**Table S1. Raw changes in 25(OH)D and sphingolipids.**

| Metabolites | | Placebo | 600 IU/day | 2000 IU/day | 4000 IU/day |
|---|---|---|---|---|---|
| 25(OH)D | Pre | 39.7 ±14.7 | 35.0 ±7.7 | 39.8 ±10.7 | 32.9 ±10.3 |
| | Post | 42.0 ±12.1 | 56.5 ±12.2 | 90.0 ±32.2 | 83.2 ±21.0 |
| | Changes | 2.2 ±13.0 | 21.5 ±11.2 | 50.2 ±27.1 | 50.3 ±19.6 |
| | p-value | 0.501 | <0.001 | <0.001 | <0.001 |
| C16Cer | Pre | 0.99 ±0.31 | 1.11 ±0.41 | 1.03 ±0.26 | 0.93 ±0.16 |
| | Post | 0.98 ±0.28 | 1.10 ±0.38 | 1.05 ±0.24 | 1.00 ±0.23 |
| | Changes | -0.01 ±0.10 | -0.00 ±0.22 | 0.01 ±0.19 | 0.07 ±0.18 |
| | p-value | 0.766 | 0.965 | 0.787 | 0.164 |
| C18Cer | Pre | 1.02 ±0.43 | 1.17 ±0.56 | 1.03 ±0.44 | 0.95 ±0.22 |
| | Post | 0.87 ±0.39 | 1.19 ±0.52 | 1.10 ±0.50 | 1.12 ±0.41 |
| | Changes | -0.15 ±0.30 | 0.02 ±0.28 | 0.08 ±0.29 | 0.17 ±0.28 |
| | p-value | 0.074 | 0.784 | 0.307 | 0.034 |
| C16dhCer | Pre | 1.08 ±0.50 | 1.13 ±0.74 | 1.24 ±0.65 | 1.21 ±0.54 |
| | Post | 1.13 ±0.39 | 1.16 ±0.58 | 1.22 ±0.56 | 1.32 ±0.56 |
| | Changes | 0.05 ±0.40 | 0.03 ±0.38 | -0.02 ±0.56 | 0.11 ±0.39 |
| | p-value | 0.628 | 0.735 | 0.875 | 0.289 |
| C18dhCer | Pre | 1.14 ±0.77 | 1.12 ±0.85 | 1.08 ±0.97 | 1.15 ±1.08 |
| | Post | 0.98 ±0.99 | 1.00 ±0.78 | 1.38 ±1.52 | 1.35 ±1.29 |
| | Changes | -0.16 ±1.10 | -0.13 ±0.56 | 0.30 ±0.73 | 0.20 ±0.92 |
| | p-value | 0.557 | 0.404 | 0.111 | 0.406 |
| Sphingosine | Pre | 1.05 ±0.68 | 0.85 ±0.37 | 1.07 ±0.59 | 0.92 ±0.39 |
| | Post | 0.90 ±0.41 | 0.75 ±0.36 | 0.94 ±0.66 | 0.72 ±0.32 |
| | Changes | -0.15 ±0.55 | -0.11 ±0.59 | -0.13 ±0.44 | -0.20 ±0.45 |
| | p-value | 0.307 | 0.498 | 0.256 | 0.094 |
| S1P | Pre | 1.08 ±0.28 | 1.04 ±0.25 | 1.09 ±0.28 | 1.11 ±0.30 |
| | Post | 1.05 ±0.31 | 0.96 ±0.25 | 1.21 ±0.24 | 0.98 ±0.26 |
| | Changes | -0.03 ±0.27 | -0.07 ±0.25 | 0.03 ±0.32 | -0.13 ±0.25 |
| | p-value | 0.652 | 0.290 | 0.683 | 0.057 |
| C16SM | Pre | 0.99 ±0.19 | 1.05 ±0.23 | 1.03 ±0.19 | 0.98 ±0.10 |
| | Post | 1.00 ±0.18 | 1.10 ±0.23 | 1.09 ±0.20 | 1.04 ±0.16 |
| | Changes | 0.01 ±0.11 | 0.05 ±0.11 | 0.06 ±0.08 | 0.07 ±0.11 |
| | p-value | 0.728 | 0.095 | 0.010 | 0.024 |
| C18SM | Pre | 1.01 ±0.24 | 1.10 ±0.35 | 1.05 ±0.31 | 0.95 ±0.15 |
| | Post | 0.95 ±0.28 | 1.10 ±0.33 | 1.14 ±0.33 | 1.08 ±0.22 |
| | Changes | -0.06 ±0.23 | 0.01 ±0.18 | 0.10 ±0.19 | 0.13 ±0.17 |
| | p-value | 0.326 | 0.891 | 0.055 | 0.008 |

