Possible role of salt intake in the development of essential hypertension*

LK Dahl

Introduction

Although the practice of adding salt to food is an ancient one, there seems to be little doubt that until relatively modern times its widespread use as a condiment was uncommon. At present, the practice is a ubiquitous one and, in the United States at least, salt may be added at any stage before, during or after food-processing as well as before, during or after cooking. And sometimes salting takes place during each of these steps!

The ancient valuation of salt as a precious possession\(^1\) may have contributed to the modern notion that the addition of salt to food is necessary or even beneficial.\(^2\) Nonetheless, during the 20th century, there has been evidence accumulating which suggests a possible relationship between salt ingestion and hypertension in man.\(^3\) In this paper we will review the sum of the evidence, which we have been gathering since 1954.\(^1,4-14\) The original papers should be consulted both for the primary data as well as for correlation with the experiences of others in this field. These studies are in line with the modern effort against subtle lethal agents as, for example, fall-out, carcinogens and atherogenic factors.

Salt need, salt intake, salt appetite

We have dealt with these considerations at some length elsewhere.\(^9-14\)

Need

There is no doubt that some salt is required by man, and estimates of normal daily requirements for adults have ranged up to 15 g per day. For the most part, such estimates were arrived at by a circular argument in which, over any given period, the amount of salt excreted in the urine was equated with the need for ingestion of an equal amount in order to maintain metabolic balance. As opposed to such opinion there are numerous careful metabolic studies which indicate unequivocally that in people with normal renal function, salt balance can be maintained easily on daily intakes well below 1 g. Our own group has studied many individuals who were limited to 100–375 mg for periods of 3 to 12 months.\(^15-18\) We have reported 3 subjects whose intake was proven to have been restricted to 250–375 mg NaCl continuously for periods ranging from about 2 to 5 years.\(^13\) We recently studied a 17-year-old girl for several months who easily maintained salt balance while her daily intake was only 10–12 mg of salt. We do not imply that such low intakes are either necessary or advisable, but we do suggest that under ordinary circumstances the adaptive mechanisms of the body are so exquisitely effective in conserving salt that intakes of only 1 or 2 g a day are more than sufficient for metabolic needs, including periods of growth.\(^1\)

Intake

There are—were—is perhaps more accurate today—many vigorous peoples which for countless generations added no salt to their food and ate only that which was present naturally. Among such groups are the Eskimos, some of the northwest American Indians, and the Masai of Africa. Analysis of the diets among such groups or maximal estimates based on the rather constant salt content of foods in their natural state indicate maximal daily intakes of not more than 5 g, with some eating 1 g or less.\(^1\) Calculations based on the analyzed sodium content of known foods indicate that salt intake rarely could exceed 4 or 5 g per day without the addition of salt to food, save in areas where drinking water had a high salinity.

Determinations of actual as contrasted with estimated salt consumption are remarkably few in all societies, and no less so in western than in other societies. Measurement of 24 hr urinary excretion is a reliable index of minimal salt intake. Except when sweat losses are significant it is even an accurate index of total intake\(^1\) in normal people. In view of the ubiquitous sources of salt in modern diets the errors of this technique are in my opinion less than those of any other method. There are two criticisms of this means of evaluating salt consumption: 1. losses from the skin as well as inevitable losses from lack of total co-operation will cause underestimation of salt intake in some subjects; and 2. salt consumption may vary so widely from day to day that a single or even several consecutive 24 hr collections will hardly give an accurate index of a person's average intake. These criticisms are more applicable when determining maximal consumptions but less so when minimal consumptions are being investigated.

Similar problems have existed in estimating the exact consumption by a single individual of such common items as fat, cigarettes, or alcohol, but excesses are well recognized here, whether committed by an individual or a nation. I suggest that this be also applied to salt: single 24 hr urine collections may be inaccurate, but my own considerable experience during the last ten years with five different peoples in five different parts of the
world indicates that this method is an excellent index of average salt consumption by a group as well as by individuals. It has been checked against known national and community salt purchases in Japan, where salt is controlled by a monopoly; against actual 24 to 48 hr diet collections in Japan, in the United States, and among natives of the Marshall Islands in the Pacific; and finally against known salt content of natural foods eaten by Alaskan Eskimos.

