Temperature and Composition Dependence of Ultrasound Properties of Medical Nutrition Solutions Containing Carbohydrate, Protein, and Lipid

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The speeds of sound and densities of nutrition solutions containing (50 to 200) $mg \cdot mL^{-1}$ of carbohydrates, (10 to 40) $mg \cdot mL^{-1}$ of proteins, and (10 to 40) $mg \cdot mL^{-1}$ of lipids at different temperatures were measured. Isentropic compressibilities were calculated from the experimental results. The results show that ρ, u, and κ_s depend on the temperatures and compositions of carbohydrates, proteins, and lipids. These results may provide an opportunity to use acoustic parameters for the characterization of lipid, carbohydrate, and protein content in nutrition solutions.

Introduction

Adequate nutrition plays an important role in maintaining optimal health. Many patients in the hospital cannot obtain adequate nutritional intake via the gastrointestinal tract and so require parenteral nutrition.[1,2] Parenteral nutrition is the administration of nutrition directly into the bloodstream. Specialized nutrition solutions are available for parenteral nutrition. The mixture contains different compositions of carbohydrates, proteins, and lipids. The solutions are prepared individually for each patient depending on their weight, height, and clinical conditions.[3,4]

These specialized solutions usually contain (50 to 200) $mg \cdot mL^{-1}$ compositions of carbohydrate, including dextrose; (10 to 40) $mg \cdot mL^{-1}$ compositions of protein, including amino acids; and (10 to 40) $mg \cdot mL^{-1}$ compositions of lipid, including fatty acids.[3,4]

Acoustic techniques have been used for many years in food industry research.[5−13] Ultrasound measurements were used in the study of bovine serum albumin, blood, hemoglobin, plankton, polysaccharides, and other biological solutions.[14−28] Some of the new applications simply look for an empirical correlation between the acoustic properties of various biosolutions and their biological functions.[29] In the acoustic technique, the attenuation and/or speed of sound are measured. The speed of sound is more sensitive to the variations of concentration and temperature than is attenuation. McClements, too, stresses the importance of the speed of sound for food products.[5] Acoustical parameters studies in parenteral solutions have proved to be useful in understanding the physicochemical behavior of the particular system. This might be used for diagnostic purposes.

In the present work, we report the measurements of density, ρ, and speeds of sound, u, in nutrition solutions as a function of temperature and composition. In these systems, the above properties were studied to examine the effect of temperature. The experimental values of speed of sound and densities measured were used to calculate isentropic compressibilities. The main purpose of this study is to determine the temperature and concentration dependence of the acoustic properties of nutrition solutions.

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Experimental Section

A solution containing Dextrose 30 % (Eczacibasi-Baxter, Turkey), Intralipid 20 % (Fresenius Kabi, Germany), and Primene 10 % (Baxter, USA) was used. Dextrose 30 % is a sterile, nonpyrogenic standard solution for intravenous administration. Each 100 mL contains 30 g of dextrose monohydrate. Intralipid 20 % is a sterile standard fat emulsion which includes 20 g of purified soybean oil, 1.2 g of purified egg phospholipids, 2.2 g of glycerol anhydrous, and water in 100 mL each. Each 100 mL contains 20 g of fat. Primene 10 % is a standard protein solution which includes organic compounds made of amino acids. The solution contains 0.67 g of L-isoleucine, 1.00 g of L-leucine, 0.76 g of L-valine, 1.1 g of L-lysine, 0.24 g of L-methionine, 0.42 g of L-phenylalanine, 0.37 g of L-threonine, 0.20 g of L-tryptophan, 0.84 g of L-arginine, 0.38 g of L-histidine, 0.80 g of L-alanine, 0.60 g of L-aspartic acid, 0.19 g of L-cysteine, 0.l0 g of L-glutamic acid, 0.40 g of glycine, 0.30 g of L-proline, 0.40 g of L-serine, 0.05 g of L-tyrosine, 0.32 g of L-ornithine, and 0.06 g of hydrochloride taurine in 100 mL each. Each 100 mL contains 10 g of protein. Parenteral nutrition solutions were compounded by pharmacy staff in a laminar airflow cabinet in an Automix Compounder System (Baxter, USA). Concentrations are expressed as milligrams per milliliter. The densities and speeds of sound of solutions were measured by using a vibrating-tube densimeter and sound analyzer, Anton Paar DSA-5000. The apparatus was automatically thermostatted within a temperature uncertainty of $\pm\ 2 \cdot 10^{-3}$ K. These measurements were repeated three times with the last measurements presented in this paper. Calibration of the apparatus was achieved with air and deionized double-distilled water. The uncertainty of the measurements was estimated to be $\pm\ 5 \cdot 10^{-6}$ $g \cdot cm^{-3}$ for density and $\pm$ 0.5 $m \cdot s^{-1}$ for speeds of sound; the