**Table S2.** Adjusted associations between sphingolipids and 25(OH)D concentrations at baseline*.

| Metabolites | 25(OH)D | |
|---|---|---|
| | β | p |
| C16Cer | -0.67 | 0.150 |
| C18Cer | -0.47 | 0.233 |
| C16dhCer | -0.58 | 0.230 |
| C18dhCer | -0.24 | 0.513 |
| Sphingosine | 0.18 | 0.684 |
| S1P | 0.41 | 0.372 |
| C16SM | **-1.29** | **0.004** |
| C18SM | -0.78 | 0.061 |

* Linear regression models were adjusted for age, sex, and BMI. Levels of metabolites were standardized. Serum 25(OH)D concentrations were log transformed. Abbreviations: C16Cer, N-palmitoyl-sphingosine (d18:1/16:0); C18Cer, N-stearoyl-sphingosine (d18:1/18:0); C16dhCer, N-palmitoyl-sphinganine (d18:0/16:0); C18dhCer, N-stearoyl-sphinganine (d18:0/18:0); S1P, sphingosine 1-phosphate; C16SM, palmitoyl sphingomyelin (d18:1/16:0); C18SM, stearoyl sphingomyelin (d18:1/18:0).


**Figure S1. Flow diagram of participants.**

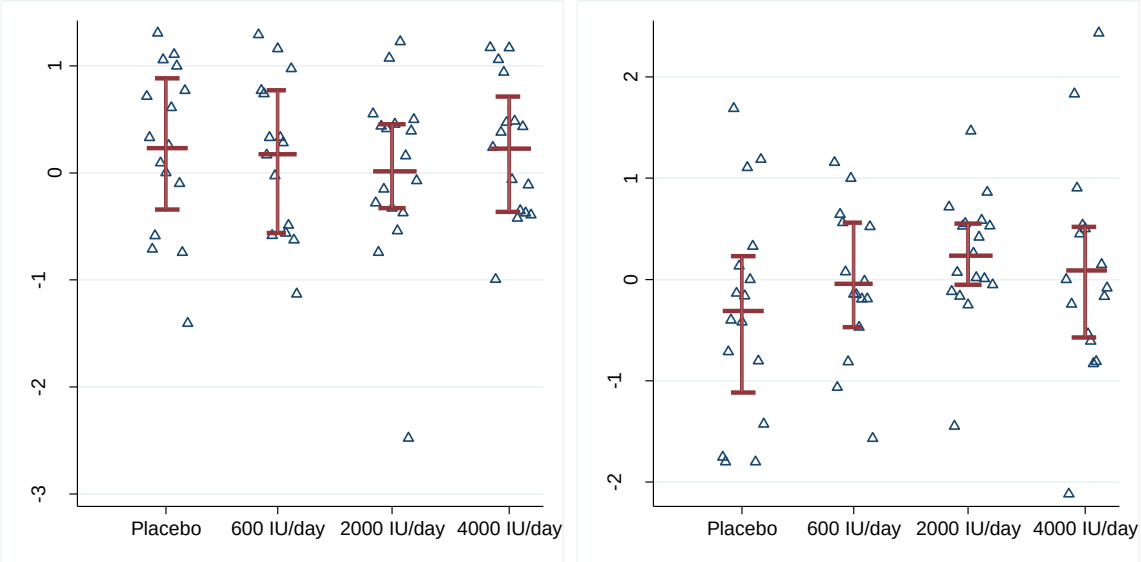


**Figure S2. Effect of vitamin $D_3$ supplementation on serum dihydroceramide levels.** Left is C16dhCer, and right is C18dhCer. Y-axis is the change of standardized levels of dihydroceramide (dhCer). Red lines indict 25 percentile, mean and 75 percentile of standardized levels of dhCer in each group. Abbreviations: C16dhCer, N-palmitoyl-sphinganine (d18:0/16:0); C18dhCer, N-stearoyl-sphinganine (d18:0/18:0).

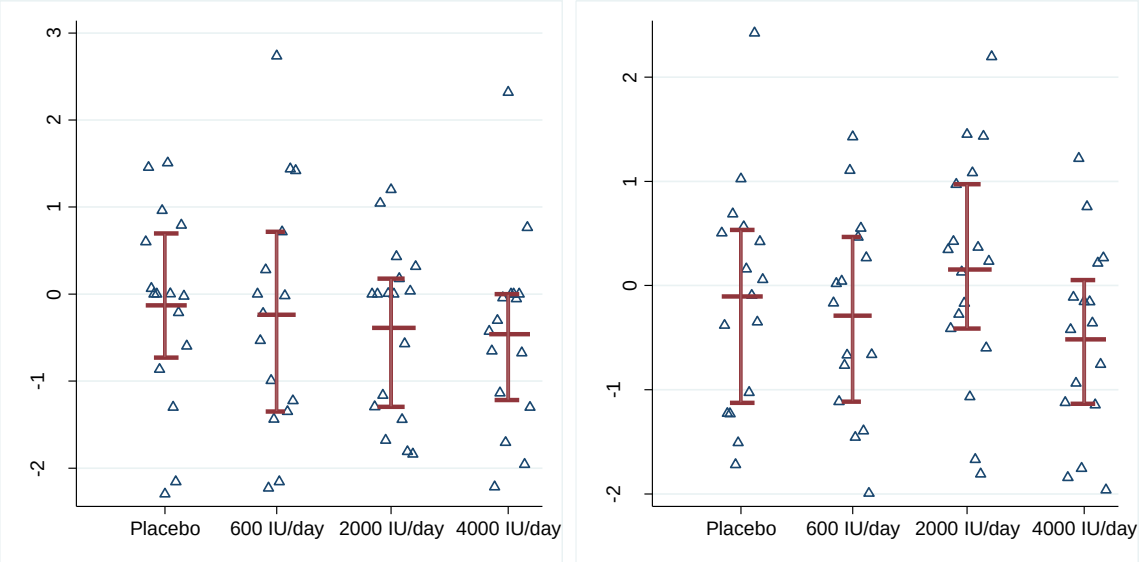


**Figure S3. Effect of vitamin $D_3$ supplementation on serum sphingosine and 1-phosphate derivate levels.** Left is sphingosine, and right is S1P. Y-axis is the change of standardized levels of the metabolites. Red lines indicate 25 percentile, mean and 75 percentile of standardized levels of metabolites in each group. Abbreviations: S1P, sphingosine 1-phosphate.

