THE ELECTRICAL CONDUCTIVITY AND CHLORIDE CONTENT OF WOMEN'S MILK

PART I: METHODS AND PRACTICAL APPLICATION

BY

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Few observations have been recorded on the electrical conductivity of women's milk. Koeppe (1898) measured the conductivity of 19 specimens of milk taken from five women who were in various stages of lactation. The values of specimens taken in the first month ranged from 174 to $454 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$ and those taken during the second to eleventh months varied from 150 to $238 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$. In the twelfth month only one specimen was taken and that eight days after the infant had ceased to be breast-fed. It had a conductivity of $843 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$. All these measurements were made at 18° . Jackson and Rothera (1914) made a fuller investigation on the electrical conductivity of milk at 25° taken from 22 women. Their results showed that the conductivity of colostrum was 321 to $391 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$ and of normal milk was 214 to $315 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$ and that of one specimen of abnormal milk was $959 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$. They stated that milk taken in the evening had a lower conductivity than milk taken in the morning, and in five out of six cases the conductivity was higher in the 'after-milk' than in the 'fore-milk' (the after-milk being milk taken after a breast feed and the fore-milk before a breast feed).

It is apparent that conductivity values tend to vary greatly and that the stage of lactation and the time of day or stage of feed at which the specimen is taken may influence the results. It was considered desirable to carry out similar investigations on a much larger series of specimens in order to ascertain more precisely the influence of various factors upon the electrical conductivity. It also seemed of interest to carry out concurrently a series of observations on the chloride content of the milk to determine the relationship between the conductivity of the milk and the chloride value.

Methods

In the series of women investigated, 4-8 ml. of breast milk were expressed just before the infant's first feed in the morning or its mid-day feed, into a container which had been washed, rinsed in distilled water, and dried in an oven. The samples were kept in a cool place and the conductivity of each specimen was measured as soon as possible after it had been obtained. In no case was there a delay of more than 24 hours. Observations showed that no appreciable alteration in conductivity took place during 24 hours, provided the temperature was less than 12° C .

Apparatus for Measuring Electrical Conductivity. To measure the conductivity the milk was placed in a cell and its resistance was measured in the usual way by using a commercial Wheatstone bridge manufactured by Taylor Electrical Instrument Ltd., Slough. The apparatus worked on alternating current at 50 cycles, and the cathode ray indicator or 'magic-eye' incorporated in the apparatus showed when the bridge was balanced. The cell employed was similar to that used by Daly, Eggleton, Elsdon, and Hebb (1946). The cells were constructed from glass tubing of $\frac{1}{2}$ in. external diameter and $\frac{3}{8}$ in. internal diameter. The tubing was drawn out and bent to form a U-shaped capillary, parts of the original tubing being left at each end to form two cups. The amount of milk required to fill the cell was about 1 ml.

The two electrodes for the cell consisted of platinum wire. The free ends of the platinum wire were made into loops and immersed in the milk in the cups of the cell, while the other ends were connected to the test terminals on the Wheatstone bridge. Because the resistance in the cell was almost entirely in the capillary portion, the exact position of the electrodes in the two cups did not have an appreciable effect upon the measurements. Furthermore, the resistance was high and the current low, and a quick and accurate measurement of the resistance was easily obtained. The electrodes were kept clean by passing them through an oxidizing flame and by occasionally cleaning them with

concentrated nitric acid. At no time was it necessary to platinize the electrodes.

Calculation of Specific Conductivity of Milk. The milk was placed in the cell, immersed in a water bath, and the resistance measured. A standard temperature of 18° was chosen, as most investigations of this nature in the past have been expressed at that temperature. The change in the resistance of milk per degree change in temperature was found to be 2.1% for whole milk, and 2.0% for partially separated milk, and these corrections were applied when necessary.

The specific conductivity of the milk was calculated from the formula $C = K \cdot R$, where C is the specific conductivity, R the resistance as measured and corrected for temperature, and K the cell-constant. The cell-constant was obtained by measuring the resistance of the cell filled with potassium chloride of known concentration and making use of the specific conductivity value of such salt solution given in the literature. The value of K for the cell employed in our experiments was 249.5 .

