeOD): δ 9.35 (s, 6H), 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.49 (m, 16H), 4.24 (m, 2H), 1.89 (b, 2H), 1.34 (b, 6H), 0.90 (t, 3H).
IBN-C10: ^{1}H NMR (MeOD): δ 9.35 (s, 6H), 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.50 (m, 16H), 4.24 (m, 2H), 1.91 (b, 2H), 1.35 (b, 14H), 0.90 (t, 3H).
IBN-C12: ^{1}H NMR (MeOD): δ 9.35 (s, 6H), 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.47 (m, 16H), 4.23 (m, 2H), 1.90 (b, 2H), 1.32 (b, 18H), 0.90 (t, 3H).
IBN-C14: ^{1}H NMR (MeOD): δ 9.35 (s, 6H), 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.47 (m, 16H), 4.23 (m, 2H), 1.89 (b, 2H), 1.33 (b, 22H), 0.90 (t, 3H).
IBN-C16: ^{1}H NMR (MeOD): δ 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.46 (m, 16H), 4.23 (m, 2H), 1.90 (b, 2H), 1.32 (b, 26H), 0.90 (t, 3H).
IBN-Cy: ^{1}H NMR (MeOD): δ 9.35 (s, 6H), 7.35-7.70 (m, 32H), 5.70 (s, 4H), 5.49 (m, 16H), 4.09 (m, 2H), 0.98-1.89 (m, 11H).

Antimicrobial Studies
Minimum Inhibitory Concentration: *Staphylococcus aureus* (ATCC 6538, Gram-positive), *Escherichia coli* (ATCC 25922, Gram-negative), *Pseudomonas aeruginosa* (Gram-negative), and *Candida albicans* (ATCC 10231, fungus) were used as representative microorganisms to challenge the antimicrobial functions of the imidazolium salts. All bacteria and fungus were stored frozen at -80 °C, and were grown overnight at 37 °C in Tryptic Soy broth (TSB) prior to experiments. Fungus was grown overnight at 22 °C in Yeast Mold (YM) broth. Subsamples of these cultures were grown for a further 3 h and diluted to give an optical density value of 0.07 at 600 nm, corresponding to 3 X10^{8} CFU mL^{-1} (McFarland' Standard 1).

The oligomers were dissolved in PBS at a concentration of 1 mg mL^{-1} and the minimal inhibitory concentrations (MICs) were determined by microdilution assay. Typically, a 100 µL microbial solutions (containing 3 X 10^{8} cells mL^{-1}) were added to 100 µL of PBS containing the test imidazolium salts (normally ranging from 500 mg mL^{-1} to 2 mg mL^{-1} in serial two-fold dilutions) in each well of the 96-well microtiter plate. The plates were incubated at 37 °C for 24 h with shaking at 300 rpm, with monitoring at the 2, 4, 6, 8, and 24 h time points. The minimum inhibitory concentrations were taken as the concentration of the antimicrobial oligomer at which no microbial growth was observed with the microplate reader.

Broth and PBS solution containing microbial cells alone were used as negative controls, and experiments were run in triplicates.

Time Kill Kinetics: The experimental setup for time kill kinetics was similar to the set up for MBC determination. The microbes were treated with oligomers at 4MIC concentration, and samples were taken out of each well at 2 minutes. 500 µl of cell suspension was removed, rescued by a series of 10- fold dilutions with growth medium, and kept on ice until plating. For plating, 50 µl to 200 µl of the diluted samples was spread on growth medium agar plates and colonies were counted after overnight incubation at 37 °C.

Minimium Biocidal Concentration: The microbes were inoculated and prepared according to the procedure for MIC determination. The microbes were then treated with the oligomers at various concentrations of 0.5 MIC, MIC, 2 MIC, and were incubated at 37 °C for 24 hours at constant shaking of 300 rpm. The bacterial samples were taken out of each well after the aforementioned period, and subjected to a series of 10-fold dilutions. 20 uL of the diluted sample was then streaked across an agar plate, before incubation of the plate at 37 °C for 24 h. Colony forming units (CFU) were counted after overnight incubation, and the results were calculated according to the formula:

Log reduction =

$$\log_{10}(number\ of\ colonies\ (PBS\ control) X\ dilution\ factor) - \log_{10}(number\ of\ colonies\ (oligomer) X\ dilution\ factor)$$

$$\% \text{ kill} = \frac{(control\ X\ dilution\ factor) - (Oligomer\ X\ dilution\ factor)}{(Control\ X\ dilution\ factor)}\ X\ 100$$

Hemolysis: Fresh rat red blood cells (RBCs) were diluted with PBS buffer to give an RBC stocksuspension (4 vol% blood cells). A 100 µL aliquot of RBC stock was added to a 96-well platecontaining 100 mL oligomer stock solutions of various concentrations (serial 2-fold dilution in PBS). After 1 h incubation at 37°C, The contents of each well was pipetted into a microcentrifuge tube and then centrifuged at 4000 rpm for 5 min. Hemolytic activity was determined as a function of hemoglobin release by measuring OD576 of 100 mL of the supernatant. A control solution that contained only PBS was used as a reference for 0% hemolysis. 100% hemolysis was measured by adding 0.5% Triton-X to the RBCs.