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respective reproducibility was $\pm 1 \cdot 10^{-6}$ $g \cdot cm^{-3}$ and $\pm$ 0.01 $m \cdot s^{-1}$. The measurements of the density and speed of sound of medical solutions containing carbohydrate, protein, and lipid in the temperature range from (293.15 to 323.15) K were taken as a function of concentration.

Results and Discussion

Isentropic compressibilities were calculated from the experimental data for density and speeds of sound with the following equation.

The isentropic compressibility, κ_s, was calculated using the Newton−Laplace equation

$$\kappa_s = \frac{1}{\rho u^2} \tag{1}$$

where ρ and u are the densities and speeds of sound of solutions, respectively.

These acoustical parameters were fitted to the equations of type

$$y = a_o + a_1 C \tag{2}$$

where a_o and a_1 are empirical parameters and C is concentration ($mg \cdot mL^{-1}$). The coefficients a_o and a_1 of eq 2 are presented in Table 2.

The standard deviation was calculated using the expression

$$\sigma = \left[\sum_i^N \frac{(Y - Y_{cal})^2}{N - m}\right]^{1/2} \tag{3}$$

where Y is the value of the property; N is the number of experimental data; and m is the number of coefficients.

The densities, speeds of sound, and isentropic compressibility of nutrition solutions at different temperatures are given in Table 1. The experimental results showed that the values of ρ and u increase in harmony with an increase of the carbohydrate and protein concentrations of the studied systems. In contrast, the values of κ_s decreased as the carbohydrate and protein concentrations in the studied systems increased, while the values of ρ and u decreased as the lipid concentrations in the studied systems increased. On the other hand, the values of κ_s increased with the increasing lipid concentrations of the studied systems. For each system studied at a certain concentration, a decrease in ρ and κ_s was observed as the temperature rose. Furthermore, at a certain concentration, an increase in u was observed at a certain concentration when the temperature increased.

These parameters were correlated with the concentration and temperature, with the correlation coefficients and standard deviations listed in Table 2. From these equations, it is clear that there are excellent linear correlations between the acoustic parameters and concentrations and temperatures.

Acoustical parameters demonstrated a good correlation and can be used to monitor carbohydrate, protein, and lipids in nutrition solutions. It was observed that 50 $mg \cdot mL^{-1}$ changes in the carbohydrate concentrations and 10 $mg \cdot mL^{-1}$ changes in the protein and lipid concentrations of parenteral nutrition solutions cause quite a change in the values of speeds of sound, density, and isentropic compressibility. From the results demonstrated in the present study regarding densities, speeds of sound, and isentropic compressibility, that acoustic properties are very suitable for detecting carbohydrate, protein, and lipids in nutrition solutions is of significance for future research.

