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Nitrogen, Electrolytes, Water and Energy Metabolism

Editor
M. Rechcigl, Jr., Washington, D.C.

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Abbreviations and Symbols

AA	Amino acid(s)
ADH	Antidiuretic hormone
AMP	Adenosine 5'-phosphate
ARC	Agricultural Research Council (UK)
ATP	Adenosine 5-triphosphate
AVT	Arginine vasotocin
BMR	Basal metabolic rate
b/w	Body weight
cal	Calorie
CE	Calorigenic effect
CEH	Critical equilibrium humidity
CF	Crude fiber
CP	Crude protein
CV	Contractile vacuole
D	Digestibility
DAPA	Diaminopimelic acid
DC	Digestion coefficient
DDM	Digestible dry matter
DE	Digestible energy
DM	Dry matter
E	Energy
EC	Enzyme Commission number
ECF	Extracellular fluid
EFE	Endogenous fecal energy
EG	Energy gain
EUE	Endogenous urinary energy
EWL	Evaporative water loss
F	Fat
FAO	Food and Agriculture Organization (UN)
FE	Fecal energy
FG	Energy gain as fat
GDP	Guanosine 5'-diphosphate
GE	Gaseous energy
GFR	Glomerular filtration rate
GMP	Guanosine 5'-phosphate
GTP	Guanosine 5'-triphosphate
Hp	Horsepower
HE	Heat energy
ICF	Intracellular fluid
IE	Intake of energy
IMP	Inosine 5'-phosphate
j, J	Joule
kcal	Kilocalorie
kj, kJ	Kilojoule
kW	Kilowatt
LD	Lethal dose
MBS	Metabolic body size
Mcal	Megacalorie
ME	Metabolizable energy
MEI	Metabolizable energy intake
ME^1	Metabolizable energy of lactation
ME_m	Metabolizable energy of maintenance
MJ	Megajoule
M^n	Maintenance term
mOsm	Media osmolality
mRNA	Messenger RNA
MT	Mammalian type
MW	Molecular weight

NAD	Nicotinamide adenosine dinucleotide
NADP	Nicotinamide adenine dinocleotide phosphate
NE	Net energy
NE_a	Net energy of activity
Ne_g	Net energy of growth
NE_l	Net energy of lactation
NE_m	Net energy of maintenance
NRC	National Research Council (USA)
P	Protein
PAH	para-Aminohippurate
PG	Energy gain as protein
Pi	Inorganic orthophosphate
Posm	Plasma osmolality
PP	Inorganic pyrophosphate
RH	Relative humidity
RNA	Ribonucleic acid
RQ	Respiratory quotient
RT	Reptilian type
SDA	Specific dynamic action
SEM	Standard error of mean
SNGFR	Single nephron glomerular filtration
T	Temperature
Ta	Ambient temperature
TDN	Total digestible nutrients
TMAO	Trimethylamine oxide
UE	Urinary energy
UMP	Uridine monophosphate
USDA	U. S. Department of Agriculture
USP	U. S. Pharmacopeia
W	Weight
WHO	World Health Organization (UN)

Preface

This volume focuses on several important aspects of nutrient metabolism, namely energy-, nitrogen-, electrolytes- and watertopics that are frequently neglected by nutritionists and which usually receive superficial treatment in the conventional texts.

Energy is central to the study and understanding of both cellular nutrition and practical problems of meeting the nutritional needs of various animal organisms, including man. Most of the specific nutrients are required in amounts proportional to the energy metabolized. In contrast to the dietary deficiencies of specific nutrients, such as vitamins or minerals, which result in characteristic clinical signs, when energy intake is inadequate the resultant conditions are less spectacular and rarely recognized except in their extreme form. For the most part, one sees such nonspecific symptoms such as reduced growth, decreased milk production or lowered reproduction, which in contemporary animal management systems can be easily translated into economic terms, because feed costs are a major factor in the production of meat, milk and eggs. The introductory chapter on energy defines the latest energy terminology concerning definitions and symbols, discusses principles of bioenergetics, gives an overview of various types of food energies, calorigenic effects and their causes, energy costs of eating and various digestive processes, efficiency of utilization of different diets and specific nutritional components, basal metabolic rate, postabsorptive state, utilization of energy for maintenance, physical activity, growth and lactation, and energy requirements for specific metabolic processes. Finally, it critically reviews various systems of food evaluation, based upon energy, used throughout the world.

One of the most interesting aspects emerging from a comparative study of the metabolism and nutrition of nitrogenous compounds, is the similarity seen between animals which would appear quite far apart on the phylogenetic tree. In the present volume, an attempt has been made to explain the metabolic reasons for the differences that do occur.

All animals require a source, dietary or otherwise, of the electrolytes sodium, potassium and chloride. Potassium which is the major inorganic constituent of the intracellular fluid is present in virtually all of the food animals utilize in nature and hence is probably only rarely limiting. Sodium and chloride, the dominant elements of the extracellular fluid, in contrast, are present in insufficient amounts in normal food to meet the requirements of animals in the wild, particularly herbivorous terrestrial and freshwater organisms. Electrolyte requirements depend on the interaction of various dietary constituents such as the ratio of fixed anions to fixed cations and the ratios of certain amino acids in the diet. In addition, the requirements may change with age and reproductive status. As a consequence, precise information on the electrolyte requirements of vertebrates for maintenance and production is still lacking. In the case of lower vertebrates and invertebrates, much work has been done on the extent to which internal homeostasis of electrolyte concentrations is maintained and the mechanisms utilized for regulating such homeostasis. Little effort has been made, however, to quantify the relative importance of dietary and non-dietary electrolytes, at least in freshwater animals.

