membranes

MDPI

Article

SUPPLEMENTARY INFORMATION

Biomimetic Stratum Corneum Liposome Models: Lamellar Organization and Permeability Studies

Susmita Roy [1], James C.S. Ho [2], Douglas L.C. Teo [1], Shikhar Gupta [2,*] and Madhavan Nallani [1,3,*]

[1] Center for Biomimetic Sensor Science, School of Materials Science and Engineering, Nanyang Technological University, Singapore 637553
[2] Procter & Gamble International Operations SA SG Branch, 138547, Singapore
[3] 3ACM Biolabs Pte Ltd, 71 Nanyang Drive, 638075, Singapore
* Correspondence: SG, s.gupta@pg.com; MN, mnallani@acmbiolabs.com

The supplementary material contains the following:
Figures S1-S2
Table S1-S2

Citation: Roy, S.; Ho, J.C.S.; Teo, D.L.C.; Gupta, S.; Nallani, M. Biomimetic Stratum Corneum Liposome Models: Lamellar Organization and Permeability Studies. *Membranes* **2023**, *13*, 135. https://doi.org/10.3390/membranes13020135

Academic Editor: Marija Raguž

Received: 22 December 2022
Revised: 18 January 2023
Accepted: 18 January 2023
Published: 20 January 2023

FT-IR spectroscopy of stratum corneum lipid liposomes (SCLL)

FTIR spectroscopy was performed to determine the lateral packing and conformational ordering of lipid matrix. The CH_2 symmetric and asymmetric stretching frequency of the hydrocarbon chains provides information on the conformational ordering of lipid tails. The low wavenumbers of the CH_2 symmetric (~2849 cm^{-1}) and asymmetric (~2918 cm^{-1}) vibrations indicate the presence of a highly ordered lipid organization (either hexagonal or orthorhombic). An increase in CH_2 stretching frequency represents the formation of a liquid disordered phase.

The CH_2 stretching vibrations of (both symmetric and asymmetric) CER:FFA: cholesterol:cholesteryl sulfate formulations are plotted in Fig. S1. The result shows that the SCLLs formulated with both saturated CERs (CER 3, CER 6) and FFAs chain have an initial CH2 stretching between 2849.0 to 2850 cm^{-1} (symmetric) and 2917 to 2819 cm^{-1} (asymmetric) respectively. These values of CH2 stretching are characteristic of tightly packed ordered chains conformation. The incorporation of unsaturated FFA (OA) in liposomal membrane increase CH_2 stretching frequency values to 2851 cm^{-1} (symmetric) and 2820 cm^{-1} (asymmetric), suggesting unsaturated fatty acid chain turns the lipid bilayer to a more disordered phase. The most remarkable change was observed in the Bovine CER formulation, where asymmetric stretching frequency shifts from 2917 to 2920 cm^{-1} with changing FFA from saturated SA to unsaturated OA. Moreover, in CER 3B formulations, asymmetric stretching frequency increases to 1-2 cm^{-1} compared to CER 3 formulations, for the same FFA. The result indicates that CER 3B makes bilayer more disordered due to the presence of unsaturation in CER acyl backbone. Thus, both CER acyl chain and FFA structure impact the conformation ordering of lipid matrix in SC bilayer.