$$\% \text{ Hemolysis} = \frac{OD576\ (oligomer) - OD576\ (PBS)}{OD576\ (Triton-X) - OD576\ (PBS)}\ X\ 100$$

Critical Micellar Concentration: The CMC values of the oligomers were determined in both DI water and PBS, using a LS50B luminescence spectrometer (Perkin Elmer, United States) and employing pyrene as a fluorescent probe. A known weight of the oligomer was dissolved in either 2mL of DI water or PBS in a 4mL glass vial and serial dilutions were effected. 10µL of pyrene stock solution in acetone (6.16 X 10^{-5} M) was added to each vial containing 1mL of a known concentration of the oligomer, and the acetone was then evaporated at room temperature. The solution was allowed to equilibrate overnight and the final concentration of pyrene in each vial was 6.16 X 10^{-7} M. The excitation spectra of the solutions were scanned from 300 to 360 nm with an emission wavelength of 395 nm, and both the excitation and emission bandwidths were set at 2.5 nm. The intensity ratios (I_{337}/I_{334}) were plotted against polymer concentration. The CMC value was given by the intersection of the tangent to the curve at the inflection and the tangent of the points at low polymer concentrations.

SEM observation: The morphologies of the organogel microstructurewere observed using a field emission SEM (JEOL JSM-7400F)operated at an accelerating voltage of 10 keV. The gels were dried via supercritical drying, and stored in under anhydrous conditions, either in a glovebox or a dessicator prior to imaging.

E. coli cells (3×10^8 CFU/ml) grown in TSB without or with IBN-C8 (MIC and 4MIC) for 2 min were collected and centrifuged at 5000 rpm for 6 min. The precipitates were washed twice with PBS buffer. Then the samples were fixed with formalin for 30 min followed by washing with DI water twice. Dehydration of the samples was performed using a series of ethanol/water solution (35%, 50%, 75%, 90%, 95% and 100%). The dehydrated samples were mounted on copper tape. After drying for 2 days, the samples were coated with platinum for imaging with JEOL JSM-7400F (Japan) field emission scanning electron microscope.

Preparation of the gels: Gels were prepared by weighing the imidazolium oligomers directly into 4 mL glass vials and subsequently adding a known weight or volume of the solvent. The vials containing both the imidazolium and the solvent were either shaken or sonicated to aid the dissolution process. The vials were left standing over night at ambient conditions. The gel state was evaluated by the stable-to-inversion-of-a-test-tube method. The critical gelation concentration (CGC) is defined as the lowest concentration of the gelator which leads to a stable gel.

Rheological characterization of the gels: Rheological measurements were performed with a control strain rheometer (ARES G2, U.S.A) equipped with a plate-plate geometry of 8 mm diameter. Measurements were taken by equilibrating the gels at 25 °C between the plates at a gap of 1.0 mm. Strain-amplitude sweeps were performed at angular frequency of 10 rad/s. The shear storage modulus (G') and loss modulus (G") were measured at each point.

Frequency sweeps were performed at strain amplitude of 5% to ensure the linearity of viscoelasticity. The dynamic storage modulus (G') and loss modulus (G") were examined as a function of frequency from 0.1 to 100 rad/s. In addition, viscosity of the gel was also examined as a function of shear rate from 0.1 to 50/s.

To test the thermal stability of the gels, the storage and loss moduli of **IBN-C8** in EtOH (11.0%), n-PrOH (9.8%), and n-BuOH (11.3%) were measured from a temperature ramp performed at 5% strain with heating rate at 5 ^{o}C/min.

Zone of inhibition test: A standard zone of inhibition test under static conditions was performed to investigate the antimicrobial activity of the gels formed by **IBN-C8** in alcohols. In this method, 100 µl of pure n-butanol or gel of **IBN-C8** in n-butanol were placed in holes (10×10 mm^2) bored into LB agar plates that were previously seeded with a confluent layer of *E. coli*. The agar plates were incubated at 37 ^{o}C for 24 h, and the size of inhibition halos was used to assess the antimicrobial activity.

Computational study: All simulations were performed using the GROMACS 4.5.3 suite of programs.[3] The GROMOS 53a6 force field [4] was used to describe the oligomer, and the lipids were described using the parameters of Berger et al.[5] Water molecules were described using the tip3p water model.[6] All simulations were performed under periodic boundary conditions at constant temperature and pressure. The overall temperature of the water and peptides was kept constant, coupling independently each group of molecules at 300 K with Nose-Hoover thermostat.[7] The pressure was coupled to a Parrinello-Rahman [8] barostat at 1 atm separately in every dimension. Long-range electrostatic interactions were computed using the fourth-order