By the use of such methods my associates and I have found that Eskimos were consuming an average of less than 4 g of salt per day, Marshall Islanders about 7, white male Americans about 10, and Southern Japanese farmers and laborers about 14 g. Northern Japanese farmers were found to average 26.3 g by my Japanese friend and investigator, Dr. Fukuda of Chiba University. Studies on Eskimos, Marshallese, and Americans (including the southern negro) are still in progress and shall be periodically reported.

These group averages indicate that salt intakes may and do vary widely among different peoples. However, these figures will be misleading if they are interpreted to mean that all individuals in such communities are consuming equivalent amounts of salt, since we have observed a wide diversity in individual salt consumption if salt is readily available. Just as data based on average alcohol consumption fail to indicate either the total abstainer or the chronic alcoholic, so average levels of salt consumption fail to show that, among individual members of the communities we have studied, some people habitually eat very little salt while others consume it gluttonously.

The accompanying table (Table 1) summarizes these data up to the present time: the variable range of values in the several communities may be as informative as the variation in averages. Comparison of these data on salt intake with the earlier estimates of metabolic need indicates a very considerable excess of intake over need in some societies. The importance of this disparity is basic to the thesis of this paper.

I have often been asked whether an average difference of only a few grams of salt per day could be important. In this regard, it is critical to remember that ‘grams per day’ defines a rate as opposed to a quantity. Relatively small rate differentials operating over long periods of time can yield striking disparities in end result, as the fable of the tortoise and the hare aptly illustrates. From some data now in preparation for publication, our group has found by means of Na\(^+\) turnover studies that the biological half-life of sodium in humans is a clear-cut function of salt intake. There is more than a two-fold difference in turnover rate between intakes of 2 and 5 g, or between 5 and 10 g; there is a five-fold difference between the effect of 2 and 10 g, and a ten-fold difference between 2 and 30 g. The thesis that such marked differences are without physiological implication appears untenable.

Appetite

Detailed consideration of the role of salt appetite as it relates to salt intake is beyond the scope of this paper. There is no doubt that salt appetites exist, as every reader can personally testify. The issue is whether salt appetites are innate or acquired. Among animals, the long treks to salt-licks are well known; less well known is the fact that the herbivores rather than the carnivores do this. Whether the high dietary K/Na ratio of about 20 : 1 in the herbivores as contrasted with the 5 : 1 ratio in the diet of the carnivores is important is not known.

We have never seen evidence of salt-craving in our subjects whose salt-intakes were drastically reduced for months or years. Reports by Stellansson\(^{19}\) and Holmberg\(^{20}\) show that the primitive Eskimos and Bolivian Indians, with whom they were associated respectively, did not like salt initially, although they could grow to like it rapidly. Within my own family, where the children were reared without added salt, there was no evidence of a salt appetite until it was induced by well-meaning friends. Furthermore, it seems clear that if an innate appetite exists it is surprisingly easy to change, in contrast to some of the better-established ones. In our patients who were on diets containing only 100 to 250 mg of NaCl per day, the addition of as little as 0.5 to 1 g to their total daily intakes evoked initial comments of ‘too salty’, although later adaptation occurred. In sharp contrast, among subjects on 10 to 20 g per day, the addition of 5 or 10 g went unnoticed. Thus it seems evident that salt appetite is induced rather than innate. This is fundamental, since having shown that salt intake bears no necessary relationship to salt requirement, it now seems highly likely that salt appetite is also unrelated to requirement.