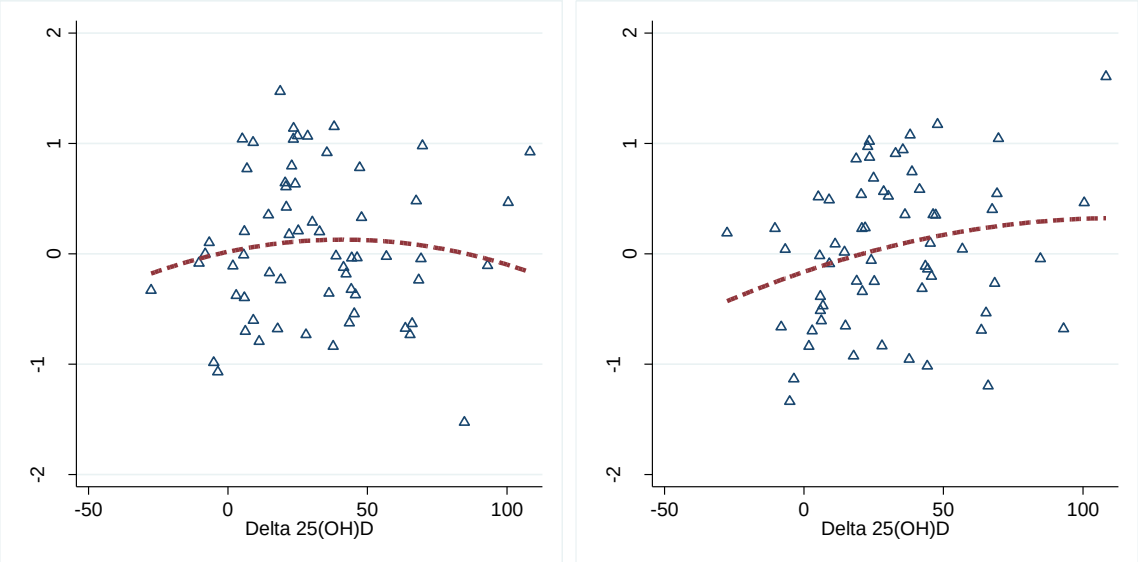


**Figure S4. Associations between the changes of ceramides and 25(OH)D concentrations.** Left is C16Cer, and right is C18Cer. Y-axis is the change of standardized levels of Cer. Red line is the quadratic prediction.

Abbreviations: C16Cer, N-palmitoyl-sphingosine (d18:1/16:0); C18Cer, N-stearoyl-sphingosine (d18:1/18:0).

