HUMAN
PHYSIOLOGY
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Dedicated
to
My Students
This book on *Human Physiology* written and edited by Prof NM Muthayya, an eminent Professor of Physiology, who has contributed to the field of Physiology as the Faculty lead in various Universities in India and abroad. A revision of this textbook became inevitable for two reasons. The author has also tried to prune to some of the old wood. Even though the book has been revised with many editions, the bulk has been reduced. This edition of the book is a student friendly and easy to understand. The schematic pictures are too good. Abbreviations and symbol used in this book may be of great help to the students. Although the main framework of the textbook has been retained, almost all paragraphs have been revised.

The present edition provides additional knowledge in many sections.

The information provided in each section is exam-oriented for the benefit of the students.

Several illustrative diagrams and tables have been included to make the subject comprehensive and to revise it more easily.

Comparing to the previous edition this 4th edition is updated with reasonable additions and deletions.

The publication of the Textbook *Human Physiology* for medical students by Dr NM Muthayya is a timely and laudable venture. Although many costly textbooks written by western authors are available in the market, there are only very few standard textbooks prepared by Indian authors. I am glad to note that the present textbook keeps a balance between the basic essentials and advanced areas of knowledge in Physiology. I am pleased to introduce the book to the medical students and attractive to the teachers.

I have no doubt that this will be a valuable addition to the armamentarium of students of Physiology who are preparing for examination and are seeking a strong foundation. This book of Human Physiology 4th Edition will be kept for reference in the Tamil Nadu Dr MGR Medical University for the benefit of the undergraduate and postgraduate students.

As the Vice-Chancellor of the Tamil Nadu Dr MGR Medical University, I wish and congratulate Prof Dr NM Muthayya for taking much effort to bring this 4th edition of this book successfully.

Dr K Meer Mustafa Hussain
It gives me great pleasure to write a foreword for this comprehensive book of Physiology which incorporates latest information on Physiology.

The book “Human Physiology” is well written and tastefuly illustrated.

The author, Professor NM Muthayya, an eminent physiologist has made it possible for any beginner undergoing Medical as well as Paramedical Courses to grasp the fundamentals of Physiology through this easily readable book.

I wish to congratulate Dr Muthayya on this achievement and wish him all success.

Dr P Vijayalakshmi
Preface to the Fourth Edition

Since this book was published in 1986, it has undergone several modifications in its format and content. Two new editions and number of reprints have been published. This new fourth edition has been revised very extensively, new materials have been added, errors have been corrected, suggestions and information from physiology colleagues and readers have been taken into account and incorporated. Recent concepts have been included and the materials which are no longer relevant have been deleted. Number of new diagrams, tables and flow charts have been added. The format of the book is completely changed. By these changes this edition is made up-to-date and accurate to the extent possible and published under the title Human Physiology.

In order to emphasize the clinical significance of physiology to medical students the necessary clinical aspects have been included in relevant places then and there in the body of the subject matter and also at the end of each chapter.

To make the clinical aspects more striking and attractive these clinical aspects have been printed in italic type with red colour. The very purpose of this effort is only to initiate and induct the preclinical students to clinical studies and not to teach the clinical medicine in details which you will get during the clinical years of study.

As in the previous editions of this book, in this edition also the historical aspects, the names of Pioneer Scientists who contributed to some new discoveries and the names of Nobel Laureates in Medicine and Physiology have been given in the respective areas in order to honour them. With an intention of creating some interest in “The History of Medicine” among students these facts have been highlighted by printing them in "Green" colour.

I am always grateful to Dr (Mrs) S Parvathi Devi, Director and Emeritus Scientist (Retd) Institute of Physiology, Madurai Medical College, Madurai, India for the encouragement she has given as my guide, friend and philosopher. I am very much thankful to Dr N Harihara Subramanian, Professor of Physiology (Retd) and Mr PV Masilamani, Artist (Retd) Madurai Medical College for their contribution of some diagrams to the first edition of this book which forms and continues as the foundation for the present new edition.