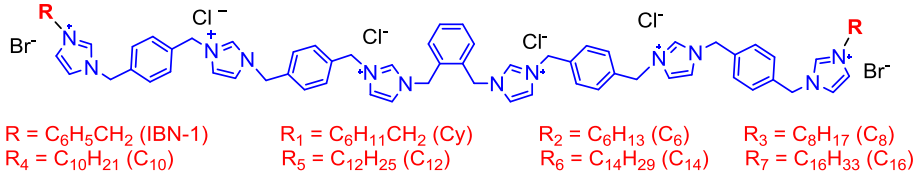
particle mesh Ewald (PME) method [9] with a Fourier spacing of 0.12 nm. A cutoff of 1.4 nm was implemented for the Lennard–Jones and the direct space part of the Ewald sum for Coulombic interactions. Bond lengths within the small molecules and lipids were constrained using the LINCS algorithm.[10] The initial coordinates of the small molecules were made from Gaussview [11] and the force field parameters are obtained from PRODRG.[12] Since the small molecules carry a net positive charge, Cl^- counter ions were added to achieve neutrality of the system. A potential of mean force (PMF) is a potential that is obtained by integrating the mean force from an ensemble of configurations as follows,.

$$W(\xi) = -\int \langle F(\xi) \rangle d\xi \quad (1)$$

Wwhere ξ is the order parameter taken as the separation distance between the center of mass of the oligomers and that of the POPC. We consider the average of forces $\langle F(\xi) \rangle$ acting on the oligomer over the sampled configurations at each separation distance.

TPSA and *log P*: Calculated by Molinspiration property engine v2013.09, available at http://www.molinspiration.com/cgi-bin/properties.

Table S1.Minimum inhibitory concentrations (MIC) and selectivity indices of **IBN-1** analogues.[a]



IBN-	*LogP*	MIC				GM	HC_{10}	Selectivity Index
		S. A.	E. coli	P. A.	C. A.			
C6	-5.91	4	8	8	16	8	>100000	>>1000 [b]
C8	-5.56	4	8	16	16	9.51	12500	1314
C10	-5.03	4	8	8	31	9.44	500	25
C12	-3.70	4	8	16	31	11.22	31	2.81
C14	-1.75	4	16	16	31	13.35	15	1.15
C16	0.27	8	16	16	62	18.88	15	0.83
Cy	-6.06	8	16	16	31	15.87	12500	787
1	-6.14	3	4	31	31	10.36	>100000	>>1000[b]

[a] MIC values are in $ugmL^{-1}$; *Log P* is calculated by Molinspiration Property Engine (v2013.09); *S. A.: S. aureus; P. A.: P. aeruginosa; C. A.: C. Albicans*; GM: geometric mean of the MICs of the 4 microbes. [b] Did not induce ~10% hemolysis at maximum concentration tested (100,000 ppm); Selectivity index = HC_{10}/GM.

Table S2. Antimicrobial activity screening Controls.

Entry	compound	MIC (µg/ml)			
		E. Coli	*S. aureus*	*P. Aeruginosa*	*C. Albicans*
1	1,3-bisbenzyl-imidazolium chloride (monomer)	>250	>250	> 250	>250
2	Chlorhexidine	15.6			

3	Vancomycin	----	1.3		----
4	amphotericin B				3.9
5	Benzalkonium chloride*	31	31	62.5	16
6	Chloroxylenol*	>100	>100	>100	>100

* Active components in common healthcare products.

Table S3. CMC Values of IBN-1 analogues in DI H_2O and PBS buffer solution.

Oligomer IBN-	**CMC in DI H_2O (ppm)**	**CMC in PBS (ppm)**
C12	938.5	10.9
C14	200.3	4.9
C16	38.5	1.3

Table S4. Concentration of oligomers to form gels in various solvents.

Solvent	**IBN-C6**	**C8**	**C10**	**C12**	**C14**	**C16**
Ethylene glycol	Solution	Solution	Solution	Solution	Solution	Gel (4.7wt%)
Glycerol	Solution	Solution	Solution	Solution	Solution	Gel (6.3wt%)
Acetonitrile	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble
Acetone	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble
*n*BuOH	Gel (9.2wt%)	Gel (11.3wt%)	Gel (7.9wt%)	Gel (5.8wt%)	Gel (5.3wt%)	Gel (6.9wt%)
*n*PrOH	Gel (7.8wt%)	Gel (9.8wt%)	Gel (7.9wt%)	Gel (7.2wt%)	Gel (5.3wt%)	Gel (6.9wt%)
EtOH	Gel (11wt%)	Gel (11wt%)	Gel (12wt%)	Gel (9.0wt%)	Gel (12.9wt%)	Gel (9.6wt%)

Table S5. Critical gelation concentrations (CGC) of **IBN-C8** in selected alcohols at room temperature (25^{o}C). **IBN-C8** showed moderate gelation ability in ethanol, *n*-propanol or *n*-butanol with the CGC in the range of 2.0 to 4.0%.