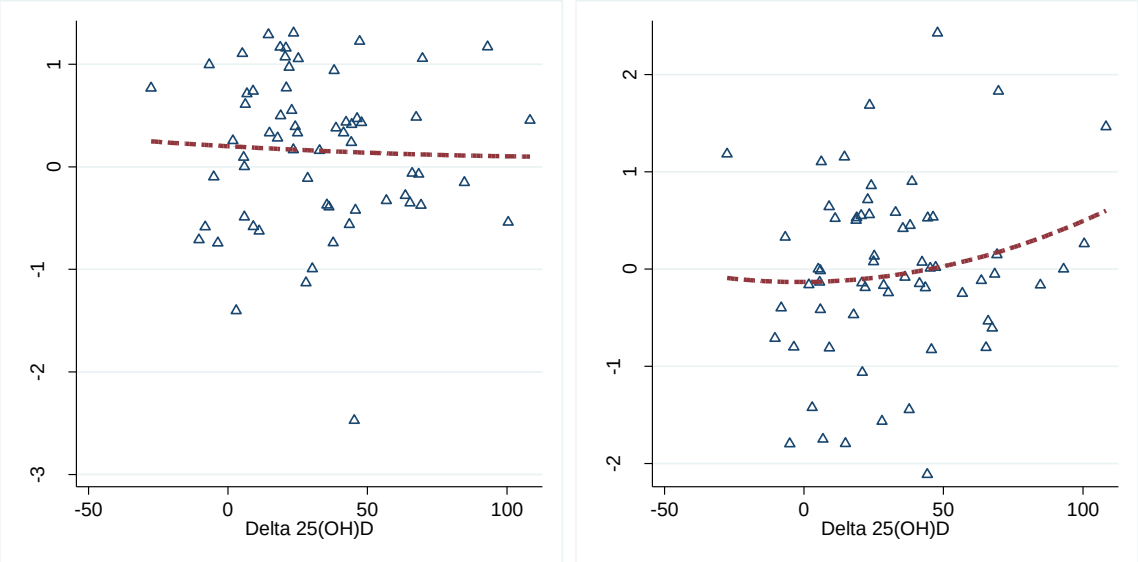


**Figure S5. Associations between the changes of dihydroceramide and 25(OH)D concentrations.** Left is C16dhCer, and right is C18dhCer. Y-axis is the change of standardized levels of dihydroceramide (dhCer). Red line is the quadratic prediction. Abbreviations: C16dhCer, N-palmitoyl-sphinganine (d18:0/16:0); C18dhCer, N-stearoyl-sphinganine (d18:0/18:0).

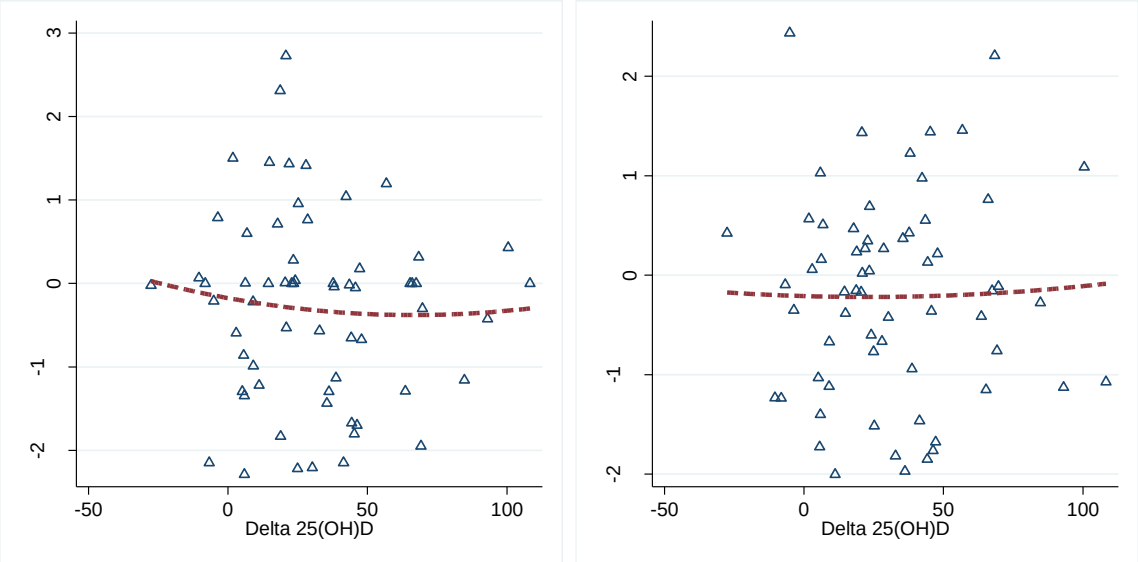


**Figure S6. Associations between the changes of sphingosine, 1-phosphate derivate and 25(OH)D concentrations.** Left is sphingosine, and right is S1P. Y-axis is the change of standardized levels of Cer. Red line is the quadratic prediction. Abbreviations: S1P, sphingosine 1-phosphate.