I thank profusely Mr S Pusparaj and Mrs S Maithili Yogaraj of Mythe Creators, Coimbatore for their sincere effort to make the computer designing more attractive and colourful in the present form.

I am also thankful to my family members particularly my son Engineer RM Pratheep Pratap for his help in bringing out this edition.

I thank and appreciate Shri Jitendar P Vij (Chairman and Managing Director), Mr Tarun Duneja (Director-Publishing) of Jaypee Brothers Medical Publishers (P) Ltd, New Delhi and Chennai Branch, India who brought out this book at a very short notice of time. My heart felt desire is to dedicate this book to my students from whom I got the feedback and encouragement to venture on this task.

Madurai
Tamil Nadu, India

NM Muthayya
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<td>µ</td>
<td>Micro, (10^{-6})</td>
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<tr>
<td>A (A)</td>
<td>Angstrom unit(s) (10(^{-10})m, 0.1nm); also alanine</td>
</tr>
<tr>
<td>ABC</td>
<td>ATP-binding cassette</td>
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<tr>
<td>ABP</td>
<td>Androgen-binding protein</td>
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<tr>
<td>ACE</td>
<td>Angiotensin-converting enzyme</td>
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<tr>
<td>Acetyl-CoA</td>
<td>Acetyl-coenzyme A</td>
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<td>Ach</td>
<td>Acetylcholine</td>
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<td>ACTH</td>
<td>Adrenocorticotropic hormone</td>
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<tr>
<td>Acyl-CoA</td>
<td>General symbol for an organic compound coenzyme A ester</td>
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<td>ADH</td>
<td>Antidiuretic hormone (vasopressin)</td>
</tr>
<tr>
<td>ADP</td>
<td>Adenosine diphosphate</td>
</tr>
<tr>
<td>AGEs</td>
<td>Advanced glycosylation end products</td>
</tr>
<tr>
<td>AHG</td>
<td>Antihemophilic globulin</td>
</tr>
<tr>
<td>Ala</td>
<td>Alanine</td>
</tr>
<tr>
<td>ALS</td>
<td>Amyotrophic lateral sclerosis</td>
</tr>
<tr>
<td>AMP</td>
<td>Adenosine 5’-monophosphate</td>
</tr>
<tr>
<td>ANP</td>
<td>Atrial natriuretic peptide</td>
</tr>
<tr>
<td>APC</td>
<td>Activated protein C; also antigen-presenting cell</td>
</tr>
<tr>
<td>APUD cells</td>
<td>Amine precursor uptake and decarboxylation cells that secrete hormones</td>
</tr>
<tr>
<td>Arg</td>
<td>Arginine</td>
</tr>
<tr>
<td>Asp</td>
<td>Aspartic acid</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine triphosphate</td>
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<tr>
<td>A-V difference</td>
<td>Arteriovenous concentration difference of any given substance</td>
</tr>
<tr>
<td>AV node</td>
<td>Atrioventricular node</td>
</tr>
<tr>
<td>aVR, aVF, aVL</td>
<td>Augmented unipolar electrocardiographic leads</td>
</tr>
<tr>
<td>AV valves</td>
<td>Atrioventricular valves of heart</td>
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<tr>
<td>BGP</td>
<td>Bone Gla protein</td>
</tr>
<tr>
<td>BMR</td>
<td>Basal metabolic rate</td>
</tr>
<tr>
<td>BNP</td>
<td>Brain natriuretic peptide</td>
</tr>
<tr>
<td>cal</td>
<td>The calorie (gram calorie)</td>
</tr>
<tr>
<td>Cal</td>
<td>1000 calories; kilocalorie</td>
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<tr>
<td>cAMP</td>
<td>Cyclic adenosine 3’,5’-monophosphate</td>
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<tr>
<td>CBF</td>
<td>Cerebral blood flow</td>
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<tr>
<td>CBG</td>
<td>Corticosteroid-binding globulin, transcortin</td>
</tr>
<tr>
<td>cc</td>
<td>Cubic centimeters</td>
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<tr>
<td>CCK, CCK-PZ</td>
<td>Cholecystokinin-pancreozymin</td>
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<tr>
<td>CFF</td>
<td>Critical fusion frequency</td>
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<td>cGMP</td>
<td>Cyclic 3’,5’-guanosine monophosphate</td>