Evidence that salt ingestion may be related to hypertension

A) Experimental hypertension

In several forms of experimental hypertension, the simultaneous ingestion of excess salt appears to be necessary. Grollman and his associates were the first to demonstrate that various steroids were hypertensogenic only if additional salt was provided.\(^{21}\) The effectiveness of desoxycorticosterone acetate in producing hypertension with the addition of extra salt is well known.\(^{22,23}\) Salt feeding with fluid restriction by means of hypertonic saline as the sole source of liquid has been used to produce hypertension in the chick,\(^{24}\) rat\(^{25}\) and rabbit.\(^{26}\) Finally, Meneely and his collaborators have shown that chronic ingestion of excess sodium chloride alone will produce a hypertension in rats which mimics human hypertension morphologically.\(^{27-30}\) We have been using this same technique in our laboratory for some years and have confirmed the potential of chronic salt-feeding to produce hypertension. I suspect that inability to confirm Meneely’s work may be caused by failure to engage in long-term, chronic experiments.

Table 1 Average daily salt intake (based on 24 hr urine excretion) in several societies

<table>
<thead>
<tr>
<th>Group</th>
<th>Year, Sex</th>
<th>Average (g/d)</th>
<th>Range (g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaskan Eskimo</td>
<td>1958, 1960</td>
<td>4</td>
<td>1–10</td>
</tr>
<tr>
<td>Marshall Islander</td>
<td>1958</td>
<td>7</td>
<td>1.5–13</td>
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<tr>
<td>(Pacific Ocean)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>United States</td>
<td>1954–1956</td>
<td>10</td>
<td>4–24</td>
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<tr>
<td>(Brookhaven)</td>
<td></td>
<td></td>
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<tr>
<td>Japan</td>
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<td></td>
</tr>
<tr>
<td>Hiroshima (South)</td>
<td>1958</td>
<td>14</td>
<td>4–29</td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akita (North, Japan)</td>
<td>1954</td>
<td>26</td>
<td>5–55</td>
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</table>
rapidly evolving varieties of experimental hypertension, that
which follows chronic salt-feeding will seem negligible or
non-existent because of its slow onset. Nonetheless, from
extensive personal experience I would like to state
unqualifiedly that hypertension ultimately will result in most
rats that are chronically fed extra salt. Its onset may occur
at different intervals following the onset of salt-feeding; its
character may vary from mild to severe; however, once present,
it rarely if ever disappears if salt-feeding is continued. It is
usually slowly progressive, but may reach only a modest level
and remain on this plateau for the remainder of the animal's
life; in contrast we see animals whose disease is marked by early
onset, rapid severe elevation of blood pressure and death within
a few months. In all of these respects it must be conceded that
it resembles the picture of the human disease more closely than
the commoner varieties of experimental hypertension.

Hence, chronic salt-feeding in rats can produce a picture
resembling human essential hypertension. Furthermore, the
evidence is unequivocal that, as the amount of salt ingested daily
is increased, both incidence and severity of the hypertension will
be increased.

B) Human hypertension
Let us now turn to man. Here, salt restriction has long been
used as part of the therapeutic regimen against established
hypertension. Much of the early work either failed to separate
sodium from chloride or frankly ascribed the results to chloride.
In 1945 Grollman and his associates clearly demonstrated that
it was the sodium restriction which was important.1 This idea is
today so widely accepted and used that dilution would belabor
the obvious.

Although there were a number of carefully controlled
metabolic studies which had established the usefulness of
sodium restriction in hypertension, widespread acceptance of
this fact came only after the recent development of effective,
relatively non-toxic natriuretic agents such as chlorothiazide.
Here, too, salt ingestion seems to modify the response, since a
high salt diet appears to limit or even block the hypotensive
response to chlorothiazide.32

In our experience, which is now more extensive than
the early report,13 addition of salt to the diets of individuals who
have responded to its restriction generally results in a return of
the elevated blood pressure. Furthermore we have found a few
reports indicating that the addition of salt to the diet of
normotensive individuals for short periods of time has resulted
in significant elevations of pressure. McQuarrie33,34 reported
that some diabetic children rapidly became hypertensive when
salt was presented, and McDonough and Wilhelmj35 made
similar observations on a normal young adult male.