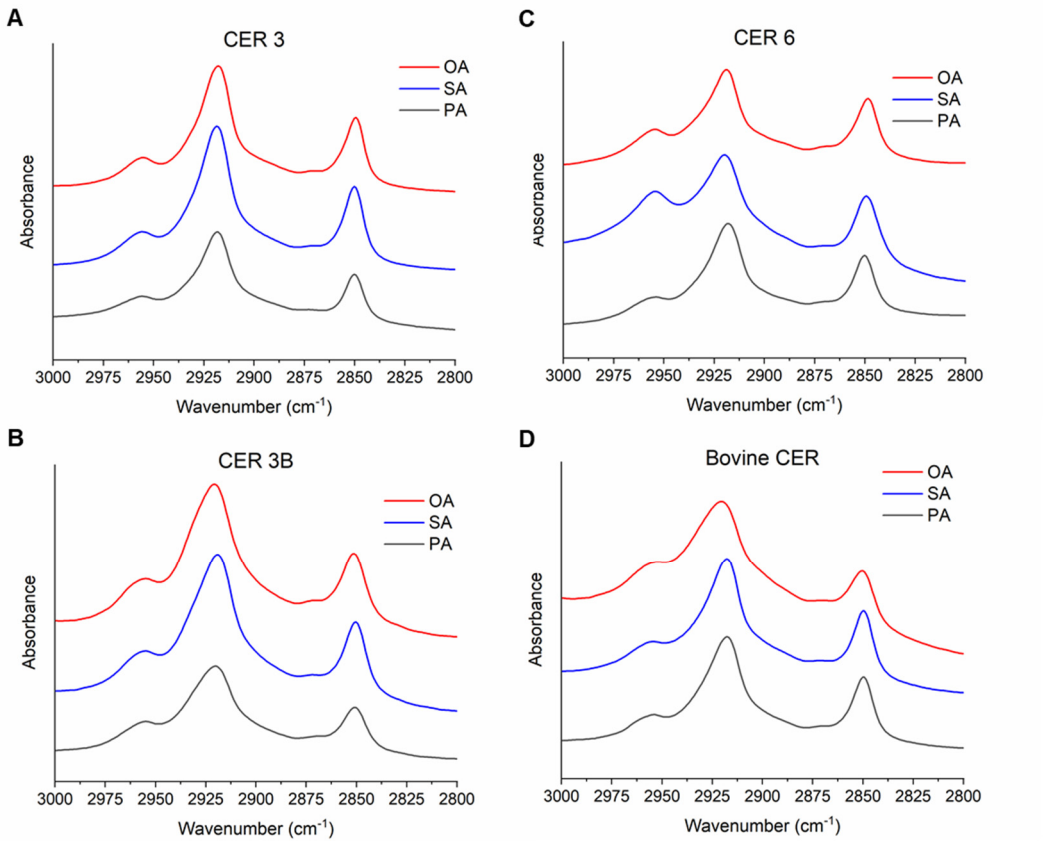

Figure S1. The FT-IR spectroscopy analyses of SCLLs. Representative plots of (A) CER3-FFAs. (B) CER3B-FFAs. (C) CER6- FFAs. (D) Bovine CER-FFAs.

Dynamic light scattering (DLS) measurement of SC lipid liposomes (SCLL)

The 12 SCLLs were extruded and examined by dynamic light scattering (DLS). The hydrodynamic diameters, based on intensity distribution are comparable for all SCLLs, and fall between 120-170 nm (Fig. S2 and Table 1). The polydispersity indices (PDIs) vary between 0.01-0.14, suggesting that monodisperse SCLLs are formed.