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<td>Central nervous system</td>
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<tr>
<td>CoA</td>
<td>Coenzyme A</td>
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<td>Carbonmonaxyhemoglobin</td>
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<td>Compound A</td>
<td>11-Dehydrocorticosterone</td>
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<tr>
<td>Compound B</td>
<td>Corticosterone</td>
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<tr>
<td>Compound E</td>
<td>Cortisone</td>
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<tr>
<td>Compound F</td>
<td>Cortisol</td>
</tr>
<tr>
<td>Compound S</td>
<td>11-Deoxycortisol</td>
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<tr>
<td>COMT</td>
<td>Catechol-O-methyltransferase</td>
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<td>cps</td>
<td>Cycles per second, hertz</td>
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<td>CR</td>
<td>Conditioned reflex</td>
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<tr>
<td>Cr</td>
<td>Creatinine</td>
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<td>CRH, CRF</td>
<td>Corticotropin-releasing hormone</td>
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<td>CRO</td>
<td>Cathode-ray oscilloscope</td>
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<tr>
<td>CS</td>
<td>Conditioned stimulus</td>
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<tr>
<td>CSF</td>
<td>Cerebrospinal fluid; also colony-stimulating factor</td>
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<td>CT</td>
<td>Computed tomography</td>
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<td>C terminal</td>
<td>COOH end of a peptide or protein</td>
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<td>Cyclic adenosine 3’,5’-monophosphate</td>
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<td>Cysteine</td>
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<td>Crystalline zinc insulin</td>
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<td>Diacylglycerol</td>
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<tr>
<td>dB</td>
<td>Decibel</td>
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<td>DEA, DHEA, DHA</td>
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<td>Acronym</td>
<td>Description</td>
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<td>---------</td>
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<td>DFP</td>
<td>Diisopropyl fluorophosphosphate</td>
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<td>Dihydrotestosterone</td>
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<td>DIT</td>
<td>Dihidrototyrosine</td>
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<td>DNA</td>
<td>Deoxyribonucleic acid</td>
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<td>D₂O</td>
<td>Deuterium oxide (heavy water)</td>
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<td>Deoxycorticosterone acetate</td>
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<td>DPG, 2,3-DPG</td>
<td>2,3-Diphosphoglycerate</td>
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<td>Extracellular fluid</td>
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<td>ECG, EKG</td>
<td>Electrocardiogram</td>
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<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
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<tr>
<td>EMG</td>
<td>Electromyogram</td>
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<td>EPSP</td>
<td>Excitatory postsynaptic potential</td>
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<tr>
<td>ERG</td>
<td>Electroretinogram</td>
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<tr>
<td>FAD</td>
<td>Flavin adenine dinucleotide</td>
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<tr>
<td>FEV₁</td>
<td>Forced expiratory volume in first second of forced expiration after maximum inspiration</td>
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<td>FFA</td>