Failure to observe a rise in blood pressure on short-term salt-
feeding is not surprising to me for two reasons: 1. If it be granted
that excess salt ingestion plays a primary role in the etiology
of human hypertension, then the paucity of essential
hypertension before the 4th decade would suggest that the salt
effect must operate over a considerable span of time, possibly
starting well before maturity is reached. Both our own
experience as well as that of Meneely's group27–30 indicates
younger animals are more susceptible and that the
development of significant disease ordinarily requires a third or
more of the animals' expected life-time. 2. Even if salt-feeding
is continued throughout the life of a colony, some 20% of
the rats remain normotensive; this variability in response to
salt-feeding, exhibited by a relatively inbred species like the
Sprague-Dawley rat, must operate to a much higher degree in
an animal with the mixed ancestry of man. It is intriguing to
speculate on the possibility that a susceptibility to salt could be
bred in or out of isolated communities depending upon the
original make-up of the members.

It will be recalled that earlier in this paper we stated unless
drinking water had a high salinity it was unlikely that on the
average more than 4 or 5 g of NaCl per day would be ingested
from foods not salted by man; ordinarily it would be less,
particularly among people who were largely vegetarians. Since
hypertension appeared to be uncommon among groups which
did not add salt to their food, we thought that it might be
common among groups which did add it and that the higher the
salt consumption, the higher the incidence of hypertension.
This would have been in agreement with our experimental
animal data as well as those of Meneely and collaborators.27–30
The remainder of this paper will be devoted to exploring the
studies which we have made to test this hypothesis.

Preliminary to epidemiological investigations, we considered
a pilot method of estimating average salt intakes in an effort to
judge whether this hypothesis warranted the time and expense
of a formal study. In our milieu, salt shakers are ubiquitously
available. Therefore some inferences might be made from an
individual's use of salt at the table. We arrived at the following
3 classifications: 1. Low intake—did not add and never had
added salt to food at all; 2. Average intake—added salt to food
only if, after prior tasting, it was insufficiently salty for the
palate; 3. High intake—added salt to foods routinely without
prior tasting for degree of saltiness.

We were aware then, as we are now, of the defects in such a
classification: 1. It is qualitative and not quantitative; 2. No
allowance is made for addition of salt to food prior to its arrival
at the table; 3. No provision is made for differences in sensitivity
to saltiness among different individuals or even the same
individual at different times. In spite of all these reservations
the pilot technique proved to be a useful one in our hands.
Nevertheless there was no suggestion then, nor is there now,
that it is a generally applicable technique, for it clearly is
dependent upon salt-eating practices in a community. We have
evidence that salt-adding customs may be very different in the
northern area, where the original study was made, from those
in the deep south of the United States, where a small rural
community is now under study. This technique would have
been misleading in Japan, where salt consumption is high, but
where I found that the salt ordinarily was added to foods and
sauces prior to reaching the table.

It would be unfortunate if this pilot study were interpreted
mean that we were or are interested in salt-shakers. On the
contrary, let me state categorically that what we are
interested in is actual salt consumption, whatever its source and however it
gets into the gastro-intestinal tract.