Table 1. Densities, ρ, Speeds of Sound, u, and Isentropic Compressibilities, κ_s, of the Nutrition Solutions at Range (293.15 to 323.15) K

	carbohydrate	protein	lipid	ρ	u	κ_s
T/K	$mg \cdot mL^{-1}$	$mg \cdot mL^{-1}$	$mg \cdot mL^{-1}$	$kg \cdot m^{-3}$	$m \cdot s^{-1}$	TPa^{-1}
293.15	50	20	20	1032.09	1534.74	411.35
298.15	50	20	20	1030.60	1546.01	405.96
303.15	50	20	20	1028.91	1556.09	401.38
308.15	50	20	20	1026.97	1564.68	397.73
313.15	50	20	20	1024.57	1571.76	395.08
318.15	50	20	20	1021.65	1577.19	393.49
323.15	50	20	20	1018.77	1581.56	392.42
293.15	100	20	20	1046.59	1545.46	400.05
298.15	100	20	20	1045.11	1556.09	395.16
303.15	100	20	20	1043.33	1565.23	391.22
308.15	100	20	20	1041.37	1572.76	388.21
313.15	100	20	20	1039.23	1578.97	385.96
318.15	100	20	20	1036.95	1583.91	384.40
323.15	100	20	20	1034.51	1587.62	383.51
293.15	150	20	20	1061.53	1558.81	387.69
298.15	150	20	20	1059.87	1569.10	383.22
303.15	150	20	20	1058.04	1577.89	379.61
308.15	150	20	20	1056.05	1585.16	376.85
313.15	150	20	20	1053.91	1590.88	374.91
318.15	150	20	20	1051.61	1595.34	373.63
323.15	150	20	20	1049.16	1598.58	372.98
293.15	200	20	20	1074.70	1573.54	375.80
298.15	200	20	20	1072.98	1582.91	371.96
303.15	200	20	20	1071.08	1590.88	368.90
308.15	200	20	20	1069.02	1597.48	366.56
313.15	200	20	20	1066.82	1602.64	364.95
318.15	200	20	20	1064.47	1606.29	364.10
323.15	200	20	20	1061.98	1608.97	363.74
293.15	150	40	20	1064.62	1567.91	382.09
298.15	150	40	20	1062.92	1577.59	378.02
303.15	150	40	20	1061.04	1585.63	374.86
308.15	150	40	20	1059.00	1592.43	372.38
313.15	150	40	20	1056.81	1597.90	370.60
318.15	150	40	20	1054.50	1602.13	369.45
323.15	150	40	20	1052.03	1605.14	368.93
293.15	150	30	20	1063.76	1564.40	384.11
298.15	150	30	20	1062.08	1574.60	379.76
303.15	150	30	20	1060.14	1583.49	376.19
308.15	150	30	20	1057.78	1590.85	373.55
313.15	150	30	20	1054.54	1596.74	371.94
318.15	150	30	20	1051.05	1601.35	371.03
323.15	150	30	20	1047.48	1604.70	370.74
293.15	150	10	20	1058.02	1554.49	391.14
298.15	150	10	20	1055.93	1565.12	386.61
303.15	150	10	20	1053.60	1574.32	382.95
308.15	150	10	20	1050.86	1581.89	380.28
313.15	150	10	20	1047.73	1588.04	378.47
318.15	150	10	20	1044.38	1592.79	377.42
323.15	150	10	20	1040.79	1596.23	377.09
293.15	150	20	40	1057.41	1555.99	390.61
298.15	150	20	40	1055.67	1565.41	386.56
303.15	150	20	40	1053.69	1573.31	383.41
308.15	150	20	40	1051.01	1579.66	381.30
313.15	150	20	40	1047.54	1584.49	380.23
318.15	150	20	40	1043.31	1587.95	380.11
323.15	150	20	40	1038.11	1589.97	381.05
293.15	150	20	30	1060.22	1557.29	388.92
298.15	150	20	30	1058.50	1567.18	384.65
303.15	150	20	30	1056.61	1575.63	381.22
308.15	150	20	30	1054.52	1582.66	378.59
313.15	150	20	30	1052.02	1588.37	376.77
318.15	150	20	30	1049.08	1592.63	375.81
323.15	150	20	30	1044.95	1595.63	375.87
293.15	150	20	10	1063.10	1560.82	386.12
298.15	150	20	10	1061.46	1571.14	381.65
303.15	150	20	10	1059.64	1580.18	377.95
308.15	150	20	10	1057.65	1587.85	375.01
313.15	150	20	10	1055.48	1594.1	372.84
318.15	150	20	10	1053.09	1599.04	371.38
323.15	150	20	10	1050.36	1602.67	370.66