Entry	**alcohol**	**CGC**
1	Ethanol	4.0 wt%
2	*n*-propanol	2.0 wt%
3	*n*-butanol	2.5 wt%

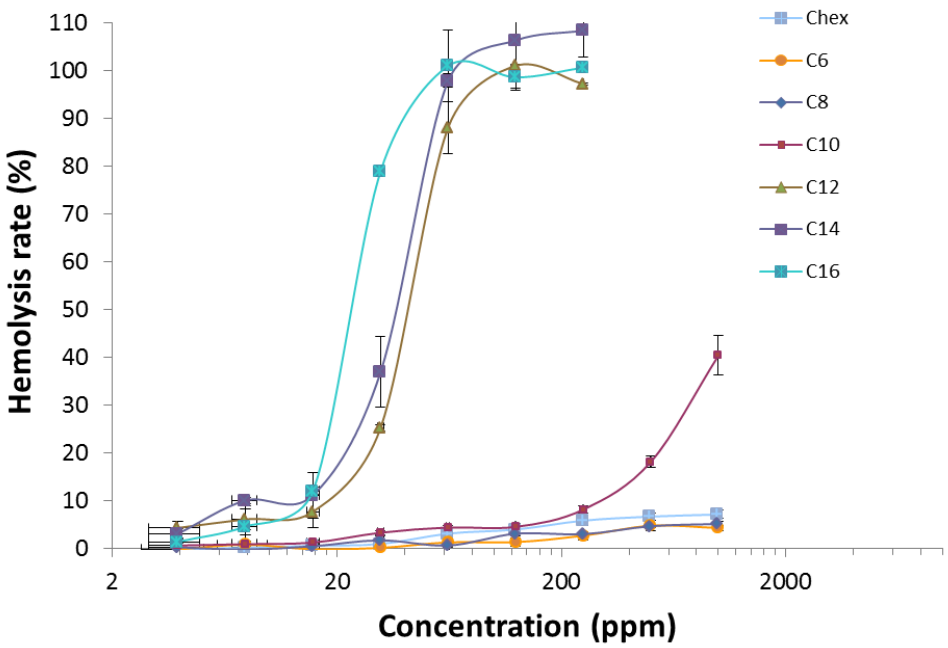


Figure S1. Hemolytic properties of the **IBN-1** analogues at lower concentrations (up to 1000 ppm).

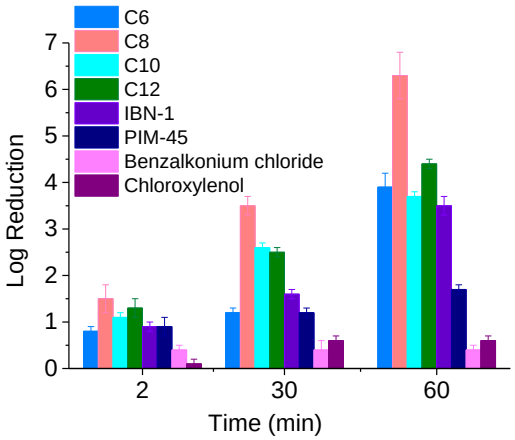


Figure S2. Time killing efficiency for imidazolium oligomers, polymer, small molucles against *E. coli* at 8 mg/ml concentration. **IBN-C8** demonstrated constant high activity.

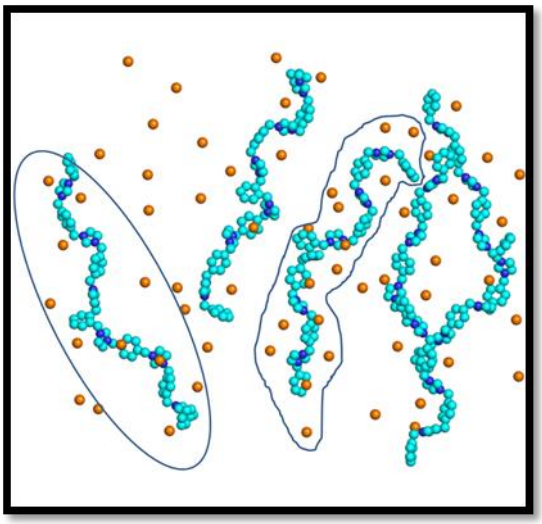


Figure S3. Top view of the near layer with the **IBN-1** bounded to the lipid bilayer surface. The **IBN-1** molecules attract phosphate groups creating depletion zones as lined out. The **IBN-1** molecules are shown in blue color and the phosphor atoms are shown in gold color.