Effect of Separation of Fat on Conductivity. Jackson and Rothera (1914) have stated that when measuring the electrical conductivity of cow's milk, it is preferable first to remove the fat, because the fat content of milk is variable and the removal of the fat reduces the range of conductivity values. In a series of 20 milk specimens, the fat content ranged from 1.1 to 6.2% . For 1 g. of fat in 100 ml. milk, the electrical conductivity value was reduced on the average 1.93% , and the total reduction in the electrical conductivity of the various milk specimens was 2.12 to 11.97% . When the speed of the centrifuge was approximately $2,500$ revolution per minute a rise in conductivity occurred in the first 15 minutes due to the separation of the fat. When these specimens were centrifuged for more than 15 minutes they showed no further change in electrical conductivity. In the present work, therefore, 15 minutes' centrifuging was adopted as a standard period, and a number of observations were made on the effect of the removal of fat in this way. It appeared possible that the range of electrical conductivity values for women's milk might be smaller if fat-free milk were used for the estimations instead of whole milk, and that, consequently, the effect of other factors might be brought out more clearly by the use of fat-free milk.

In a series of specimens, the value of estimating the electrical conductivity of separated milk was assessed. The electrical conductivities of 390 specimens were measured, of which 210 were taken from mothers in the first month of lactation and 180 from mothers in the second to fifth months of lactation. The specimens were both from women with adequate lactation and from those with inadequate lactation. The criterion for adequate lactation on the part of the mother was that her infant gained weight satisfactorily. The infants of mothers with inadequate lactation failed to gain weight, and this failure was shown by test-feeding to be due to the infants receiving less than 2 oz. of milk per lb. of body weight per day. Of the 390 specimens, 233 came from mothers with adequate, and 157 from mothers with inadequate, lactation. After the electrical conductivity of each sample was estimated the sample was centrifuged

and its electrical conductivity again determined. The results of the investigations are given in Fig. 1. The values

FIG. 1.—Diagram showing that the scatter of results for whole milk is similar to that for separated milk. This applies to values obtained for women with both adequate lactation (O) and to those obtained for women with inadequate lactation (X).

for separated milk are plotted in two groups; those for milk taken from women in the first month of lactation, and those from women in the second to fifth months of lactation. From a comparison of these groups of values for women's milk, it is apparent that the scatter of the results for separated milk does not differ appreciably from that of whole milk, and suggests that there is no conclusive advantage in separating fat from women's milk before measuring conductivity.

Determination of Chloride Content of Milk. The chloride content was estimated by the method described by Patterson (1928). Milk (2 ml.) was mixed with nitric acid (30 ml.) and to this mixture 40 ml. acetone and 10 ml. $N/_{50}$ silver nitrate were added. The excess silver nitrate was titrated with $N/_{60}$ ammonium thiocyanate, three drops of iron alum being added as indicator. The chloride content was calculated in terms of milligrams of sodium chloride per 100 ml. of milk.

Results

The electrical conductivity of the samples of whole milk varied from 150 to 320×10^{-5} ohm $^{-1}$ cm. $^{-1}$ in

mothers with adequate lactation, and from 170 to $675 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$ in mothers with inadequate lactation. Women with adequate lactation tend to have milk of a lower conductivity than women with inadequate lactation, the mean value of the former being $194 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$ and of the latter $301 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$. The chloride content of milk from mothers with an adequate milk supply ranged from 24 to 107 mg. % and had an average chloride content of 57 mg. per 100 ml., whilst the corresponding values for mothers with an inadequate milk supply ranged from 43 to 355 mg. %, and the average chloride content was 135 mg. % (in terms of sodium chloride) per 100 ml. These results on chloride content are in keeping with the observations made by Sisson and Denis (1921), Widdows, Lowenfeld, Bond, Shiskin, and Taylor (1935), and Ishii (1937).