Table 2. Fitting Coefficients, a_o and a_1, for the Variation in the Compositions of Carbohydrate, Protein, and Lipid at Different Temperatures for Equation 2 and Corresponding Standard Deviations, σ

	ρ/kg·m^{-3}			u/m·s^{-1}			κ_s/TPa^{-1}		
T/K	$\frac{a_o}{\text{kg·m}^{-3}}$	$\frac{a_1}{\text{kg·m}^{-3}}$	$\frac{\sigma}{\text{kg·m}^{-3}}$	$\frac{a_o}{\text{m·s}^{-1}}$	$\frac{a_1}{\text{m·s}^{-1}}$	$\frac{\sigma}{\text{m·s}^{-1}}$	$\frac{a_o}{\text{TPa}^{-1}}$	$\frac{a_1}{\text{TPa}^{-1}}$	$\frac{\sigma}{\text{TPa}^{-1}}$
for the variation in carbohydrate composition									
293.15	1017.90	2.87	0.56	1520.55	2.61	1.01	423.60	−2.39	0.08
298.15	1016.53	2.85	0.58	1532.46	2.49	0.94	417.68	−2.29	0.12
303.15	1014.90	2.84	0.57	1543.13	2.35	1.02	412.66	−2.19	0.19
308.15	1013.01	2.83	0.59	1552.18	2.23	1.19	408.67	−2.11	0.29
313.15	1010.65	2.84	0.67	1559.79	2.10	1.30	405.69	−2.04	0.31
318.15	1007.76	2.87	0.87	1565.87	1.98	1.24	403.74	−1.99	0.27
323.15	1004.91	2.90	1.01	1570.76	1.87	1.29	402.41	−1.94	0.27
for the variation in protein composition									
293.15	1056.48	2.20	0.76	1549.94	4.58	0.49	393.94	−3.07	0.46
298.15	1054.40	2.32	0.90	1560.88	4.29	0.59	389.21	−2.92	0.53
303.15	1052.10	2.44	1.03	1570.45	3.95	0.82	385.33	−2.77	0.64
308.15	1049.39	2.61	1.21	1578.26	3.73	0.97	382.51	−2.70	0.70
313.15	1046.28	2.79	1.46	1584.53	3.54	1.11	380.62	−2.66	0.66
318.15	1042.93	2.98	1.87	1589.39	3.40	1.23	379.51	−2.65	0.64
323.15	1039.36	3.20	2.37	1592.95	3.29	1.34	379.12	−2.67	0.69
for the variation in lipid composition									
293.15	1065.16	−1.84	0.42	1562.23	−1.60	0.21	384.66	1.47	0.11
298.15	1063.56	−1.87	0.42	1572.99	−1.91	0.08	379.98	1.62	0.12
303.15	1061.81	−1.93	0.44	1582.47	−2.29	0.01	376.05	1.80	0.17
308.15	1060.17	−2.14	0.61	1590.60	−2.71	0.13	372.78	2.06	0.29
313.15	1058.66	−2.57	0.89	1597.30	−3.13	0.33	370.17	2.41	0.47
318.15	1057.23	−3.19	1.27	1602.74	−3.60	0.48	368.14	2.84	0.66
323.15	1055.89	−4.10	1.63	1606.98	−4.11	0.67	366.62	3.41	0.85

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