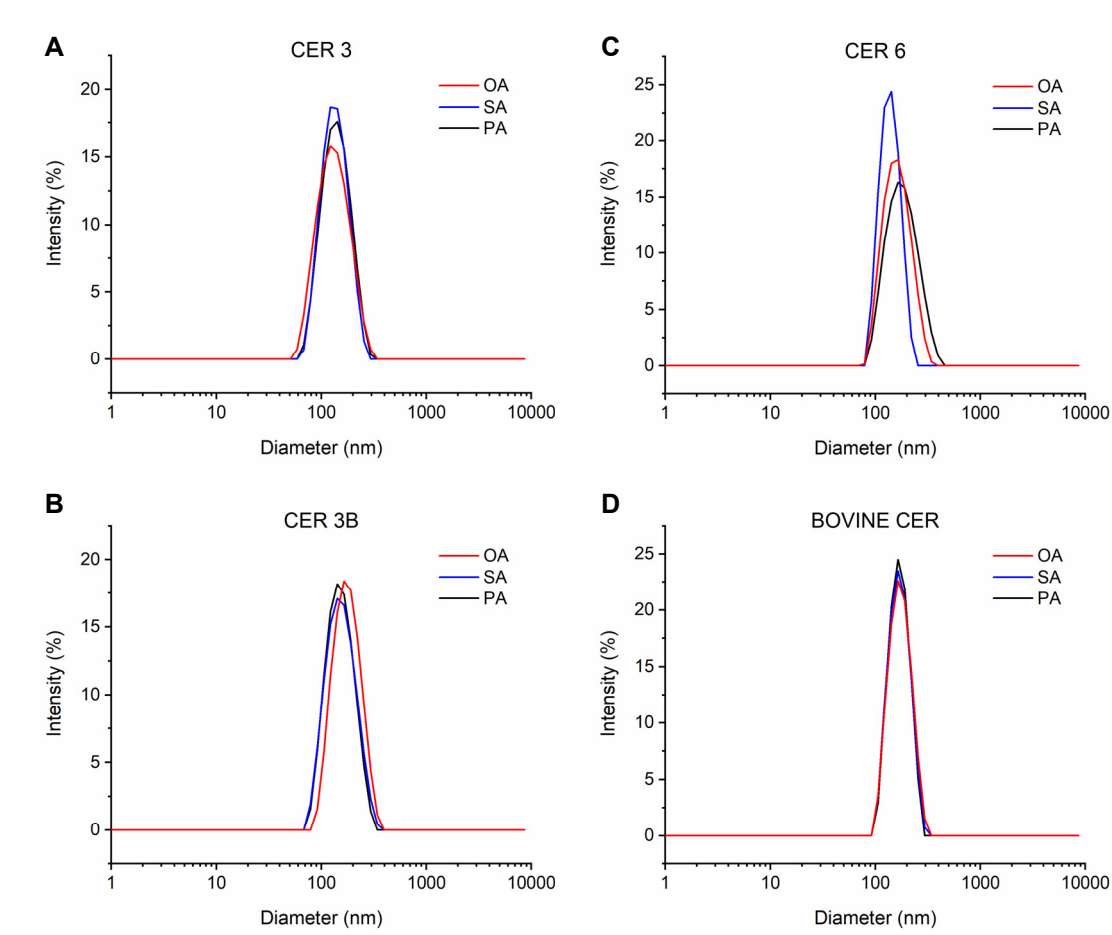

Figure S2. Dynamic light scattering (DLS) measurements of extruded SCLL. Intensity-weighted size distributions are shown for (A) CER3-FFAs, (B) CER3B-FFAs, (C) CER6- FFAs, and (D) Bovine CER-FFAs.

Table S1. Comparison of lamellar phases observed for different lipid compositions.

No.	Lipid composition	SPP (Å)	LPP (Å)	Others (Å)	Ref.
	CER 3 (NP)				
1.	CER 3:FFA mixture:cholesterol (44:31:25, wt%) FFA mixture = OA:LA:PA:MA:SA (10.7:4.0:11.9:1.2:3.2)	74.5	-	-	[54]
2.	CER 3:lignoceric acid:cholesterol (1:1:1, mol%) + 5mol% Cholesteryl Sulfate	52.4	-	42.5, 37.1	[31]
3.	CER 3:FFA:cholesterol:cholesterol sulfate (40:25:25:10, mol%)				This study
	FFA = PA	41.9, 48.3		39.3	
	FFA = SA	48.3		39.3	
	FFA = OA	57.1		39.3	
	CER 6 (AP)				