Relation of Electrical Conductivity to Chloride Content. In the present work 668 specimens taken in the first five months of lactation have been examined for both conductivity and chloride content. The results are summarized in Fig. 2 in which the conductivity value for each specimen has been plotted against the chloride value of the same specimen. It is apparent from the figure that the higher the chloride content, the greater, on the average, is the electrical conductivity. This relationship is also exhibited in Fig. 3, which shows the average conductivity value of milk with a given chloride content. Fig. 3 also shows the electrical conductivity of solutions of pure sodium chloride

FIG. 3.—Graph showing the relationship of the electrical conductivity of human milk to the electrical conductivity of pure salt solution of the same chloride concentration.

of various concentrations; it will be seen that the conductivity of the milk was greater than that of a solution of pure sodium chloride of the same chloride content. Moreover, the conductivity of milk specimens with a relatively high chloride content tends to approximate more closely to that obtained for a solution of pure sodium chloride of the same chloride concentration than do conductivity values for milks of low chloride content. Thus, when the chloride content is low, the contribution of the other electrolytes to the electrical conductivity of milk becomes more important relatively and absolutely.

FIG. 2.—Graph showing the relationship between the electrical conductivity of human milk and its chloride content.

Discussion

The conductivity of an aqueous solution depends on the number and nature of the ions present and also on the viscosity of the aqueous medium through which they move under the influence of the electric field. The chloride ion is the one which is most plentiful in milk and is said to account for either 57% (Flohil, 1911), or 49 to 78% (Coste and Shelbourn, 1919) of the conductivity of cow's milk. In milks which have been secreted by diseased glands, it is the chloride content which is usually increased at the expense of constituents such as lactose, and so in these milks the conductivity is raised. It is, therefore, not surprising that high conductivity is characteristic of milk produced by mothers whose lactation is inadequate.

Although non-electrolytes, such as sugar and fats, do not directly contribute to the electrical conductivity, they affect it through their influence on the viscosity. In general, the effect of the presence of compounds with relatively large molecules, such as proteins or lactose, is to raise the viscosity compared with that of pure water. The effect, however, of variations in the protein and lactose content of milk on the electrical conductivity is relatively small compared with that of variation in salt content. In both women's milk and cow's milk it has been found that the conductivity falls as the lactose content increases (Schweers, 1932, and Jackson and Rothera, 1914). Schnorf (1904) states that the protein present in cow's milk reduces its conductivity by 10 to 17%, while Bagarsky and Tangl (1898) and Jackson and Rothera (1914) found a fall of 2.5 to 2.75% in the conductivity for every gram of protein present. Our results suggest that, on the average, every 1% of fat reduces the conductivity by about 2% for human milk, whilst Taylor (1914) found a corresponding reduction of 2.3% for cow's milk.

A more important influence on the conductivity of an aqueous solution is that produced by variations of temperature, mainly as the result of the change of viscosity when the temperature is varied. The change in electrical conductivity of milk was found to be approximately 2% per degree.

A high chloride content or conductivity is a strong indication of inadequate lactation, but there is a considerable overlap between the values for mothers with adequate and those with inadequate lactation. Electrical conductivity can be measured quickly and accurately and is particularly suitable for clinical use, as the apparatus involved is compact, relatively inexpensive, and simple to operate, and it would appear that the measurement is a useful adjunct in investigating problems of lactation.

Summary

The electrical conductivity of over 700 samples of women's milk has been measured by the convenient method used by Daly *et al.* (1946), and their chloride content has also been determined. The electrical conductivity values are given for a temperature of 18°, a correction being applied to the observed values when readings were made at temperatures different from 18°.

The removal of the milk fat by centrifugation results in an increase in conductivity, the average increase being 1.93% per gram of fat. Though the removal of fat eliminates a variable factor affecting the electrical conductivity, the gain in uniformity of results is not appreciable.

The electrical conductivity of women's milk shows considerable variation, the range observed extending from 150 to $675 \times 10^{-5} \text{ ohm}^{-1} \text{ cm.}^{-1}$. The lower values generally found for mothers with adequate lactation and the higher values are more characteristic of mothers with inadequate lactation. There is, however, a certain overlap between the two groups.

The chief factor influencing the electrical conductivity of women's milk is the chloride content. The conductivity of milk does not bear a constant relationship to salt solution of the same concentration, the relationship being closer when the chloride of milk is high than when it is low. The effect of other factors is discussed.

The electrical conductivity of women's milk affords information as to its quality comparable with that given by estimation of its chloride content. In view of the ease and rapidity with which the conductivity can be measured its determination is recommended as a valuable aid in assessing the quality of the milk.

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