<td>Unesterified free fatty acid (also called NEFA, UFA)</td>
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<td>FGF</td>
<td>Fibroblast growth factor</td>
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<tr>
<td>FGFR</td>
<td>Fibroblast growth factor receptor</td>
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<td>FMN</td>
<td>Flavin mononucleotide</td>
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<td>FRH, FSH-RH, FRF</td>
<td>FSH releasing hormone</td>
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<td>FSH</td>
<td>Follicle-stimulating hormone</td>
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<tr>
<td>ft</td>
<td>Foot or feet</td>
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<tr>
<td>g, gm</td>
<td>Gram(s)</td>
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<tr>
<td>g</td>
<td>Unit of force; 1 g equals the force of gravity on the earth's surface</td>
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<tr>
<td>GABA</td>
<td>Gamma-aminobutyrate</td>
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<td>GAD</td>
<td>Glutamate decarboxylase</td>
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<td>GBG</td>
<td>Gonadal steroid-binding globulin</td>
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<tr>
<td>G-CSF</td>
<td>Granulocyte colony-stimulating factor</td>
</tr>
<tr>
<td>GFR</td>
<td>Glomerular filtration rate</td>
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<tr>
<td>GH</td>
<td>Growth hormone</td>
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<tr>
<td>GHH,GIF</td>
<td>Growth hormone-inhibiting</td>
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<tr>
<td>GIP</td>
<td>Gastric inhibitory peptide</td>
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<tr>
<td>Gla</td>
<td>Gamma-carboxyglutamic acid</td>
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<td>Glu</td>
<td>Glutamic acid</td>
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<td>GLUT</td>
<td>Glucose transporter</td>
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<tr>
<td>Gly</td>
<td>Glycine</td>
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<tr>
<td>GM-CSF</td>
<td>Granulocyte-macrophage colonystimulating factor</td>
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<td>GnRH</td>
<td>Gonadotropin-releasing hormone; same as LHRH</td>
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<td>Guanosine triphosphate</td>
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<td>h, Hour(s)</td>
<td>Hour(s)</td>
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<td>H</td>
<td>Histidine</td>
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<tr>
<td>Hb</td>
<td>Deoxygenated hemoglobin</td>
</tr>
<tr>
<td>HBE</td>
<td>His bundle electrogram</td>
</tr>
<tr>
<td>HbO₂</td>
<td>Oxyhemoglobin</td>
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<tr>
<td>HCC, 25-HCC</td>
<td>25-Hydroxycholecalciferol, a metabolite of vitamin D₃</td>
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<tr>
<td>hCG</td>
<td>Human chorionic gonadotropin</td>
</tr>
<tr>
<td>hCS</td>
<td>Human chorionic Somatomammotropin</td>
</tr>
<tr>
<td>Hct</td>
<td>Hematocrit</td>
</tr>
<tr>
<td>HDL</td>
<td>High-density lipoprotein</td>
</tr>
<tr>
<td>hGH</td>
<td>Human growth hormone</td>
</tr>
<tr>
<td>5-HIAA</td>
<td>5-Hydroxyindoleacetic acid</td>
</tr>
<tr>
<td>HIOMT</td>
<td>Hydroxyindole-O-methyltransferase</td>
</tr>
<tr>
<td>His</td>
<td>Histidine</td>
</tr>
<tr>
<td>HIV</td>
<td>Human immunodeficiency virus</td>
</tr>
<tr>
<td>HLA</td>
<td>Human leukocyte antigen</td>
</tr>
<tr>
<td>H substance</td>
<td>Histaminelike capillary vasodilator</td>
</tr>
<tr>
<td>5-HT</td>
<td>Serotonin</td>
</tr>
<tr>
<td>IDDM</td>
<td>Insulin-dependent diabetes mellitus</td>
</tr>
<tr>
<td>IDL</td>
<td>Intermediate-density lipoprotein</td>
</tr>
<tr>
<td>IFN</td>
<td>Interferon</td>
</tr>
<tr>
<td>IGF-I, IGF-II</td>
<td>Insulinlike growth factors I and II</td>
</tr>
</tbody>
</table>
I-IMP: \(^{123}\)I-labeled iodoamphetamine