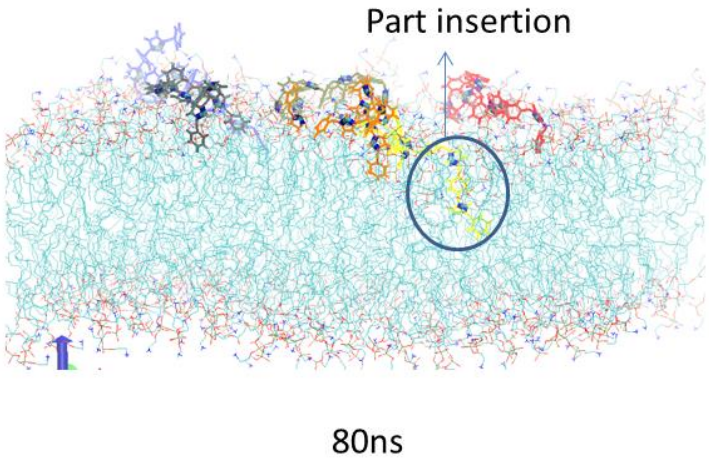


Figure S4. The snapshot of six **IBN-1** binding on the surface of POPC membrane. The system was equilibrated for 600 ps and then was simulated for 80 ns without restraints. For the first 10 ns the oligomers appeared to diffuse randomly on the surface of the membrane, catching phosphate groups but causing little obvious disruption of the membrane. The oligomers migrated toward the center of the depression, making the planar membrane bent, suggesting it was under considerable stress. Some spontaneous part insertion of small molecules was observed. However, the crucial insertion of whole molecules into the membrane was still not observed at the current time scale. The membrane is shown in thin stick, the **IBN-1** are shown in thick stick using different color for each chain. The nitrogen atoms in **IBN-1** are shown in blue color.

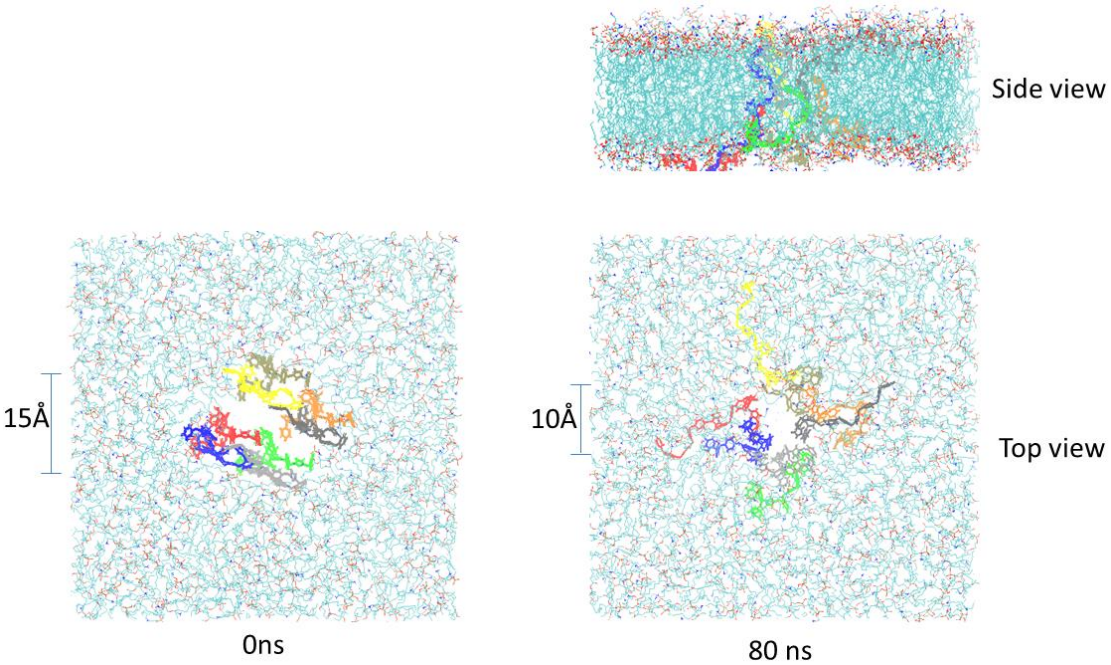


Figure S5. As a reserve process, we put six **IBN-1** molecules into the hole of the membrane and run the MD simulation. After 80 ns, the diameter of the hole shrinks from 15 Å to 10 Å. The six **IBN-1** molecules are still packed tightly in the center of the hole and have no tendency to move to the surface of membrane, indirectly showing the possibility of spontaneous insertion of small molecules into membrane.