With the use of the pilot technique we obtained information
which was suggestive of a relationship between salt
consumption and hypertension. Upon completion it indicated
that further expense and effort were warranted in exploring
this area. During the years 1953–1956, Dr. Robert A. Love, at
Brookhaven Laboratory, kindly queried for me all employees
upon whom he made a physical examination as to their customary salt-adding habits, according to the classification above. The incidence of hypertension among these 3 groups was significantly different from random distribution (p < .001). Those classified as having been on low intakes throughout their lives showed significantly less hypertension (p < .01) and those classified as having been on high intakes showed significantly more hypertension (p < .02) than would have been predicted by chance alone. We have assessed the validity of this method of estimating salt intake in a series of 28 males who were willing to collect 24 hr urines for from 6 to 38 days and found that the average of those classified as ‘Low’ was significantly lower (p < .01) than those who had been classified as ‘High’. More importantly, the non-hypertensives appeared to be eating significantly less (p < .01) salt than the hypertensives. We have pointed out that in this relatively young group of males (40.3 ± 10.6 years) even the non-hypertensive individuals classified as being in the ‘Low’ category were consuming on the average about nine and a half grams per day. On the basis of such intakes I expect some of these men to develop hypertension later in life.

These data indicate the probability of a group developing hypertension. It would be most fallacious to surmise that a person who consumed a given amount of salt would carry the same probability as the group. An individual obviously would have, as a rule, either a higher or a lower probability than the group, depending upon the type of distribution defining his particular group.

We were encouraged by these results to explore actual salt intake among groups in which the prevalence of hypertension is variable. These data are summarized briefly in Table 2, which is an extension of Table 1, as well as in the accompanying graph (Fig. 1). These data suggest in conformity with the animal data that with higher average salt consumption there is higher prevalence of hypertension. It will be of interest to compare these data with those from other areas as they become available.

Table 2 Salt intake (measured by urinary salt excretion) compared with prevalence of hypertension in five geographic areas

<table>
<thead>
<tr>
<th>Group</th>
<th>Year</th>
<th>Sex</th>
<th>No.</th>
<th>Age (average)</th>
<th>Salt Intake</th>
<th>% HT</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average (g/d)</td>
<td>Range (g/d)</td>
</tr>
<tr>
<td>Alaskan Eskimo</td>
<td>1958, 1960</td>
<td>both</td>
<td>20</td>
<td>38</td>
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<td>1–10</td>
</tr>
<tr>
<td>Marshall Islanders (Pacific)</td>
<td>1958</td>
<td>both</td>
<td>231</td>
<td>41</td>
<td>7</td>
<td>1.5–13</td>
</tr>
<tr>
<td>United States (Brookhaven)</td>
<td>1954–1956</td>
<td>Male</td>
<td>1124</td>
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<td>43</td>
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<td>4–29</td>
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<tr>
<td>Akita (North. Japan)</td>
<td>1954</td>
<td>both</td>
<td>5301</td>
<td>45</td>
<td>26</td>
<td>5–55</td>
</tr>
</tbody>
</table>

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* Systolic and diastolic pressures reported separately. This number (39%) is based on diastolic pressure of 90 mm Hg or more.
Agent is established as a requisite. It does not mean that salt is not involved but rather that not only salt is involved.

Summary

We wish to reiterate what we have said before. Among societies or groups habitually consuming low salt diets (perhaps 5 g of NaCl per person per day or less) essential hypertension will be uncommon. Among societies or groups consuming high amounts of salt (in excess of 10–15 g per person per day) essential hypertension will be common. Individual susceptibility will determine which one individual in a group will develop the disease.

Résumé

L'hypertension essentielle se rencontre plus rarement dans les sociétés ou communautés consommant d'ordinaire des rations alimentaires pauvres en sel (par exemple 5 g ou moins de NaCl par personne et par jour) que chez celles qui en consomment de grandes quantités (plus de 10–15 g par personne et par jour). La susceptibilité individuelle reste le facteur essentiel pour déterminer l'apparition de la maladie.

Bibliography

Commentary: Possible role of salt intake in the development of essential hypertension

Niels Graudal

Salt is one of the cornerstones on which the mammalian biochemical structure is built. Total exclusion of salt from the diet leads to disaster, namely death.¹ Still, salt is considered by some authorities, to be toxic on a level comparable with alcohol and tobacco. Why is salt the only essential component of mammals to have obtained this unattractive status? As of 2004, the history behind this is exactly 100 years old and LK Dahl²