IL: Interleukin

Ile, lleu: Isoleucine

IP\(_3\): Inositol 1,4,5-triphosphate, inositol triphosphate

IPSP: Inhibitory postsynaptic potential

IU: International unit(s)

IUD: Intrauterine device

JG cells: Juxtaglomerular cells

k: Kilo- \(10^{-3}\); see Table 3, above

kcal (Cal): Kilocalorie (1000 calories)

LATS: Long-acting thyroid stimulator

LDH: Lactate dehydrogenase

LDL: Low-density lipoprotein

LES: Lower esophageal sphincter

Leu: Leucine

log: Logarithm to base 10

LRH, LHRH, LRF: Luteinizing hormone-releasing hormone; same as GnRH

LTD: Long-term depression

LTP: Long-term potentiation

M: Molarity (mol/L); also mega-, \(10^{-6}\); also methionine

M cells: Microfold cells

MAO: Monoamine oxidase

MBC: Maximal breathing capacity (same as MVV)

M-CSF: Macrophage colony-stimulating factor

MDMA: 3,4-Methylenedioxy methamphetamine

MHC: Major histocompatibility complex; also myosin heavy chain

MHPG: 3-Methoxy-4-hydroxyphenylglycol

MRI: Magnetic resonance imaging

mRNA: Messenger RNA

MSH: Melanocyte-stimulating hormone

MVV: Maximal voluntary ventilation

N: Normality (of a solution): also Newton (SI unit of force); also asparagine

NAD: Nicotinamide adenine dinucleotide; same as DPN

NADH: Dihydronicotinamide adenine dinucleotide; same as DPNH

NADP+: Nicotinamide adenine dinucleotide phosphate; same as TPN

NADPH: Dihydronicotinamide adenine dinucleotide phosphate; same as TPNH

NGF: Nerve growth factor

NIDDM: Non-insulin-dependent diabetes mellitus

NMDA: N-Methyl-D-aspartate

NO: Nitric oxide

NREM sleep: Nonrapid eye movement (spindle) sleep

NSAID: Nonsteroidal anti-inflammatory drug

NTS: Nucleus of the tractus solitarius

NOS: Organum vasculosum of the lamina terminalis

P: Pico-, \(10^{-12}\)

P450: Cytochrome P450

P\(_{50}\): Partial pressure of \(O_2\) at which hemoglobin is half-saturated with \(O_2\)

PAF: Platelet-activating factor

PAH: Para-Aminohippuric acid

PBI: Protein-bound-iodine

P cells: Principal cells in the renal tubules; also pacemaker cells of SA and AV nodes