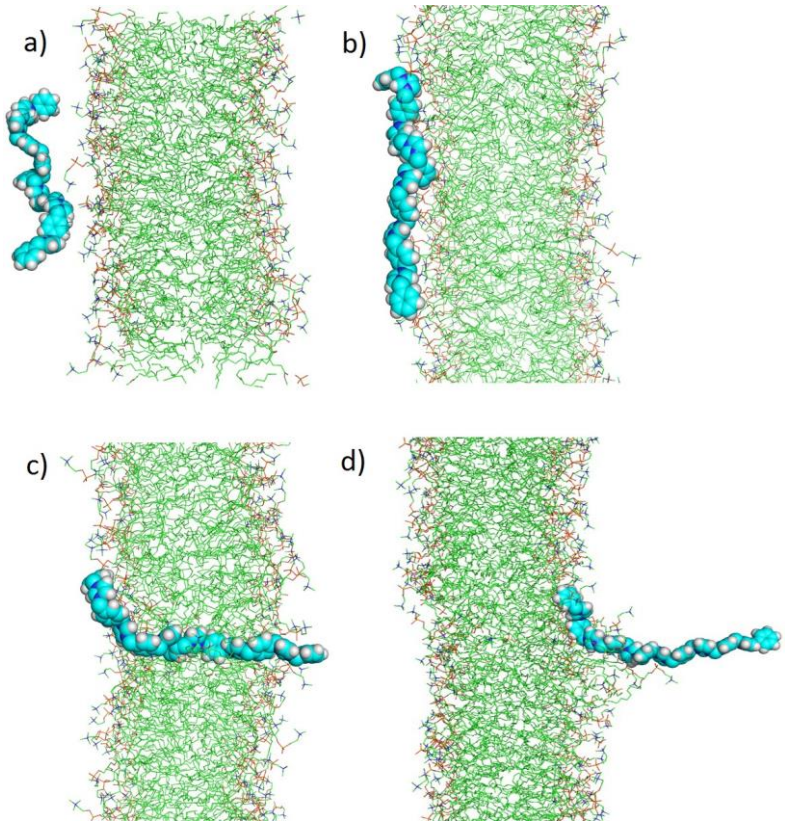


Figure S6. Key stages during the pulling of one motif1 molecule through the membrane. The motif1 molecule are shown in sphere representation (carbon in light blue, hydrogen in white),

and the lipids are shown in stick representation (carbon in green, hydrogen in white, oxygen in red, nitrogen in dark blue, phosphor in orange). The explicit waters are not shown. (a) The initial system. (b) The molecules bind to the upper monolayer. (c) The molecule reaches the center of bilayer. (d) The molecule reaches the surface of the lower monolayer.

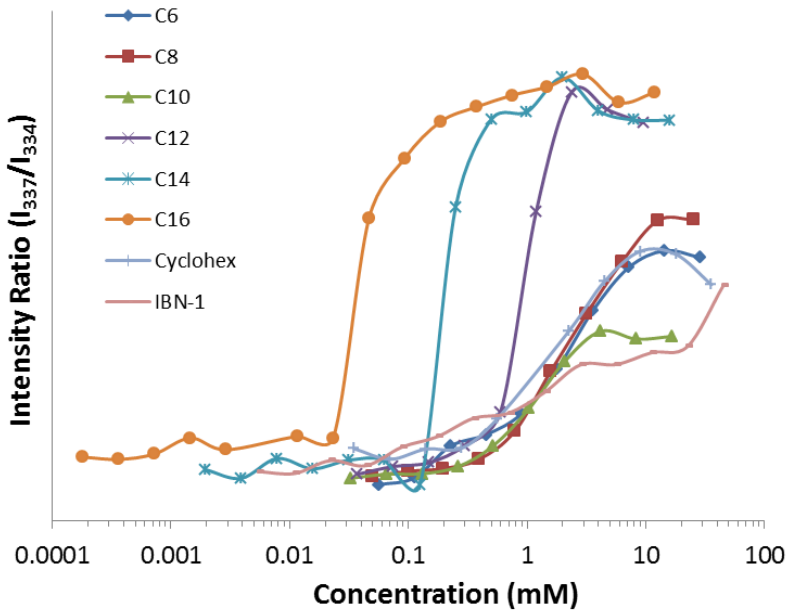


Figure S7. CMC determination in deionized water.

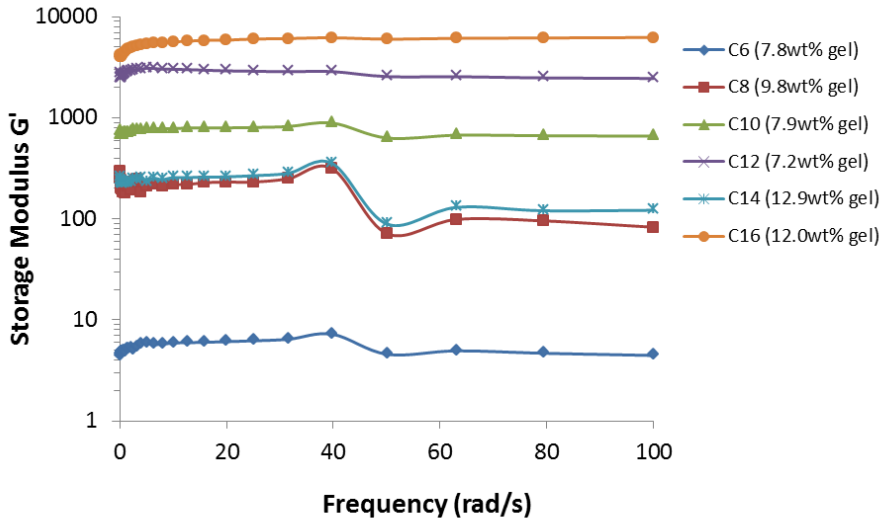


Figure S8. Storage moduli of gels of different **IBN-1** analogues in n-propanol obtained from an angular frequency sweep performed at 5% strain.