4.	CER 6:PA:cholesterol:cholesteryl sulfate (55:15:25:5, mol%)	46.0	-	42.1	[56]
5.	CER 6:FFA:cholesterol:cholesteryl sulfate (40:25:25:10, mol%)				This study
	FFA = PA	78.6 – 83.8	-	-	
	FFA = SA	69.8, 44.9	-	-	
	FFA = OA	68.0, 44.9	-	-	
	Bovine CER (NS)				
6.	Bovine CER:FFA mixture:cholesterol (1:1:1, mol%) FFA mixture = C16:C18:C20:C22:C22:3:C24:C26 (1.3:3.3:6.7:41.7:5.4:36.8:4.7)	57.6, 51.8	-	33.5	[53]
7.	Bovine CER:lignoceric acid:cholesterol (1:1:1, mol%) + 5mol% cholesterol sulfate	53.9	-	34.1 (c)	[31,52]
8.	Bovine CER(C24):FFA mixture:cholesterol (1:1:1, mol%) FFA mixture = C16:C18:C20:C22:C24 (1.8:4.0:7.6:47.8:38.8, mol%)	54.0	122	33.8 (c)	[55]
9.	[CER EOS(C30):Bovine CER(C24)]:FFA mixture: cholesterol ([4:6]:1:1, mol%) FFA mixture = C16:C18:C20:C22:C24 (1.8:4.0:7.6:47.8:38.8, mol%)	-	125	37	[58]
10.	Bovine CER:Cer EOS:lignoceric acid:cholesterol (0.7:0.3:1:1) + 5 wt% cholesterol sulfate	-	121.9	34	[57]
11.	[CER 1:CER 3:Bovine CER (AS)]: FFA mixture: cholesterol ([1:7:2]: 1:1) FFA mixture = C16:C18:C20:C22:C22:3:C24:C26 (1.3:3.3:6.7:41.7:5.4:36.8:4.7)	57.1	128	37.2	[27]
12.	Bovine CER:FFA:cholesterol:cholesterol sulfate (40:25:25:10, mol%)				This study
	FFA = PA	-	125.7	-	
	FFA = SA	-	125.7	-	
	FFA = OA	-	139.6	-	
	CER 3B				
13	CER 3B:FFA:cholesterol:cholesterol sulfate (40:25:25:10, mol%)				This study
	FFA = PA	41.9, 57.1, 69.8	-	39.3	
	FFA = SA	48.3, 62.8	-	39.3	
	FFA = OA	52.4, 69.8	-	39.3	

AS = CERs consisting of an α-hydroxylated (A) fatty acid moiety and a sphingosine (S) moiety.

Table S2: Phase transitions detected in the DSC measurement of SCLLs.

Ceramides T_m (°C)	PA		SA		OA	
	T_m (°C) ΔH (J/gm)	Phase Transition	T_m (°C) ΔH (J/gm)	Phase Transition	T_m (°C) ΔH (J/gm)	Phase Transition
CER 3 T_m (1): 126.4 T_m (2): 30.8	T_m (1): 82.3	liquid crystalline to H_{II} phase	T_m (1): 60.3	Orthorhombic to hexagonal I packing to H_{II} phase	T_m (1): 77.2	orthorhombic→ hexagonal → liquid crystalline → H_{II} phase
			T_m (2): 81.3	gel → liquid crystalline→ H_{II} phase	T_m (2): 101.0	Further fluidizing transition
CER 3B T_m: 100.9	T_m (1): 70.5	Orthorhombic to hexagonal packing to hexagonal II phase	T_m (1): 106.6	Further fluidizing transition	T_m (1): 50	orthorhombic to hexagonal packing
	T_m (2): 108.9	Further fluidizing transition			T_m (2): 95.4	Further fluidizing transition
CER 6 T_m: 100.3	T_m (1): 94. 3	liquid crystalline to H_{II} phase	T_m (1): 49.6	orthorhombic to hexagonal packing	T_m (1): 70.0	orthorhombic→ hexagonal → liquid crystalline → H_{II} phase
	T_m (2): 113.0	Further fluidizing transition	T_m (2): 89.6	gel → liquid crystalline → H_{II} phase	T_m (2): 113.2	Further fluidizing transition
Bovine CER T_m: 80.1	T_m (1): 116.5	fluidizing transition	T_m (1): 87.8	Orthorhombic to hexagonal I packing to hexagonal II phase	T_m (1): 109.5	fluidizing transition
			T_m (2): 111.4	Further fluidizing transition		