Closely related to electrolytes is the topic of water metabolism. As the medium of life, the importance of water stems from its prevalence as a substance on this planet. It is not known whether life developed exploiting the physicochemical properties of water because of its ubiquity or because the properties of water are innately requisite to the development of living forms, but its properties are so necessary to life as we know it that they appear to have an almost special design for biological forms. The present volume, to our knowledge, presents the most comprehensive review ever written on the subject of comparative water metabolism in animals, including protozoa, porifera, cnidaria, worms, arthropods, fish, amphibians, reptiles, birds and mammals. Covered in great depth are the aspects of water uptake, avenues of water losses, water content of tissues, control of water exchange and tolerance of animal organisms to changes in medium osmolality and composition.

With this volume we have essentially concluded the discussion of the major nutrient groups and their metabolism. The subsequent volumes of the series will focus on the functional aspects of nutrition.

The Editor is indebted to the individual authors for their splendid cooperation and to the S. Karger Staff, particularly to Mr. THOMAS KARGER and Miss DENISE GREDER for their thoughtful guidance and support. Special thanks are due to Miss KAREN RECHCIGL for her assistance in the preparation of the index.

Washington, D.C., October 1978 MILOSLAV RECHCIGL. Jr.

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Electrolytes

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Comp. Anim. Nutr., vol. 3, pp. 1–33 (Karger, Basel 1979)

Energy Metabolism

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Introduction

During the evolutionary process, animals have occupied a variety of ecological niches, their digestive systems reflect their food habits and, accordingly, the source of dietary energy differs. Energy is central to the study and understanding of both cellular nutrition and practical problems of meeting the nutritional needs of domestic and feral livestock. Most of the specific nutrients are required in amounts proportional to the energy metabolized, thus for example thiamin (B_1) requirement increases in proportion to basal metabolism or metabolic body size (metabolic body size = $W_{kg}^{3/4}$; KLEIBER, [1961]). Biochemists have also shown that thiamin, in its pyrophosphate form, is a coenzyme necessary for the oxidative decarboxylation of pyruvic acid to acetyl coenzyme A, an important step in the release of energy during carbohydrate metabolism. Dietary deficiencies of any one of the specific nutrients (any of the individual B complex vitamins, vitamin A, calcium, etc.) will eventually result in clinical signs characteristic of the nutrient. However, when energy intake is inadequate the resultant conditions are less spectacular and rarely recognized except in their extreme form. For the most part one sees reduced growth rates, decreased milk production and lowered reproduction. In contemporary animal management systems, such effects can be easily translated into economic terms, because feed costs are a major factor in the production of meat, milk and eggs under intensive agriculture. Managers are cognizant of the effects of improper feeding on economic returns and thus frank energy malnutrition is rarely seen under commercial conditions of animal production.

Definition of Terms

The literature concerning energy utilization is fraught with terms and symbols inconsistently applied among research groups. The following terminology, definitions and symbols shall be used; they are mostly those agreed to at the 7th Symposium on Energy Metabolism of Farm Animals held at Vichy, France, in September 1976.

Symbol	Terminology and definition
j	joule; an absolute unit of energy, j = 1 voltcoulomb, 10^3j = kilojoule (kj).
IE	intake of energy; total feed consumed × energy density usually determined by a bomb calorimeter.
cal	a unit of heat energy; the amount of heat required to raise 1 g of water 1^0 C; 10^3 cal = kilocalorie (kcal); 10^6 cal = megacalorie (Mcal); 1 kcal = 4.18j.
FE	fecal energy; total fecal residue voided × energy density.
UE	urinary energy; total urine excreted × energy density.
GE	gas energy; primarily CH_4 in ruminants.
DE	digested energy; DE = IE – FE.
ME	metabolizable energy; ME = DE – UE – GE.
MEI	metabolizable energy intake.
HE	heat energy; the total amount of heat emitted by an animal.
CE	calorigenic effect; CE = ME – NE.
NE	net energy; the energy available for basal metabolism, activity associated with locomotion and standing, growth and lactation.
BMR	basal metabolic rate; HE produced by the inactive animal in a postabsorptive state.
NE_a	net energy of activity; that fraction of the NE used for activity.
NE_g	net energy of growth; that fraction of the NE used for growth of new tissue.
NE_l	net energy of lactation; that fraction of the NE used for lactation purposes.
NE_m	net energy of maintenance; that fraction of the NE used for maintaining body mass.

Bioenergetics

Bioenergetics is concerned with energy transformations in living organisms and the term developed from the application of physical laws of thermodynamics to biological systems. The principle of 'Conservation of Energy' or the First Law of Thermodynamics asserts that in an isolated system the total amount of energy remains constant. According to BRODY [1945, p. 13], in 1885 RUBNER (dogs), in 1903 ATWATER and BENEDICT (man), and in 1903

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