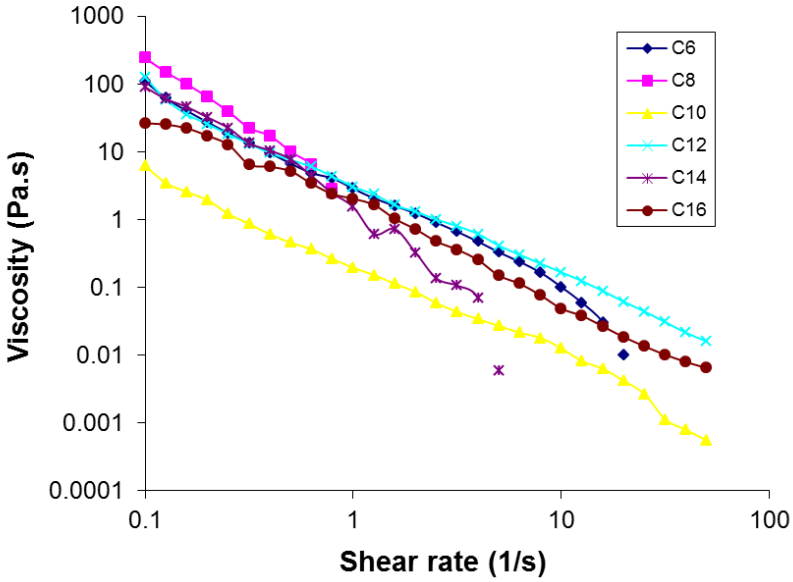


Figure S9. Viscosity as a function of the shear rate for gels of different **IBN-1** analogues in *n*-butanol.

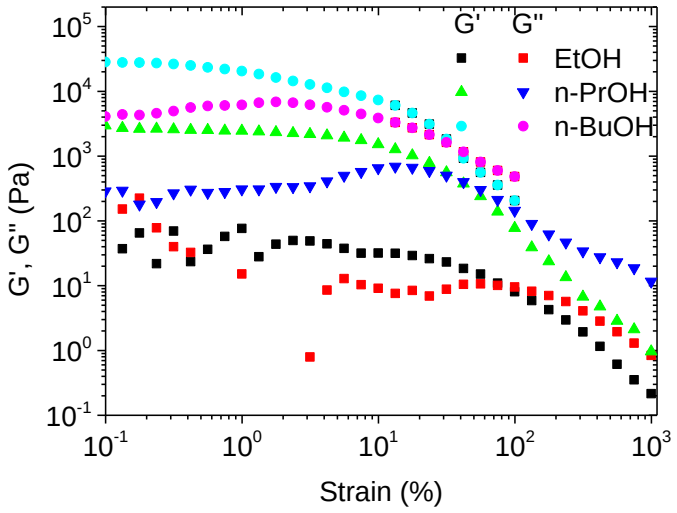


Figure S10. Storage and loss moduli of **IBN-C8** in EtOH (11.0%), *n*-PrOH (9.8%), and *n*-BuOH (11.3%) obtained from a strain-amplitude sweep performed at 10 rad/s.

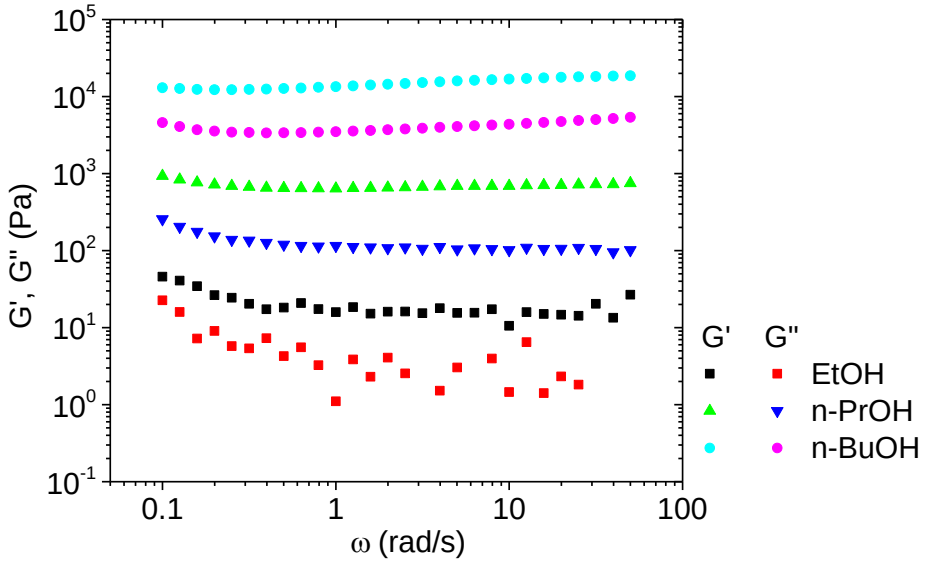


Figure S11. Storage and loss moduli of **IBN-C8** in EtOH (11.0%), *n*-PrOH (9.8%), and *n*-BuOH (11.3%) obtained from an angular frequency sweep performed at 5% strain.

