31P NMR Studies of Oriented Multilayers Formed from Isolated Sarcoplasmic Reticulum and Reconstituted Sarcoplasmic Reticulum

ARTICLE *in* BIOCHIMICA ET BIOPHYSICA ACTA · MAY 1981

Impact Factor: 4.66 · DOI: 10.1016/S0006-3495(82)84593-1 · Source: PubMed

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of MAO. In addition, the dynamic redistribution of phosphatidylcholine might further affect the functional level of the MAO-*A* type activity.

Supported by grant NS-14434 from the National Institutes of Health.

Received for publication 30 April 1981.

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^{31}P NMR STUDIES OF ORIENTED MULTILAYERS FORMED FROM ISOLATED SARCOPLASMIC RETICULUM AND RECONSTITUTED SARCOPLASMIC RETICULUM

EVIDENCE THAT "BOUNDARY-LAYER" PHOSPHOLIPID IS NOT IMMOBILIZED

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Sarcoplasmic reticulum is one of the most intensively studied membrane systems. As isolated in highly purified form, it is capable of energized calcium uptake and has a relatively simple composition. The major protein constituent (>90%) is the calcium pump protein (1, 2), which has been dissociated from the sarcoplasmic reticulum membrane and reconstituted to form functional membrane vesicles (3, 4). Such membranes of defined lipid content make possible detailed studies aimed at correlating membrane composition with structure and structure with function (4–7).

^{31}P NMR has been used previously to study the motion of the polar head group region of model phospholipid membranes (8–10). Oriented multilamellar systems have proved particularly useful for this purpose (8, 9, 11). The angular dependence of the position of the ^{31}P NMR signal from oriented membranes can be used to calculate the phosphorus chemical shift anistropy and the direction of the symmetry axis for the motion of the phosphate group. The angular dependence of the width of the ^{31}P NMR signal can be used to calculate the dipolar interaction between the phosphorus nucleus and the protons on the two adjacent methylene groups, and the direction of the symmetry axis for the motion of these two groups.

RESULTS AND DISCUSSION

Fig. 1 shows the angular dependence of the ^{31}P NMR signal from oriented sarcoplasmic reticulum membranes. Similar spectra were obtained from oriented reconstituted sarcoplasmic reticulum membranes with lipid-to-protein ratios ranging from 42:1 to 110:1 and from oriented bilayer membranes formed from sarcoplasmic reticulum phospholipids (12). We used the dependence of the ^{31}P NMR spectra on the alignment of the membranes with respect to the magnetic field to draw two conclusions about the motion of the phospholipid molecules that contribute to the observed spectra. First, the phosphate group and the two adjacent methylene groups are able to rotate rapidly (i.e., faster than 10^{-5} s) around the normal to the plane of the membrane. Second, the restricted internal motion of the phosphate group and the glycerol CH_2OP group is very similar to that found in liposomes formed from sarcoplasmic reticulum phospholipids. Calibration experiments showed that all (100 ± 7%) of the

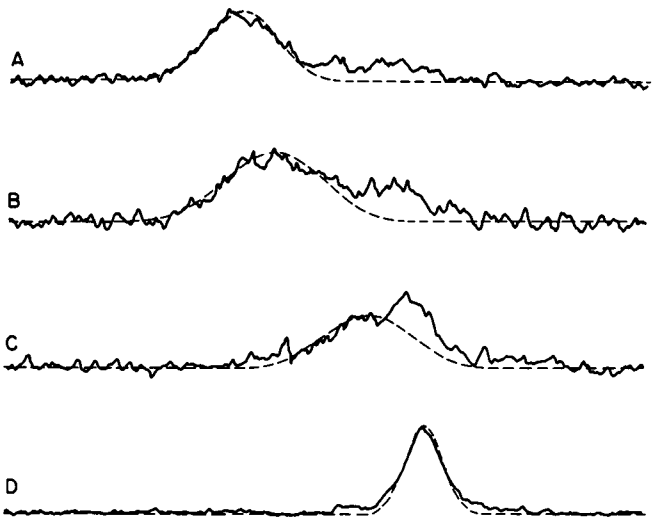

FIGURE 1 The angular dependence of the ^{31}P NMR signal from oriented sarcoplasmic reticulum membranes. The spectra shown in traces *A–D* were taken with membranes aligned so that the angle between the magnetic field and the normal to the plane of the membrane was 0°, 30°, 55°, and 90°, respectively. The dashed lines are theoretical Gaussian curves which were used to define the position and the width of the component of the signal arising from planar regions of the flattened spherical vesicles (12). The spectra were taken at 145.7 MHz. The total sweep width is 20 kHz. Each spectrum was accumulated for approximately two hours at 8 ± 1°.

phospholipid molecules in the membrane can be accounted for in the observed spectra. Thus, essentially all the phospholipid molecules in the sarcoplasmic reticulum and the reconstituted sarcoplasmic reticulum membranes have the same motion in the polar headgroup region as found in model bilayer membranes. Since a large fraction of the phospholipid molecules (between one-quarter and one-half depending on the lipid-to-protein ratio) are immediately surrounding the calcium pump protein, we conclude that the calcium pump protein does not perturb the motion of these "boundary-layer" lipids.

Research carried out at Brookhaven National Laboratory under the auspices of the United States Department of Energy.

Received for publication 23 April 1981.

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