PCD: Programmed cell death, apoptosis

PDECGF: Platelet-derived endothelial cells growth factor

PET: Positron emission tomography

PGO spikes: Ponto-geniculo-occipital spikes in REM sleep
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Negative logarithm of the $H^+$ concentration of a solution</td>
</tr>
<tr>
<td>PIH, PIF</td>
<td>Prolactin-inhibiting hormone</td>
</tr>
<tr>
<td>pK</td>
<td>Negative logarithm of the equilibrium constant for a chemical reaction</td>
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<tr>
<td>PLC</td>
<td>Phospholipase C</td>
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<tr>
<td>PRH, PRF</td>
<td>Prolactin-releasing hormone</td>
</tr>
<tr>
<td>PTA</td>
<td>Plasma thromboplastin antecedent (clotting factor XI)</td>
</tr>
<tr>
<td>PTC</td>
<td>Plasma thromboplastin component (clotting factor IX); also phenylthiocarbamide</td>
</tr>
<tr>
<td>PTH</td>
<td>Parathyroid hormone</td>
</tr>
<tr>
<td>PZI</td>
<td>Protamine zinc insulin</td>
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<tr>
<td>RAS</td>
<td>Reticular activating system</td>
</tr>
<tr>
<td>rbc</td>
<td>Red blood cell(s)</td>
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<tr>
<td>RDS</td>
<td>Respiratory distress syndrome</td>
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<tr>
<td>REM sleep</td>
<td>Rapid eye movement (paradoxical) sleep</td>
</tr>
<tr>
<td>RNA</td>
<td>Ribonucleic acid</td>
</tr>
<tr>
<td>RPF</td>
<td>Renal plasma flow</td>
</tr>
<tr>
<td>RQ</td>
<td>Respiratory quotient</td>
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<tr>
<td>s</td>
<td>second(s); also standard deviation of a sample</td>
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<tr>
<td>SA node</td>
<td>Short-chain fatty acid(s)</td>
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<tr>
<td>SCUBA</td>
<td>Self-contained underwater breathing apparatus</td>
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<tr>
<td>SDA</td>
<td>Specific dynamic action</td>
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<tr>
<td>SGLT 1</td>
<td>Sodium-dependent glucose transporter 1</td>
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<td>SGOT</td>
<td>Serum glutamic-oxaloacetic transaminines</td>
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<td>SIDS</td>
<td>Sudden infant death syndrome</td>
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<tr>
<td>SIF cells</td>
<td>Small, intensely fluorescent cells in sympathetic ganglia</td>
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<td>SPCA</td>
<td>Proconvertin (clotting factor VII)</td>
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<tr>
<td>SS 14</td>
<td>Somatostatin 14</td>
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<tr>
<td>SS 28</td>
<td>Somatostatin 28</td>
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<tr>
<td>SS 28 (1-12)</td>
<td>Polypeptide related to somatostatin that is found in tissues</td>
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<tr>
<td>STH</td>
<td>Somatotropin, growth hormone</td>
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<tr>
<td>T3</td>
<td>3,5,3,-Triiodothyronine</td>
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<tr>
<td>T4</td>
<td>Thyroxine</td>
</tr>
<tr>
<td>TBG</td>
<td>Thyroxine-binding globulin</td>
</tr>
<tr>
<td>TBPA</td>
<td>Thyroxine-binding prealbumin (now called transthyretin)</td>
</tr>
<tr>
<td>TBW</td>
<td>Total body water</td>
</tr>
<tr>
<td>Tc cells</td>
<td>Cytotoxic T cells</td>
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<tr>
<td>TEA</td>
<td>Tetraethylammonium</td>
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<tr>
<td>TETRAC</td>
<td>Tetraiodothyroacetic acid</td>
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<tr>
<td>TF/P</td>
<td>Concentration of a substance in renal tubular fluid divided by its concentra</td>
</tr>
<tr>
<td>TGF</td>
<td>Transforming growth factor</td>
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<tr>
<td>Tm</td>
<td>Renal tubular maximum</td>
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<td>TNF</td>
<td>Tumor necrosis factor</td>
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<tr>
<td>TSH</td>
<td>Thyroid-stimulating hormone</td>
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<td>T/s ratio</td>
<td>Thyroid/serum iodide ratio</td>
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<td>TTX</td>
<td>Tetrodotoxin</td>
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<td>Tyr</td>
<td>Tyrosine</td>
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<td>U</td>
<td>Unit(s)</td>
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<td>Unesterified free fatty acid (same as FFA)</td>
</tr>
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<td>US</td>
<td>Unconditioned stimulus</td>
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<tr>
<td>UTP</td>
<td>Uridine triphosphate</td>
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<td>V1, V2, etc</td>
<td>Unipolar chest electrocardiographic leads</td>
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<tr>
<td>VIP</td>
<td>Vasoactive intestinal polypeptide</td>
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<tr>
<td>VLDL</td>
<td>Very low density lipoprotein</td>
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<tr>
<td>VMA</td>
<td>Vanillylmandelic acid (3-methoxy-4-hydroxy-mandelic acid)</td>
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<tr>
<td>VOR</td>
<td>Vestibulo-ocular reflex</td>
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<tr>
<td>VR</td>
<td>Unipolar right arm electrocardiographic lead</td>
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<tr>
<td>wbc</td>
<td>White blood cell(s)</td>
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<td>X chromosome</td>
<td>One of the sex cortex in humans</td>
</tr>
<tr>
<td>Y chromosome</td>
<td>One of the sex chromosomes in humans</td>
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## Greek Alphabet

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<th>Greek Letter</th>
<th>English Name</th>
<th>Greek Letter</th>
<th>English Name</th>
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<td>alpha</td>
<td>ν</td>
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</tr>
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<td>ξ</td>
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<td>gamma</td>
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<td>ω</td>
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