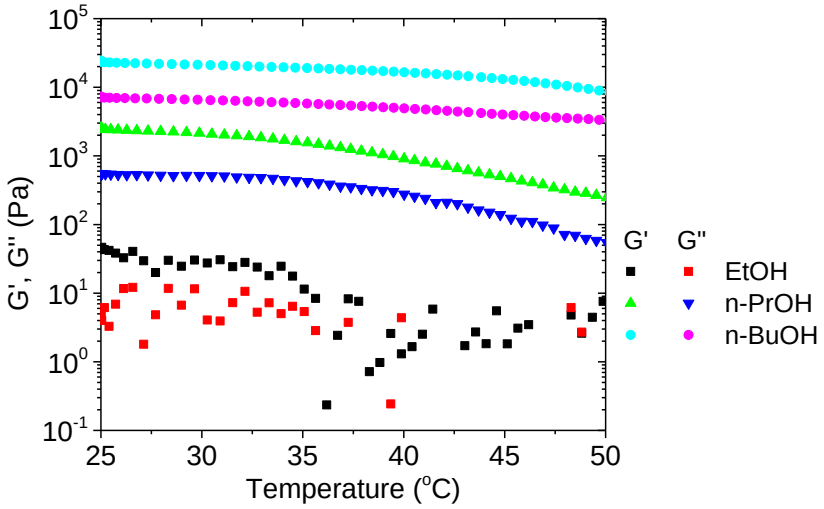


Figure S12. Storage and loss moduli of **IBN-C8** in EtOH (11.0%), *n*-PrOH (9.8%), and *n*-BuOH (11.3%) obtained from a temperature ramp performed at 5% strain. The heating rate was 5°C/min.

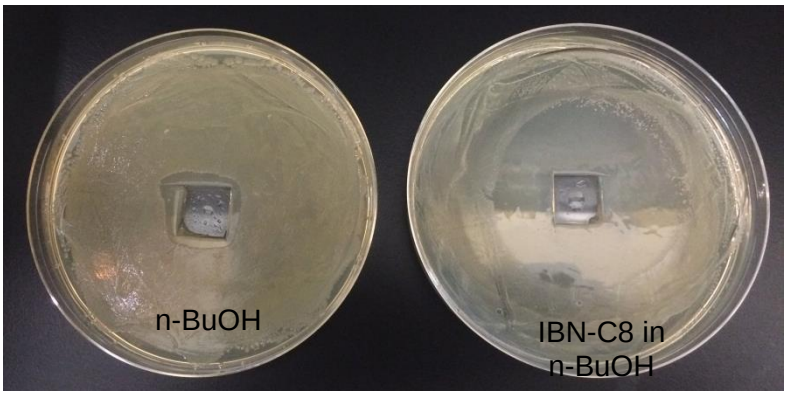


Figure S13. Inhibition zone of *n*-BuOH (100 µl) and the gel of **IBN-C8** in *n*-BuOH (5.0 wt%, 100 µl) against *E. coli*. The zone of inhibition for *n*-BuOH is about 7 mm, while the zone of inhibition for **IBN-C8**/*n*-BuOH gel is 23 mm.

References:

1. Liu, L., Huang, Y., Riduan, S. N., Gao, S., Yang, Y.-Y., Fan, W., Zhang, Y. Main-chain imidazolium oligomer material as a selective biomimetic antimicrobial agent. Biomaterials 33, 8625-8631 (2012).
2. Zhang, Y., Zhao, L., Patra, P. K., Hu, D., Ying, J. Y. Colloidal poly-imidazolium salts and derivatives. Nano Today 4, 13-20 (2009).
3. D. van der Spoel, et al. J. Comput. Chem. 2005, 26, 1701–1718.
4. C. Oostenbrink, A. Villa, A. E. Mark, W. F. van Gunsteren, J Comput Chem. 2004, 25, 1656-1676.
5. O. Berger, O. Edholm, F. Jahnig, Biophys. J. 1997, 72, 2002–2013.
6. W. L. Jorgensen, J. Chandrasekhar, J. D. Madura, R. W. Impey, M. L. Klein, J. Chem. Phys. 1983, 79, 926-935.
7. A. Cheng, K. M. Jr. Merz, J. Phys. Chem. 1996, 100, 1927-1937.
8. M. Parrinello, A. Rahman, J. Appl. Phys. 1981, 52, 7182–7190.
9. D. Tom, Y. Darrin, P. Lee, J. Chem. Phys. 1993, 98, 10089–10092.
10. B. Hess, H. Bekker, H. J. C. Berendsen, J. G. E. M. Fraaije, J. Comput.Chem. 1997, 18, 1463–1472.
11. R. Dennington, T. Keith, J. Millam, GaussView, Version 5, Semichem Inc., Shawnee Mission, KS, 2009.
12. A. W. Schüttelkopf, D. M. F. van Aalten, ActaCrystallogr 2004, D60, 1355–1363.