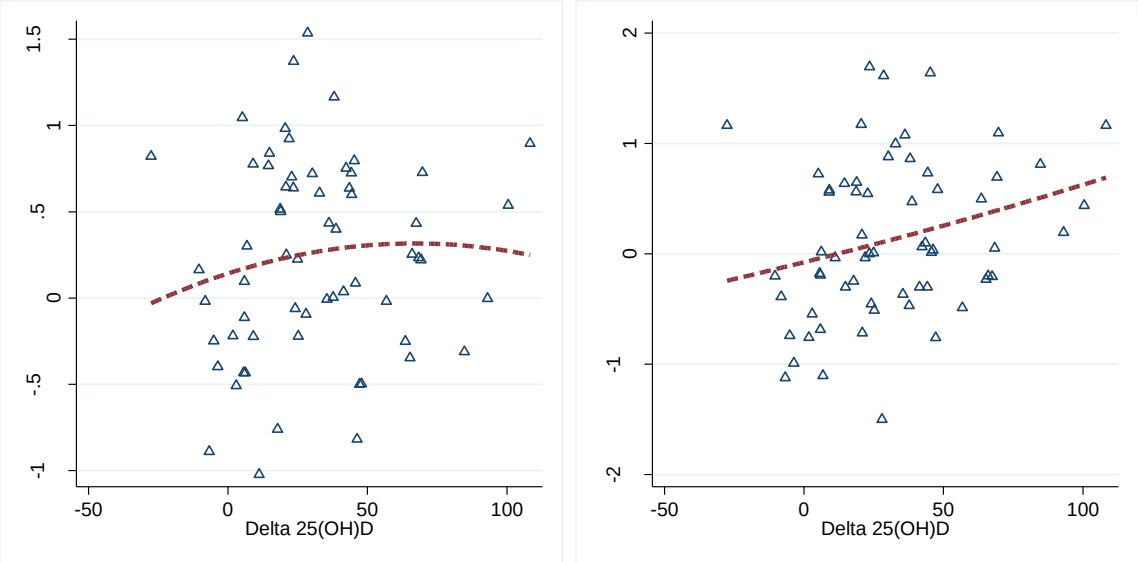


**Figure S7. Associations between the changes of sphingomyelin and 25(OH)D concentrations.** Left is C16SM, and right is C18SM. Y-axis is the change of standardized levels of SM. Red line is the quadratic prediction. Abbreviations: C16SM, palmitoyl sphingomyelin (d18:1/16:0); C18SM, stearoyl sphingomyelin (d18:1/18:0).

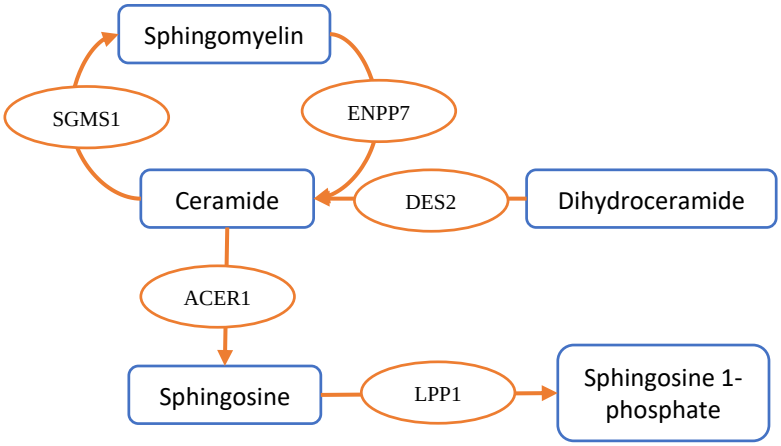


**Figure S8. Sphingolipid metabolism.** Dihydroceramide (dhCer) is the precursor of Cer, and can be synthesized through N-acylation dihydrosphingosine by one of six ceramide synthases (CerS1-CerS6), each using specific acyl chains. dhCer then dehydrogenated to Cers by dihydroceramide desaturase 2 (Des2). Sphingosine and sphingosine 1-phosphate (S1P) are the degradation products of Cers by alkaline ceramidase 1 (Acer1). Cer and SM are able to transform to each other with the help of ectonucleotide pyrophosphatase/phosphodiesterase family member 7 (Enpp7), and phosphatidylcholine: ceramide cholinephosphotransferase 1 (SGMS1). Abbreviations: Enpp7, Ectonucleotide pyrophosphatase/phosphodiesterase family member 7; SGMS1, Phosphatidylcholine:ceramide cholinephosphotransferase 1; DES2, Sphingolipid delta(4)-desaturase/C4-hydroxylase DES2; ACER1, Alkaline ceramidase 1; LPP1, lipid phosphate phosphohydrolase 1.